The growth and decline of the semiconductor industry within the U.K. 1950-1985

Thesis

The Growth and Decline of the Semiconductor Industry within the U.K. 1950-1985

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P.R. Morris

BA(Hons), M.Phil, C.Eng., M.I.E.E., M.I.E.E.E.

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Abstract

This thesis reviews the history of the semiconductor industry during the period 1950 to 1985 and identifies the major factors governing its development. It also analyses the reasons for the failure of British manufacturing companies to develop on a more competitive scale.

The development of the British semiconductor industry, almost from the start, took place within an environment dominated by large foreign multinational companies. Operating under conditions of technical lag and with increasing penetration of its markets, it concentrated, aided by funding from the Ministry of Defence, on producing specialised solid-state components for the much smaller military market. Because of its size, this market was not sufficiently large to initiate the pump-priming action which was such an important feature in bringing about the success of its American counterpart.

Generous Government inducements, aimed at attracting multinational companies to British shores, did little to assist the development of the indigenous industry, which, underfunded, underprotected and increasingly restricted to niche markets by competitors, soon fell into relative decline. Direct Governmental assistance to the ailing commercial sector of the British semiconductor industry came too late substantially to affect the situation. Both inconsistency and lack of continuity in policy towards the industry, under successive Governments, did not improve the confidence of industrial management, nor encourage a more long-term outlook.

It is argued within this thesis that the best chance of industrial success would have been to adopt a national policy towards the industry at an early stage, with substantial funding on a long-term basis, together with adequate import controls. The epilogue concludes that only within a European framework might it now be possible to build a semiconductor manufacturing industry, eventually capable of competing on equal terms with overseas rivals.

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Because of its nature, this work has relied, to a considerable extent, upon a wide range of information obtained through interviews with those in Government, industry and university departments. Almost all of those approached were extremely helpful, friendly and informative. This fact undoubtedly lightened my task and added to the enjoyment of the work. Some extent of my indebtedness may be obtained from a glance at the lengthy list of names of those who have assisted me and which I have included as an appendix.

More generally, although also importantly, I am indebted to my ex. colleagues for the numerous and often rewarding conversations held through the years, when employed as a semiconductor engineer within the industry. Although it is impossible to properly evaluate their influence, there can be little doubt that my views regarding the industry have been, at the very least, strongly stimulated and tested by their opinions.

Last but not least, I would also like to thank my daughter, Siani, for her welcome assistance in arranging the printing of the final version of this thesis.

In order to conform to Open University regulations concerning previously published work, attention is drawn to the fact that some material contained within chapters 5 & 6 of this thesis has already been published under the title "The role of the Ministry of Defence (MOD) in influencing the commercial performance of the British semiconductor industry", History and Technology Vol.II, (1994), pp. 181-193.

Contents

		Page
Abstract		i
Acknowledgements		ii
Table of Contents		iii
List of Tables		vii

Chapter 1 Introduction

The Importance of Microelectronics	1
Introductory Theoretical Framework	2
Previous Contributions to the History of Semiconductor Manufacture: a Brief Survey	9
References	18

Chapter 2 A Review of the General Characteristics of the British Thermionic Valve Industry

Introduction	21
The Development of the Thermionic Valve: The Initial Phase 1906-20	21
Development of the Valve Industry During the Inter-War Period	26
The UK Valve Manufacturing Industry in World War Two	36
Post-War Developments	41
Economies of Scale in Valve Manufacture	43
The Influence of Mullard Ltd upon Post-War Valve Manufacture	44
Cathode-ray Tube Production	47
Tube Sales and Import/Export Figures	48
Some Factors Affecting the Development of the Industry	50
Valve Manufacture within the United States	53
The Role of Patents	55
References	56

Chapter 3 Aspects of Early Semiconductor Development in the UK and USA

Introduction	60
Genesis of the Transistor	60
Transistors versus Valves	66
Replacement of the Thermionic Valve by the Transistor	68
Aspects of Early (Germanium) Transistor Development	70
The Impetus of Military Involvement: Development of the Silicon Transistor	73
Transistor and Integrated Circuit Development	75
Product Innovation and Technical Lag	80
The British Contribution to Semiconductor Device Innovation	85
Infrastructural Factors Contributing to Technical Lag	86

Page

The Nature of Semiconductor Development
and its Contribution to Technical Lag 91
References 93

Chapter 4 Direct Governmental Involvement within the Semiconductor Manufacturing Industry

Introduction 97
The Structure of Governmental Industrial
Assistance - a Brief Chronological Survey 97
Governmental Policy - Organisations and Attitudes 102
Non-Defence Government Support Policy 109
INMOS 116
The Microelectronics Programme: Support
within a Hostile Environment 120
Commercial Exploitation of Defence Contracts 125
Factors Involving Government Policies Directly
Inhibiting Industrial Performance 127
Government Funding: A Conflict of Aims? 134
References 139

Chapter 5 Government Involvement within Non-Industrial Semiconductor Research

Introduction 146
The Role of the Ministry of Defence 146
MOD Procurement: The Organisational Framework 149
MOD Procurement: The Strategy 151
Government R & D Establishments 153
Technological Innovation: Devices and Materials 155
The Post Office 161
University Involvement in Government Research 162
Government Policy: The Research Establishment View 165
Government Policy: The Industrial Viewpoint 170
References 174

Chapter 6 A Review of the Performance of Semiconductor Firms within the UK

Introduction 178
Overseas Investment in Semiconductor Manufacture
Within the United Kingdom 179
Mullard Ltd. 181
ITT Semiconductors 186
Texas Instruments 188
Overseas Subsidiaries in Scotland 194
The Effect of Foreign Market Penetration on
Device Development in Britain 196
Ferranti Ltd. 197
The Plessey Company 205
The General Electric Company (GEC) 212
References 222

Chapter 7 Factors involving Industrial Performance - a Comparison between Britain and the United States

Introduction	230
Research and Development: R & D Resources within America and Britain	231
British and American Public Funding - a Comparison	233
Early Government Involvement in Transistor Manufacture	235
University Research	237
Industrial and Economic Factors: Availability of Venture Capital	239
Wage Rates	240
Cost of Entry into the Industry	241
Technical Spin-off Under Conditions of an Assured Market	244
Skill Clusters	245
Labour Mobility	247
Communications	247
Conditions Governing Market Entry	248
Marketing	250
The Integrated Circuit: The US Circuit Procurement Programme	252
Patents and Licensing	256
References	263

Chapter 8 Technical Innovation and Economic Factors: Their Part in the Cycle of Industrial Growth and Decline

Introduction	268
The Concept of Industrial Synergy and its Importance in Semiconductor Manufacture	269
The Manner of Industrial Growth	274
Factors Governing Synergistic Industrial Growth in the Components Industry	276
The Failure of Semiconductor Manufacture in Britain to Establish a Condition of Synergy	278
The Rise of Computer Manufacture and its Consequences for the Development of the British Semiconductor Industry	282
The American Technical Lead in Components: its Consequences for European Equipment Markets	286
Research Programmes and Commercial Spin-offs	289
References	290

Chapter 9 The Influence of Multinational Companies

Introduction	294
Multinationals - The Advantages	294
Multinationals - The Costs	298
Multinationals - The Response	301
References	309

Page

Chapter 10 Summary and Conclusions

Introduction 312
Industrial Factors 312
Governmental Factors 318
External Factors 323
Epilogue 324
References 328

Bibliography 330

Appendix A Glossary of Commonly Used Terms in Semiconductor Technology 343

Appendix B Interviews and Private Communications 349

List Of Tables

	Page
Chapter 1	
Leading US discrete and IC semiconductor manufacturers in order of ranking	6
Number of entries into semiconductor manufacture within the US	6
Chapter 2	
Imports from the US as a % of total imports, 1933-39	35
Valve imports, 1950-55	42
Number of valves manufactured within the UK, 1950-55	43
Valve import & export figures, 1950-55	43
Domestic & industrial valves: sales & profit, 1951-54	45
Domestic & industrial valve sales, 1951-54	46
Mullard Ltd. TV tube production, 1947-51	48
TV tube sales & import/export figures, 1950-55	49
Chapter 3	
Principal logic families	78
Initial production of early device types in the UK	81
Major semiconductor device innovations, 1951-70	84
Semiconductor R&D expenditure by UK firms (1968)	87
Chapter 4	
British trade in integrated circuits, 1967-69	121
Chapter 5	
CVD yearly investments in IC's, 1961-68	156
Innovations within UK Research Establishments	158
GaAs research at SERL, 1958-80	160

Page

Chapter 6

Firm shares in the British semiconductor market (%) 180

Foreign semiconductor manufacture in Scotland, 1962-77 195

Chapter 7

Direct US funding for semiconductor R&D Production Engineering Measures, 1955-61 234

Sales to the US Government by semiconductor manufacturers, 1950-56 236

Sales of silicon devices by US manufacturers, 1957-65 236

Estimated National Science Foundation obligations for student support, 1954-58 238

Number of employees within the domestic sector of the US & UK semiconductor industries, 1954-78 239

Hourly wage rates for assembly workers, 1966/7 & 1973/4 241

Average capital investment needed to set up a semiconductor production facility, 1950-93 242

Electronic industry sales per employee, 1981 251

Average price per device / % consumed by military, 1962-69 254

Volume of production destined for US commercial market, 1963-1970 255

Number of firms operating in the UK / % market share held by the three top companies, 1958-68 255

Texas Instruments royalty income & semiconductor operating income, 1989-92 258

Chapter 8

Wholesale semiconductor (discrete & integrated) price index, 1968-74 275

Changing market distribution of US integrated circuits, 1962-78 278

Number of computers installed, IBM/ICT, 1962-67 280

Page

Percentage of European computers manufactured within the US 287

Chapter 9

% shares of the European semiconductor market 307

European semiconductor firms market share (% value) 308

Chapter 1

Introduction

This thesis reviews the development of the British semiconductor industry from its beginnings in the early nineteen-fifties until the mid-eighties. It therefore contains an account of the fortunes of a technologically advanced and rapidly changing industry, firmly rooted in twentieth-century physics. The object of this investigation is to identify and evaluate the principal factors which determined the manner of development of the industry, and thus ascertain the reasons for its inability to compete effectively in commercial and industrial markets.

The most detailed studies of the industry so far have been undertaken from a mainly economic standpoint. The alternative approach adopted in this work has been largely by way of a technical and historical review. However, to have kept strictly to a chronological scheme would have resulted in a lack of emphasis upon certain important factors, and lessened the impact of the argument. A compromise has therefore been made, in which certain chapters deal with specific topics thematically, but are sited within an overall chronological framework.

The Importance Of Microelectronics

It would be difficult to challenge the view that semiconductor devices hold a particularly important position within modern industry, since almost universally they form the building blocks of electronic equipment. These electronic building blocks have become all pervading, being essential within, for example, computers, telecommunications and medical equipment. They are used extensively within industrial processes, an ever widening variety of consumer products, and play a key role within the defence industry.[1] Bureaucratic organisations of all kinds, including government departments, now heavily depend upon a wide variety of electronic equipments. Should the supply of these equipments to any modern state become severely restricted, it is highly unlikely that it could continue to function efficiently.

Producers of microelectronic components consequently hold an increasingly powerful position within society, being able selectively to supply or even withold their products, and, in the event of a monopoly, dictate prices. States which do not possess a semiconductor components industry are therefore highly disadvantaged with respect to those which do, and their sovereignty is correspondingly weakened.

In Britain, at least from the late seventies onwards, the unique importance of the industry has been recognised. For example, a Cabinet report, published in 1978, referred to microelectronics components as the most influential industry of the twentieth century.[2] Freeman, a Government adviser, writing in 1982, stated:-

> *"The microelectronic revolution is not just one more step in the process of technical change or one more new product. It is far more significant for the entire British economy than aircraft development or nuclear power, which at present constitute the largest part of Government-financed R&D activities."*[3]

Introductory Theoretical Framework

The history of British semiconductor industry may be regarded as an example of an industry which failed to develop effectively, when confronted by a technologically and economically superior rival. An analysis of the development of British semiconductor manufacture can therefore hardly fail to be made without placing an emphasis on this relationship. The following theoretical framework offers an explanation for the failure of British microelectronics companies to compete successfully in terms of market share, and stresses the importance of external factors in influencing the evolution of the industry.

The development of the semiconductor industry appears to contain special features which set it apart from most other industries. For example, it is technologically complex throughout its manufacturing process, relies on a highly specialised type of supporting infrastructure, and requires a high degree of long-term capital investment. An outstanding feature of the industry has been its extremely rapid growth, and at no stage has a technical plateau yet been reached. Any analysis of the industry can hardly fail to take this particular phenomenon into account, since it is a salient feature, differing from most other industries in this respect. Such a fundamental difference suggests that general conclusions regarding a theory of innovation, based on a large number of case studies and carried out over a considerable time scale, in the manner of Jewkes *et. al.*[4] may be of little value, in view of the industry's peculiar characteristics. It may however be possible to obtain an understanding of the development of the industry by proceeding by means of an historical review to a consideration of the features associated with successful transistor manufacture, and evaluating these features in terms of an appropriate theoretical model.

An evaluation of the factors governing the manner and growth of the electronics industry, including semiconductor production was made by J. Davidse.[5] Writing in 1973, he mentioned two essential mechanisms limiting the growth of a technology as being "the exhaustion of the material and energy involved" and also "the saturation of the function served by a particular technical achivement".[6] Certainly in the case of the electronic components industry, these basic limiting mechanisms appear not to have affected its growth. The conditions for such growth, as argued by Dickson,[7] rest upon the quality of innovation, which in turn depends upon a well established technical base and infrastructure upon which the industry can draw for such resources as technical support, new supplies, services, expertise and information. These resources are only likely to be present within a highly developed economy, and the more highly industrialised an economy, the greater the advantage in this respect. Disparity of resources is therefore a key factor in the development of the industry, and this aspect is considered in detail in chapter 7.

Two principal factors appear to have contributed to the growth of an internationally competitive semiconductor industry. Firstly, a "pump-priming" mechanism enabling the industry to produce large quantities of devices, thereby reducing unit costs and also establishing efficient mass-production facilities. In the case of the American semiconductor industry, this mechanism was established through contracts awarded by the Department of Defense. [How this was done has been described, for example, by Tilton[8] in 1971 and in an OECD report,[9] published in 1968]. Secondly, by establishing a close relationship with a market which constantly demands a technically improved product, and is large enough to allow advantages over competitors in terms of economies of scale.

If such a relationship is established between supplier and user, it may lead to a situation where both the rate of growth and technical advance within both producer and user industries is considerably enhanced. Such a situation has been described by Mackintosh as "industrial synergy".[10] An example of industrial synergy quoted by Mackintosh is the relationship which has existed between the American semiconductor and computer industries. A more recent example is that established between the Japanese semiconductor industry and the electronics consumer industry. A consideration of these examples suggest that industrial synergy was a vital ingredient in commercial success. It is therefore important to investigate the conditions under which such a relationship might be established, and to what degree it was actually achieved.

A theory of synergistic development, although offering a plausible explanation for rapid and continuous industrial growth, does not address the situation which appears to have occurred in certain industries where some companies, or groups of companies have, after an initial period, established themselves as market leaders over a considerable period of time, in spite of many attempts by would-be competitors to enter the industry. Such a situation has been addressed in general terms by Prof. W.B. Arthur, who argues that in certain industries and under certain conditions, it becomes possible for a company or companies to become "locked into success" not only in the sense of becoming undisputed market leaders but also by dominating the technology to such an extent that rival technologies are unable to become established, even if technically superior.[11] Evidence exists that the semiconductor industry may be such a case, and Texas Instruments such a company. For example, during the period under review, in spite of many entrants into the industry, Texas Instruments remained the leading semiconductor manufacturer worldwide from 1957 until 1985,[12] when it was overtaken by NEC, a Japanese company.

Any challenge to the dominance of the major semiconductor companies would be most likely to arise at the time of the introduction of a new technology, since at this stage barriers to entering the industry are lowest. However, since the establishment of Texas Instruments as market leader during the early phase of the industry, none of these new entrants succeeded in displacing that company during the period under review. Not only did this company remain a market leader, but it played a major part in determining technological trends within the industry in spite of a relatively limited R&D contribution. Because of the leading role of Texas Instruments, and also its considerable influence on the development of the British semiconductor industry, this organisation is considered in detail in chapter 6.

Some idea of the significance of Texas Instruments as the long-term market leader in semiconductor device manufacture may be obtained from the following table:[13]

Leading US discrete and IC semiconductor manufacturers in order of ranking

	Ranking				
	1	2	3	4	5
Year					
1955	Hughes	Transitron	Philco	Sylvania	TI
1957	TI	Transitron	Hughes	GE	RCA
1960	TI	Transitron	Philco	GE	RCA
1963	TI	Motorola	Fairchild	GE	WE
1966	TI	Fairchild	Motorola	WE	GE
1972	TI	Motorola	Fairchild	ITT	RCA
1975	TI	Fairchild	Nat. Semi.	Intel.	Signetics
1978	TI	Motorola	Nat. Semi.	Fairchild	Intel
1981	TI	Motorola	Nat. Semi.	Intel.	Fairchild
1985	TI	Motorola	Intel.	Nat. Semi.	

GE: General Electric
ITT: International Telephone and Telegraph
Nat. Semi.: National Semiconductor
RCA: Radio Corporation of America
TI: Texas Instruments
WE: Western Electric

Entry of new firms into the US semiconductor manufacturing industry show marked clusters around periods when significant changes in manufacturing technology were taking place. This situation is illustrated in the table below: [14]

Number of Entries into Semiconductor Manufacture within the US

Year:	1951	1952-3	1954-8	1959-63	1964-7	1968-72	1973-7
No. of entries:	1	14*	8	26*	7	31*	4

[The dates indicated by an asterisk * refer to periods of technological introduction, when barriers to entry were low, whilst the remaining dates refer to periods when the new technology had become established, and the market leaders were well down the learning curve, producing devices in volume at low unit cost. Specifically, the period 1952-3 refers to the initial entry into semiconductor manufacture. The period 1959-63 covers the development of silicon planar technology and the period 1968-72 the introduction of MOS technology].

The above tables indicate that although many new companies entered semiconductor manufacture during periods when barriers to entry was relatively low, none displaced Texas Instruments during the period under review. In the case of major competitors, not all were able to maintain their position, Fairchild being an obvious example. However, a fairly stable situation existed, Motorola holding a significant position. Both Fairchild and Motorola entered semiconductor manufacture during the late 1950s, during the period of the development of silicon planar technology. It appears, therefore, that certain major US semiconductor companies and Texas Instruments in particular had become "locked into success". It is significant that these leading companies were major suppliers of components to the US Department of Defense and the computer industry and appear to have formed strong synergistic relationships with these technically sophisticated and rapidly evolving markets.

An important measure of the degree of success achieved by the major semiconductor manufacturing companies was the high concentration of production within the industry. For example, the four largest semiconductor manufacturers held 51% of the market in 1957, 50% in 1965 and 50% in 1972.[15] Texas Instruments alone averaged between 17 and 21% of the market over this period.[16] Consequent advantages due to economies of scale were therefore available to these companies.

In Britain, by contrast, there were hardly any attempts by new entrants to enter semiconductor manufacture, which was carried out almost entirely by thermionic valve companies during the period under review. The importance of thermionic valve companies and their influence upon semiconductor manufacture was therefore correspondingly larger than in the US. Because of this, significant consideration has been given to the history of the valve industry within Britain in chapter 2. Furthermore, unlike the situation in America, no major market existed in Britain, or indeed Europe, which would have permitted a synergistic relationship to become established on anywhere near the scale of the American effort.

Denied an initial pump-priming mechanism and lacking a market capable of sustaining a successful condition of synergy, the British semiconductor industry were unable to overcome the constant technical lag which arose following the introduction of the silicon transistor. Under conditions of limited production, the industry was denied the advantages of economies of scale. Furthermore, under these conditions the industry was unable to build up the technological infrastructure, including suppliers of equipment and materials, in order to support it effectively. This resulted in delays and expenses not experienced by competitors, who were themselves often situated within geographical "skill clusters"[17] such as "silicon valley". Although innovative, the relatively small British firms were effectively locked out of the technological mainstream by dominant overseas rivals. The role of the market leader, Texas Instruments, in bringing about this situation was highly significant. Faced with overwhelming market penetration by the most technically advanced overseas subsidiaries, operating within its shores, the British semiconductor industry turned more and more to relatively protected niche markets, such as the defence industry.

Previous writers, even as recently as 1989[18], have argued in favour of direct foreign investment and collaboration with American, Japanese and other producers· Whilst agreeing that some measure of co-operation is highly desirable, particularly in advanced areas such as very large-scale integration (VLSI), it is suggested in the epilogue to this thesis that only by strict control of inward investment is it possible to build a healthy European semiconductor industry. It is also concluded that virtually no prospect exists of any future effort by individual European states being able to develop a strong, competitive, industry. It therefore appears that any attempt to build an internationally competitive semiconductor industry within Europe must rest on a far higher degree of inter-state collaboration than has so far taken place.

Previous Contributions To The History Of Semiconductor Manufacture: A Brief Survey.

This survey is intended provide a convenient source of reference, and also help to provide a general background to the thesis. The following list of authors obviously cannot be exhaustive, and must therefore necessarily be selective. Consequently, I have chosen the work of individuals whose contribution I particularly regard as being of major significance. Although there cannot fail to be important omissions, it should at least offer an insight into the approaches followed by principal contributors working within the field:-

A.M. Golding

A major contribution to an understanding of the development of the semiconductor industry in both Britain and America was made by A.M. Golding, in a D.Phil Thesis (University of Sussex, 1971) entitled "The Semiconductor Industry in Britain and the United States, a Case Study of Innovation, Growth and Diffusion of Technology".[19] This extremely detailed work covers the development of the industry from its beginnings until early 1969, including an account of the principal technical innovations and the economic aspects of semiconductor manufacture in both Britain and the United States. It argues that the more technically advanced American market renders innovation more likely within that country, which consequently acts as "a locus for invention".[20] Although this advanced market exerts a "demand pull" upon innovation, large-scale US Government demand has occupied a pivotal role, this being a "critical element in the cycle of American domination".[21] Golding saw this situation being broadly maintained in the future, and the United States as the only sizable outlet for sophisticated electrical components. He felt that to change this situation, any non-American firm would have to produce a new technology markedly superior to the current one.

In spite of an extremely detailed analysis, supported by an impressive array of data, Golding's future prognosis for the industry was not borne out by subsequent events. This is demonstrated by the subsequent success of Japan in the field of VLSI. Such an unforseen development, which occurred during the latter part of the following decade, suggests that incorrect weighting had been given to certain factors, or alternatively, that factors may have been present which were ignored within the thesis.

J. Tilton

Another work of considerable importance, published in 1971, was J.Tilton's "International Diffusion of Technology: The Case of Semiconductors".[22] As the title suggests, the author is concerned principally with issues involving the rate and manner of diffusion of technology within the semiconductor industry. He considers the case of Britain within the larger European context, and pays particular attention to the reasons why barriers to entry to the industry were high for European firms, but not for foreign subsidiaries.[23] He argues that these subsidiaries were able to penetrate European markets within the sixties, primarily because the thermionic valve manufacturers were slow in adapting to the new silicon technology, both in discrete devices and integrated circuitry.[24] Since the major innovations were held by American companies, it would have been impossible for European firms to have established a patent pool in order to block the entry of new firms. Under this situation, licensing policies acted to the disadvantage of indigenous firms, because American parent companies, with licenses to trade, were able to pass the consequent savings on to their subsidiaries. Furthermore, technical information was also passed preferentially to these subsidiaries.

Further factors mentioned by Tilton as acting to the disadvantage of European producers included the size and nature of the market and lack of availability of venture capital, and also the restrictive effect of the "Buy America" Act. He also addresses the economic consequences of technical lag. Due to differences in demand structure, by the time a significant demand arose in Europe for a new device, American manufacturers were able to fill the European market requirement of pricing well below the costs of European firms.

According to Tilton, European firms faced a dilemma. Large organisations were needed to imitate American technology and compete with American subsidiaries, yet in order for Europe eventually to pioneer the diffusion of new semiconductor devices, new firms and low barriers to entry into the industry might well also be needed.

Although Tilton's description of the problems faced by European (and therefore British) semiconductor manufacturers is extremely valuable, he was writing, like Golding, at a time when the only successful model for the industry was that of America. He therefore could not anticipate the success of the Japanese VLSI programme, which was achieved by vertically integrated manufacturing companies under the auspices of the Ministry of International Trade and Industry (MITI), and afforded considerable economic protection. Nor could Tilton forsee a situation developing within the United states where the supply of venture capital available to the industry would become considerably limited. Also since that time, both the degree of technical sophistication and costs of entry into manufacture have increased greatly, and any contemporary work addressing the diffusion of technology within semiconductor manufacture would have to take this into account.

F. Malerba

A comprehensive review of the European semiconductor industry is contained in "The Semiconductor Business: the Economics of Rapid Growth and Decline" by F. Malerba,[25] which originated as a Ph.D thesis at Yale University. It contains a detailed chronological account of the development of the European semiconductor industry within the framework of World developments, but also emphasising the roles of America and Japan. Malerba argues that the decline and unsuccessful performance of the European semiconductor industry must be due to such factors as "the organisation of R & D, production and strategies of firms, the structure of industry, the composition of demand, and the type and extent of Government policy".[26]

This work emphasises the importance of technical change within the industry, and the influence of public policy. Like Golding, Malerba believes that the massive American Government procurement programmes played a significant part in bringing about that country's technical dominance. However, writing some time later, he is able to conclude that Japan obtained technical leadership in Very Large-scale Integration (VLSI), because by the mid-sixties the United States defence and space programmes were no longer playing their previous role. Although part of the Japanese success is ascribed to their relatively large home market and policies of economic protection,[27] he also points to the "cumulative" nature of semiconductor technology, and the importance of technical lead during the period of Large-scale Integration (LSI) and VLSI.[28] During this period, the structure of demand for semiconductors in Europe, America and Japan tended to coincide. Lack of success in LSI within Europe was due to late entry, and increasing technical complexity.

Although Malerba's book is of considerable importance in presenting an overview of the decline of the European semiconductor industry up to the mid-eighties, it deals with these issues on a fairly general, across-the-board level. Malerba's emphasis is therefore different from the present thesis, since he does not specifically attempt to investigate the failure of the British semiconductor industry to perform successfully in world markets.

E. Sciberras

Approaches to the study of the semiconductor industry have generally been made from an economic standpoint. "Multinational Electronic Companies and National Economic Policy"[29] by E. Sciberras, published in 1977, is no exception. The stated aim of this work is to:-

> *"explore the role of technology and innovation on the impact of the rise of the multinational firm on competitive behaviour and to suggest an alternative framework which might usefully incorporate these increasingly important factors into the theory of the firm in economics."*[30]

Unlike the contributions by Golding and Malerba, this study greatly makes use of personal interviews. It focusses largely upon competitive behaviour and discusses developments within the industry in terms of established economic models. Specifically, it refers to the phemenomenon of "market creation" through price reduction due to improved manufacturing techniques extending into equipment markets, and thus creating additional semiconductor applications. It argues that this consequent impact on equipment costs has been a stimulus in bringing about vertical integration in semiconductor manufacture. The "big league" firms (such as Texas Instruments and Philips) tended, although not exclusively, to adopt the strategy of using the learning curve to compel substantial price reductions in order to improve long-term profitability and competitiveness. The "little league" firms (such as Plessey and Ferranti) were unable to follow this policy, so engaged in "price creaming" to exploit their short-term monopoly position, following initial market penetration. Sciberras points out that neither funding from whatever source, nor industrial reorganisation, has been successful in establishing British semiconductor firms within mainstream component manufacture. Far from coming to grips with the problem, these policies may well have perpetuated it. Sciberras saw the Government as playing a leading role in establishing a competitive semiconductor industry in Britain, through some form of state enterprise.

The strategy recommended by Sciberras was indeed adopted through the setting up of the British state-assisted semiconductor manufacturing company INMOS in 1978, but was unsuccessful due to a lack of continuity in Government policy, and also lack of long-term funding. The underlying reasons for the failure of INMOS, and the inability to sustain a viable semiconductor industry through a policy of public funding, are discussed within the present thesis.

E. Braun and S. Macdonald

A highly readable and important contribution to the study of the development of the semiconductor industry on a World scale, was made by E. Braun and S. Macdonald, with the publication of their book "Revolution in Miniature".[31] This work, first published in 1972 and revised in 1982, describes the growth of the industry from its earliest days until the end of the seventies. Its emphasis is strongly upon commercial developments within the United States. Although agreeing that the factors inhibiting growth of the semiconductor industry in Europe are complex, the authors discount the importance of America having been first in the field, and also the relatively small size of the European semiconductor industry. Although European firms were deprived of the large American military market, this factor was not significant, since this market had considerably declined in size by the mid-sixties, and by the seventies accounted for no more than 10% of United States shipments.[32]

The authors do not identify any particular causes as being of outstanding significance in preventing the growth of the industry in Europe, but they do mention American subsidiaries as a barrier to the flow of innovation to overseas competitors.[33] For example, they suggest that European firms failed to take advantage of Bell technology to the same extent as American companies, the latter also proving superior in market innovation. Other factors mentioned which were applicable to Britain included poor availability of risk capital, the low status of engineers, and lack of personal mobility. They ascribe the Japanese success to the size and timing of Governmental support, good planning, and efficient dialogue between Government and industry. Unlike Europe, long-term debt was not a problem for firms in Japan.

This is an extremely informative and useful review, but in spite of listing a considerable number of possible factors which may have contributed to the poor performance of the semiconductor industry within Europe, it does not subject these elements to any significant degree of analysis. This volume is nevertheless of great assistance in obtaining an overview of the development of the industry, and an appreciation of the factors likely to have influenced its development.

A.M. Mackintosh

A.M. Mackintosh writes with a wide experience of the semiconductor industry, dating from its earliest days, when he was engaged in research at Bell Laboratories, and later at Westinghouse. Returning to Britain in 1964, he became General Manager of Elliott Automation Microelectronics Ltd. before founding his own company (Mackintosh Consultants Ltd.) in 1968. In an article entitled "Dominant trends affecting the future structure of the semiconductor industry" [34] published in 1973, Mackintosh clearly states what he considers to be the major factors involved in bringing about American technological dominance in semiconductor manufacture, and the reasons for the failure of European companies to compete effectively. He asserts: "The most important factor in providing the US technological lead was the tremendous R&D funding provided throughout the sixties by the US Government in search for more reliable, higher performance and smaller electric systems for space and defence purposes".[35] He places emphasis upon this manner of funding, stating that it was "important that the bulk of Government funding was channelled into industry, not the universities or Government research laboratories".[36] Consequently, when the situation arose which allowed commercial firms to exploit the situation, they were extremely well placed.

Mackintosh explains the continuing American domination of the semiconductor industry as being due to a condition of industrial synergism existing between that industry and computer manufacture. In this context, he wrote in 1978, there is "no doubt that the simultaneous American domination of the integrated circuit, computer and professional electronics sectors are all part of the same basic phenomenon, and that this is the main - not the only but the main - reason for today's domination by the United States of the worldwide IC business".[37] In this respect, the computer industry acted as a springboard, since "over 90% of the Western World's production was in the United States". Most importantly, he applied the concept of synergism to explain the continuing rapid expansion of the American semiconductor industry, following the "pump-priming" role of the Department of Defense.

Mackintosh also suggests a number of subsidiary factors underlying American success; for instance: "It is also important to realise that in many cases the R&D support from the US Government agencies was on a clear understanding that commercial fall-out was not only possible but desirable". In the same article he mentions "A related but subsidiary factor was the existence in the US of several industrial labs. of very high quality".[38] A further advantage mentioned was the presence of a very substantial domestic market. Also significant was that "the US was blessed with a breed of talented and technically informed entrepreneurs, backed up by a sophisticated, powerful and knowledgeable financial community, so that when the implications of the new technology became evident, the way was clear for an enormous and relatively well-managed investment in productive capability to take place". Mackintosh also states that, outside the United States, both managements and governments failed to recognise the importance of the new silicon technology. Furthermore, the human resources to develop it were not sufficient, and in most cases, markets were not yet sophisticated enough to use its latest products.

Unlike Braun and Macdonald, Mackintosh appears confident in his assessment of the relative importance of the various factors determining the success of the American semiconductor industry. He attributes the origins of American technological dominance within Europe to the introduction of silicon technology, rather than to the failure to develop integrated circuitry, as argued by Malerba. In this respect, it appears that the evidence supports Mackintosh's view.

In addition to the above authors, important contributions have been made, for example, by J.Kraus, G. Dosi, R.C. Levin, and this list is by no means exhaustive. Throughout this thesis I have used quotations from all of the authors mentioned above, and am consequently indebted.

This brief review of various important contributions to the study of the development of the semiconductor industry suggests that although a fairly general agreement exists regarding the factors responsible for the poor performance of the British semiconductor industry, their weighting varies considerably from one author to another. Moreover, the importance accorded to these factors underwent significant changes during the period under review. Prior to the success of the Japanese VLSI programme, Golding, Tilton and Mackintosh saw little likelihood of the American position of dominance being challenged. This view may have been reinforced, at least in the case of Golding and Tilton, by the particular approach adopted, namely that of considering the industry as a case study for the diffusion of technology. This approach necessarily drew upon existing economic models, which may not have been appropriate to the industry. What Golding and Tilton were unable to realise, writing in 1971, was that the rate of technological advance would not reach a stable plateau, unlike the situation in most industries, including thermionic valve manufacture. Only recently has such a situation been recognised as requiring analysis quite different from existing economic models.[39]

Mackintosh, writing in the early seventies, perceived a synergistic relationship existing between the computer industry and device manufacture. He saw this as the principal means for the continuing dominance of the United States within semiconductor manufacture. At that time, he could hardly have envisaged the implications of the development of large scale integration and the microprocessor. Perhaps the most important example of synergy in semiconductor manufacture was that which resulted from the Japanese VLSI programme, enabling Japanese microelectronics firms to enter large scale production at just the right time to take advantage of their strength in the rapidly developing commercial mass market. Not only is this an example of markets being on occasion strongly technology-led, but demonstrates that in such a situation, opportunities arise which can be exploited with skilful planning, leading to a situation where the new technology becomes "locked into success".

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Chapter 2

A Review of the General Characteristics of the British Thermionic Valve Industry

Introduction

The purpose of this chapter is to review the development of the British thermionic valve industry, in order to obtain some understanding of the environment in which the semiconductor industry was later to evolve. The structure of the valve industry formed the framework within which the development of transistor technology subsequently took place.

Experiences and attitudes formed even prior to the valve era were to play an important part in the subsequent fortunes of semiconductor manufacture. During the inter-war period, nearly all thermionic valve output was destined for the radio industry. Consequently, until the Second World War, the manner and rate of valve development was largely determined by the needs of domestic broadcasting, and only relatively late, under urgent wartime demands, was this situation significantly to change. After subsequent rapid developments in solid-state technology, the picture is one of considerable contrast. An evaluation of the characteristics of the thermionic valve industry should offer some understanding of the manner in which the industry attempted to accommodate these fundamental technical changes.

The Development of the Thermionic Valve

The Initial Phase 1906-20

The beginnings of the British thermionic valve manufacturing industry can be traced back to the latter years of the nineteenth century, the electric lighting business forming the basis from which the industry developed. Although Edison had shown in 1880 that current would flow if a wire inserted in a light bulb were connected to a positive potential, he did not investigate the possibility of rectification, being strongly opposed to the use of alternating current.[1] However, a patent application was made in 1904 by Professor J.A. Fleming, then scientific adviser to the Marconi Company, describing a two-electrode valve, or diode, which was capable of acting as a rectifier.[2] Soon afterwards, in 1906, Lee de Forest, working in the United States, modified the diode by placing a grid between the anode and cathode, thereby constructing a triode valve, the first device able to amplify electric current.[3] Remarkably, its amplifying properties do not seem to have been recognised until 1911, when the discovery was made independently by Edwin Armstrong in America and Von Lieben in Germany.

However, as soon as it was realised that the triode was capable of signal amplification, progress was rapid. In 1912, de Forest demonstrated a multistage amplifier using triodes to the American Telephone and Telegraph Company (AT & T), where the idea was soon improved. In 1914, that company bought the radio receiver rights for the triode for a sum of $90,000. Atherton comments: "It was thanks to the work of the large industrial laboratories, especially those of AT & T and General Electric, that the crude triode was transformed into a reliable and efficient device".[4]

Immediately prior to the First World War, a major technical improvement was made to the triode by the American electrical engineer and inventor E.H. Armstrong, who showed that the presence of a gas within the envelope was not essential to its functioning. Also in America in 1914, I. Langmuir, a young graduate working for the General Electric Research Laboratories, constructed the first highly evacuated (hard) valves.[5] These were of the tungsten filament type, and made by a process which ensured far more uniform characteristics than had previously been possible. Their lifetime was considerably improved by being highly evacuated, because of the reduction in cathode contamination by positive ion bombardment. In Britain, the first evacuated valves were produced by the Marconi Company at about this time, illustrating that diffusion of valve technology was by then rapid, no doubt because of the widely perceived potential of electronic amplifying devices.

The First World War quickly brought new demands upon the fledgeling radio industry. Almost immediately, attempts were made to cut the underwater continental cables, creating a pressing need for long distance radio communication. Due to military requirements, the applications of radio communication markedly increased, including, for example, the surveillance of enemy underwater, surface and aerial activities. These demands in turn created an urgent need for greatly increased quantities of thermionic valves of acceptable quality. Efforts were therefore made which resulted in great advances in valve construction during the course of the war. Principal valve applications were as amplifiers and oscillators in radio transmitting and receiving equipment. To assist military operations, efforts were concentrated upon performance, reliability, and the ability to operate under adverse conditions. As a consequence, "hard" valves quickly replaced the earlier "soft" valve types.[6]

An important wartime development was the institution of mass-production techniques of manufacture, principally in the United States, and to a lesser extent in Britain, Germany and France. From 1916, valves were being made in Britain by Ediswan, BTH and Osram. In America, such firms as AT&T and General Electric and in Germany AEG, produced valves on a very large scale. By 1918, one French firm alone was making 1000 valves per day, and W.A. Atherton mentions that over one million were manufactured during the course of the War.[7] In addition to the establishment of mass-production techniques, a clear theoretical understanding of the theory of vacuum tubes had emerged. Also at this time it began to be understood how the internal physical dimensions of a valve determined its performance as a detector, oscillator and amplifier.

From about 1920 onwards, high power transmitting valves began to be manufactured, largely made possible by the W.G. Housekeeper (Bell Labs.) method of making large diameter glass to metal seals.[8] This ability to construct large transmitting valves made reliable wireless transmission feasible over considerable distances, and set the scene for the future rapid development of broadcasting. By this time, several manufacturers within the United Kingdom were making thermionic valves, for example Marconi, GEC, British Thompson-Houston (BTH), Westinghouse, Edison Swan and Cossor. However, large surplus stocks of valves existed immediately following the end of the War, and there was little incentive to increase production until broadcasting began.

A significant event, brought about by the War was the breaking of the patent stranglehold upon the manufacture of thermionic valves and equipment, if only for the duration of the conflict. Consequently, the contestants were able to improve greatly the characteristics of the triode and also radio circuitry, without regard to royalty payments. The War also afforded an opportunity for American manufacturers to enter the European market, and certainly stimulated the growth of radio and valve production in that country. The American Marconi Company, in particular, "became, almost overnight, a great manufacturing firm".[9] Therefore by the end of the War, a powerful thermionic valve industry had emerged, particularly in the United States, capable of supplying a large domestic radio market. Also, the importance of radio in military communications had been conclusively demonstrated.

In October 1919, a merger took place between the American Marconi Company and General Electric (US), forming the Radio Corporation of America, (RCA). This merger was carried out under the auspices of the United States Navy Department. However, important patents still remained in other hands, and again the Navy Department intervened, obtaining an agreement between the parties concerned, and thus enabling RCA to obtain access to these additional licences.[10] By 1921, RCA controlled over two thousand patents, including most of the important radio patents at that time. These steps had been initiated by the American government, in order to prevent a communications monopoly by the British sponsored Marconi company.[11] However, no overall authority existed within America governing the control of broadcast transmissions, contrasting with the situation within Britain, where no transmissions were possible without the approval of the Postmaster-General. Consequently, American commercial broadcasting was able to get off to a much earlier start. This event in turn acted to stimulate valve and equipment manufacturers within the United Kingdom to press for a National commercial broadcasting service.

In Britain, events were strongly influenced by the American experience, in which a multiplicity of radio stations had led to a "jumble of signals" and a "blasting and blanketing of rival programmes".[12] Already by May 1922 there were 219 stations operating in the United States. Consequently, the Post Office pursued a cautious policy, establishing strict restrictions to regulate broadcast transmissions. Although a number of stations had been licensed to operate during 1920, the Post Office banned experimental broadcasting from November 1920 until May 1922, when the 100 watt Marconi London station 2LO was allowed to function, but only under strict controls governing broadcasting times and material. In spite of its low power and consequent small range, it had a total audience of about 50,000 by the autumn of that year, thus demonstrating wide public interest.[13]

Development of the Valve Industry during the Inter-War Period

(A) Technical Developments

Technical improvements in valve construction during this period largely resulted from the limitations of the triode, and subsequent attempts to overcome them. A major problem was the existence of inter-electrode capacitances, mainly between the anode and grid, resulting in feedback and instability, which became worse as frequency increased. A successful solution was the development of the screen-grid valve, which became known as the tetrode. This valve was invented in 1926, and is generally credited to a British engineer, R.J. Round, an employee of the Marconi Company.[14] Although the tetrode was successful in reducing inter-electrode capacitances to a much lower level, at a certain anode potential, it suffered from the defect that because of the high positive potential of the screen grid, electrons were accelerated with sufficient velocity to cause "secondary emission" of electrons from the anode, which were then collected by the screen. This effect resulted in the total anode current being reduced in value, and the screen current increased, giving a "kink" in the valve's characteristics. However, further increase in anode voltage resulted not only in the anode's receiving the primary electrons emitted by the cathode, but also a further number from the screen. Under these conditions, variation in anode voltage produced a nearly constant anode current, enabling higher values of amplification to be achieved than was possible with the triode.

The problem of secondary emission was solved by the invention of the pentode valve by Telligen and Holst of Phillips (Holland) in 1928.[15] This was done by adding a further grid to the tetrode, mounted between its anode and screen grid. The function of this additional grid, called the suppressor, was to capture the electrons released from the anode by secondary emission, thus preventing them from reaching the screen grid and causing its potential to rise. The effect was to eliminate the "kink" in the tetrode characteristic, enabling the pentode to produce an almost constant anode current for a wide range in anode voltage. Because of its linear characteristics, the pentode valve became extremely popular during the period immediately prior to the Second World War.

During the nineteen-thirties, progressive refinements in mass-production techniques continued to be made. This resulted in economies of scale, tending to favour the larger manufacturers. Further developments in valve structure and geometry took place, including double diode rectifiers and multi-grid structures, such as triode-hexodes and triode pentodes, which were used as frequency mixers in superheterodyne receivers. These designs did not however involve any new fundamental principle, and apart from increased complexity, methods of valve construction remained basically the same, and are described in the following paragraphs.

In order to obtain an insight into the nature of the industry, it might be helpful briefly to outline the manufacturing processes used in the production of thermionic valves. Thermionic valve construction is essentially a three-stage process. In the first stage, sub-assemblies, for example the electrodes, wire and glass envelopes are produced using highly mechanised equipment. The second stage involves the assembly of the constituent parts, and is labour intensive. The third stage, which consists of sealing, pumping and gettering the valves, is also highly mechanised. Gettering is the process of removing residual gas during the lifetime of the valve by the inclusion of an active substance, such as magnesium or barium. If this was not done, the lifetime of the valve would be considerably shortened.

The electrical characteristics of a valve are determined by the geometry and spacing between the various electrodes, and also by the efficiency of the cathode as an emitter of electrons. The cathode may be directly or indirectly heated, and is oxide coated to improve its emissive properties. Nickel and molybdenium are usually used for the manufacture of electrodes, because of their high melting point, and also because they do not exude excessive quantities of adsorbed gases during device operation. The manufacture of television tubes follows similar lines, except that the electron gun assembly is more complex and the glass tube itself is made in sections. The Pilkington Glass Company has been the major supplier within the United Kingdom from the mid-fifties onwards. During this period, statistical quality control in television tube manufacture was based upon carrying out a series of electrical measurements on a sample basis.

(B) The Growth of Valve Manufacture

Following the end of hostilities, the thermionic valve manufacturers, faced with excess production capacity, exerted pressure on the British Post Office to begin public broadcasting. It was largely due to their efforts that the British Broadcasting Company (BBCo) was set up in December 1922. It is notable in this context that three of the leading valve producers (GEC, British Thomson Houston (BTH), and Metro-Vickers) were among the six guarantors for the newly formed Company. This Company was the immediate precursor of the British Broadcasting Corporation (BBC), founded on the 1st January 1927 as a public corporation, the original shareholders of the BBCo then being bought out. Unlike the situation within the United States, public broadcasting was therefore introduced under conditions of monopoly, reflecting the conservative and cautious approach of the Post Office to this new development.

An important influence upon the subsequent development of the British thermionic valve industry was the extremely strong patent position of the Marconi Company. Prior to the formation of the BBCo, manufacturers wishing to make use of the Marconi patents had to negotiate individually with the Company. After this event, any licencee wishing to use any or all of the patents was required to purchase a general licence (the "A2" licence). The royalty payment under this arrangement was based upon the number of valve holders within the set, and amounted to 12s 6d per valve holder.[16] Restrictions imposed under the licence included the undertaking to use only Marconi-Osram valves, or others licensed by the Company. Licensees were not to manufacture for public entertainment, nor to export receiving sets outside the United Kingdom. A further licence was needed from the Marconi company in order to manufacture thermionic valves. In addition to these limitations, the manufacturers set a tariff payable to the BBCo. Right from the start, therefore, set manufacturers were forced to operate under highly restrictive conditions. [One method of avoiding the payment of these royalties was by home-construction, and during the 20s this method of manufacture was extremely popular.]

As set prices fell during the middle and late 20s, the burden imposed by these royalties became relatively greater, and pressure was brought to bear by the Radio Manufacturers Association for their reduction.[17] Litigation, supported by the Radio Manufacturers Association, was taken against Marconi during 1928 and 1929, but resulted in defeat of the set Manufacturers. However, during the hearings, it emerged that in 1922 the Marconi Company had granted special licences to the six major companies responsible for forming the BBCo, in direct opposition to the wishes of the Postmaster-General. Resulting from these events, the British Valvemakers Association patent pool was formed, involving a number of the largest companies. The name "Marconi licence" was however retained to describe the new patent pool licence, which continued to be administered through the Marconi Company, and reflecting its still dominant influence.[18] A further development was that in 1929 the royalty per valve holder was reduced under the "A3" licence to 5s 0d, and was yet again reduced in 1933 under the new "A4" licence to 2s 6d. These reductions reflected the decreasing influence of the patent pool.

The valve manufacturers concerned in founding the BBCo, in return for financing the Company, enjoyed limited protection against the importation of foreign equipment. Additional protection was afforded by the Marconi patents, which prohibited the use of imported radio apparatus. Tariff protection prior to 1931 amounted to 33.3% and this was felt necessary in order to avoid the market being flooded with cheaper US and European products. This highly defensive attitude was reflected in the early formation of trade associations, in an attempt to control the price structure of the industry. For example, in 1923, the National Association of Radio Manufacturers was formed. This organisation was open to any member of the BBCo, and was followed shortly by the British Radio Manufacturers and Traders Association, largely representing the smaller firms. Both these organisations came together in 1926 to form the Radio Manufacturers Association, a trade organisation principally concerned with matters such as price levels, discounts, and organising publicity for the industry. In 1924, the British Valvemakers Association (BVA) was also instituted, with the object of restricting valve imports and maintaining price levels.[19]

It has been suggested that the valvemakers "combined more aggressively, as befitted their descent from the incandescent lamp industry which had formed price-fixing rings before the First World War".[20] From 1927 onwards, receivers made by the Radio Manufacturers Association had to contain only valves made by BVA members. These restrictive practices certainly illustrate the defensive psychology of British valve manufacturers, which seem hardly to have changed since the earlier days of incandescent lamp production. The perceived threat was twofold, firstly, that of cheap foreign imports, and perhaps even more importantly, the activities of companies holding substantial patent rights outside the BVA patent pool.

Valve manufacturers outside the Association included Hivac, a firm specialising in industrial valves, British Tungsram, a Hungarian firm assembling valves in the United

Kingdom, and Mullard Ltd., who were to join the Association at a later stage. In 1931, the import duty on foreign valves was temporarily raised to 50%. The BVA at this time even argued for a 100% tariff, on the grounds that in the preceding year valve imports had increased by 89% in spite of this duty. The M-O Valve Company however, took the view that this argument was not only weak but dangerous, on the grounds that it might provoke investigation into the wide differential existing between manufacturing costs and retail prices. This attitude certainly reflects sensitivity to a situation where public concern might be aroused by current restrictive practices within the industry, should these matters receive undue attention.

The BVA were largely successful in instituting a fixed price structure within the industry, which involved establishing separate list prices for setmakers, wholesalers and retailers. Setmakers were able to purchase valves from BVA members at no more than the cost of production, or even less. Wholesalers would receive no discounts unless they agreed only to handle valves produced by BVA members.[21] Valve manufacturers profits were almost entirely made through the replacement market, where prices to customers were kept considerably above production cost.

Valve prices in the early 20s were certainly expensive to the consumer. Sturmey quotes as an example a receiving valve which at that time cost 4s 6d to manufacture and 1s 6d to advertise and sell, but retailing at 17s 6d.[22] In spite of high import duties, American valves continued to undercut local products. For example, a particular valve manufactured within Britain in 1931 retailed at 8s 6d, whilst it's imported equivalent was sold for 5s 6d.[23] Under these highly restrictive conditions, an undoubted incentive existed to import cheap foreign valves for home construction, and for overseas firms either to attempt to sell to British setmakers, or alternatively to manufacture within the United Kingdom. Both these strategies were strongly opposed by Marconi patentholders, who did not hesitate to prosecute for patent infringement. Nevertheless, these activities had some success, and resulted in helping to bring about a gradual fall in valve prices. The institution of the BVA two-price structure, by supplying cheap valves to setmakers, discouraged the purchase of overseas competitors' products, and by cutting construction costs contributed to a fall in set prices. Consequently, by the end of the 20s, home receiver construction had greatly diminished. This trend was also reinforced by increasing receiver complexity, due to the widespread introduction of superheterodyne receivers during the thirties.[24]

The decision to impose royalty payments on the number of valve holders in a radio receiver was to have important technical consequences. The obvious way to minimise royalty payments was to reduce the number of valve holders. One way of doing this was to increase the amplification factor of each amplifying valve within the set, and by 1931 Edison Swan had produced a valve with an amplification factor of 1000. The invention of the tetrode in 1926 followed by the pentode in 1928 greatly assisted the process. The pentode, with its improved signal amplification, soon became the most widely used receiving valve, giving Philips extremely important patent rights outside the Marconi pool and thus weakening the influence of the pool within the industry. This event clearly demonstrates the vulnerability of the BVA to major technical developments outside its control, and it was consequently forced to enlarge the pool to include its technically advanced competitor.

During the 30s, another attempt to overcome the cost of royalty payments, based on quantity of valveholders per set, was to design multi-function valves. Examples of this approach were the triode-pentode, triode hexode and double diode rectifier. This measure, together with the non-standardisation of valve pin connections within the industry, also tended to restrict foreign imports. Towards the end of the 30s the American industry standardised on octal (eight pin) valve bases, but within the United Kingdom, virtually no progress in valve base standardisation was being made, an example of the cautious, technically conservative and inward-looking attitude of British valve manufacturers. Mazda at this time were actually producing an octal base which was incompatible with the American version. Only during the Second World War was any progress made in Britain towards the standardising of valve-pin connections, and then only under Governmental pressure from the Committee for Valve Development (CVD).

Most technical advances made in the field of circuit design during the 30s took place within the United States. This was because the major firms there tended to be larger, and could afford to employ more research staff. American valves during the inter-War period which tended to be of relatively simple design, were largely mass-produced and consequently cheap. This was not the case within the British valve manufacturing industry, where, due to patent restrictions, companies within the United Kingdom concentrated on producing more complex (and consequently more expensive) products. Although American manufacturers produced valves which were directly interchangable with competitors, British firms did not. Furthermore, by agreement with the Valve Manufacturers Association, no manufacturer copied another's product. Aimed exclusively at protecting the British valve industry, this restrictive practice gave the Americans a decided advantage in export markets, since the practice simplified the range and quantity of spares which needed to be held by their wholesalers.

In spite of import restrictions, the number of thermionic valves entering Britain during the 30s rose rapidly. By 1937, about 80% of these came from America, where because of increasingly efficient mass-production methods, prices had fallen to a much lower level. Set production within the United States between 1930 and 1937 has been valued in excess of £40 million. However, in Britain, industrial efficiency in the radio industry remained extremely low by American standards. For example, in 1935, although Britain produced 1.79 million domestic receivers,[25] (almost double the figure for 1930) output per man-hour in radio production was under a quarter of that achieved by American manufacturers.[26] A major effect of these imports into the United Kingdom was substantially to reduce the price of valves in the replacement market, by far the most profitable part of the business. This development worked in favour of the largest valve manufacturers, since they were, with more efficient mass production facilities, better placed to withstand external competition. By 1939, the retail price of an audio frequency (AF) or radio frequency (RF) pentode was around 7s 6d, although really good quality valves were more expensive. For example, an Osram beam tetrode for RF amplification, type KT88 was listed in August 1939 at 22s 6d, and the KT66 AF beam tetrode at 15s 0d.[27]

Mullard Ltd, the largest valve producer operating within the United Kingdom, accounted for about 40% of the market by the mid-thirties.[28] [This company had been acquired by the Dutch electronics manufacturer N V Philips in 1927.] Valve production within the United States had by this time reached much higher levels than within the United Kingdom. For example, in 1935, approximately 11 million valves were produced in Britain., whilst already by 1920 American output had reached a figure of 15 million, rising to 130 million by 1940, a compound annual growth rate of 11.4%.[29] (Nevertheless, this rate of growth is extremely leisurely when compared with the increase in the American production of semiconductor devices, i.e. 26.6 million silicon transistors in 1962 to 1208.4 million in 1972, a compound annual growth rate of nearly 47%.) [30]

Throughout the 30s the British Valvemakers Association continued to fight a rearguard action against foreign valve imports, but found difficulty in preventing a decline in market share. By 1937, imports of valves had risen by 30% over the 1934 figure, and accounted for about 20% of total trade. By the latter year, the total number of valve imports equalled the number of valves sold for maintenance by BVA members. During the early 30s, an increasing proportion of these imports came from the US. However, from 1937 onwards the percentage of US imports began to decline, largely due to the BVA greatly reducing prices of replacement valves in response to this development. The situation is illustrated in the following table[31]:-

YEAR :	**1933**	**1934**	**1935**	**1936**	**1937**	**1938**	**1939**
Imports from US as a % of total imports:	20	33	60	80	70	60	54

American valve imports were substantially cheaper than their British equivalents. For example, the average wholesale price of a British valve in 1935 was stated to be 3s 9d, compared with the average duty-paid price of 2s 8d for the American equivalent.[32] In 1936, when retailers were freed from exclusive buying agreements, list prices were reduced, and discounts to wholesalers increased. The BVA, when submitting its case for the Key Industry Duty on valves to be increased from 33.33% to 50%, stated:-

> *"American valves are sold in England by leading importers at list prices from 7s 6d to 12s 6d. They are also offered for sale from indiscriminate sources in English Wireless Journals in great variety at 3s 6d to 5s 6d retail and at 1s 6d upwards to the trade inclusive of duty. The list prices for corresponding English valves are 9s 6d to 15s each."*[33]

Considering the above evidence it appears that increasingly through the 30s, in spite of a fairly high import tariff together with concerted action by the BVA, fairly substantial penetration of the British home market had occurred. Had the power of the BVA been less, or import tariffs been reduced, the British thermionic valve industry would almost certainly have been struggling for survival. At the very least, it is doubtful if the smaller British companies could have existed in a situation where they were faced with the major American valve producers, manufacturing cheap valves by mass production methods, and supported by a much larger home market. This view is supported by the fact that in spite of import restrictions, it was sometimes found economically worthwhile to modify the circuitry in British domestic receiving sets in order to accommodate imported American valves.

During the inter-war period there was little military involvement in thermionic valve manufacture, this situation contrasting strongly with the environment in which the semiconductor industry was to emerge. Market distortions due to military requirements were therefore not present, and manufacturers were almost entirely concerned with supplying a relatively unsophisticated domestic market. Consequently, research and development facilities existed only on a relatively limited scale, and this fact was to create problems when the industry was faced with wartime requirements. Nevertheless, at least a viable industry still remained. Had a free market situation existed in valve manufacture during the inter-war period, the industry, at best, would have survived only in a considerably weakened state, and therefore much less able to perform effectively under wartime conditions. Indeed, without the strategic asset of an efficient thermionic valve industry, the outcome of the impending conflict would have been doubtful.

The UK Valve Manufacturing Industry in World War Two

The situation immediately prior to the war was that the main market for thermionic device production remained the radio industry, with some specialised valve manufacture, including the beginnings of a television tube industry. Transition to a war footing was fairly slow. During 1940 and 1941 the annual number of receiving sets being produced by the industry remained at approximately the pre-war figure of about 70, 000.[34] However, in 1941 the Board of Trade stopped supplying valves for domestic receivers, except for replacements, although a limited number were still permitted to be sold for the construction of receiving sets for export. This number decreased even further following April 1941, when lend-lease came into operation, and it was made plain to Britain that the United

States "did not appreciate having to pay for equipment possibly assembled from American components".[35] From that time onward commercial exports dwindled, sales being mainly to the Empire.

From the mid thirties onwards, as risk of war increased, urgent efforts had been made to develop and install apparatus capable of locating incoming enemy aircraft. Consequently in December 1935, five radar stations were ordered which were to become part of the defensive chain stretching along the East and South coasts of England. The first of these was completed by March 1937, and in the following May a further twenty were ordered. At the same time, Government contracts were also issued for gun-laying radar and air-to-surface radar equipment. This event made demands upon thermionic valve companies to produce greatly improved types of high-power transmitting valves.[36] These were necessary in order to produce pulses of high power at microwave frequencies, without which it would have been impossible to construct efficient radar systems. Therefore at this time, goal oriented research urgently began in radar tube development in industry, Government laboratories and university research departments.

At Mullard Ltd, the possibility of a future war stimulated moves from 1936 onwards towards making valve manufacturing facilities independent of the Philips production plant, which was based at Eindhoven. Consequently, some production equipment and processes began to be transferred to the Mitcham factory. Nevertheless, it was only with the fall of Holland in May 1940, that essential EF50 valve sealing equipment was (hurriedly) removed to Britain.[37] Mullard did not possess research laboratory facilities within the United Kingdom until after the commencement of hostilities. Because of the Company's ambivalent situation as part of the Philips organisation, with headquarters in German occupied Eindhoven, and with Dutch senior staff employed in Mitcham, no work was carried out on radar throughout the duration of the War.

The other major organisation engaged in valve production, GEC, received its first Government development contract for Radar tubes in 1938.[38] The firm possessed research facilities at Wembley, which had been set up as early as 1922. At the outbreak of war the laboratory staff at GEC, Wembley amounted to a total of 550, rising to a peak of over 1700, and then falling to about 1000 by early 1945. Their major contribution during the War lay in developing special types of radio valve for both radar and communications, including the cavity magnetron, which was invented by Randall and Boot at Birmingham University in February 1940.[39] (This device is an oscillator capable of producing pulses of high power at microwave frequencies. It is far superior in this respect to the thermionic valve, which had been used until then. It was called a cavity magnetron because its construction included cavities cut into the face of a solid cylindrical anode.)

The introduction of the cavity magnetron was certainly the most important technical advance in the field of radar made by any country during the War. In September 1940 an E1189 type magnetron made by GEC was handed over to the American Government on a directive from Winston Churchill. Further development of the magnetron then continued both at GEC and at the Whippany Laboratories of Bell Telephone, in the US. An important advance took place in August 1941 when Sayers of BTH found that by connecting alternate segments of the anode of a magnetron, the device was rendered much more stable.[40] Marconi Labs, situated at Great Baddow in Essex, also undertook the production of magnetrons from August 1940 onwards, peak production at their Chelmsford plant rising to almost 2500 per month in 1945.

Although getting off to a slow start in transforming to a wartime economy, the British thermionic valve industry made great strides both in technology and production efficiency. By Government order, pooling of patents and production expertise was made compulsory from 1943 onwards. Co-operation between the various firms within the industry was extremely close, several firms perhaps being engaged upon the production of a particular equipment at a given time. Not only were demands made upon productivity, but standards of component quality required were of a much higher order than previously, since devices were expected to function reliably in a range of conditions from the arctic to the tropical, whilst being subjected to rough usage. The all-glass technique adopted in valve manufacture called for a revision to the principles of valveholder design, because of the need for these components to withstand vibration in use whilst maintaining continuous electrical contact. The solution to this problem led to the widespread adoption of the B7G valveholder. Firms were compelled by Government both to miniaturise and to standardise components and equipment to a much greater degree than previously.

In response to the need for component rationalisation, the Inter-services Technical Valve Committee was set up in mid-1940, in order to rationalise valve production for the armed services. This committee was responsible for the issue of agreed specifications, and decided which valves should be placed on a preferred list. The list, originally drawn up by the Air Ministry and the Ministry of Aircraft Production in Sept. 1940, amounted to about fifty types of valve.[41] Since all firms carrying out work on valve production during the War were under military contract, this system of Government procurement had the effect of greatly standardising valve production.[42] However, the process of standardisation was far from complete, and by the end of the War, British valves were still being manufactured with a variety of different base pin configurations.

In addition to the valve rationalisation programme, other electronic components were also considerably reduced in number through the activities of the Radio Components Standardisation Committee. As an example of the success of this programme, 10000 resistor types were reduced to 1300, and 8000 fixed-capacitor types to 750.[43] In addition, attempts at miniaturisation resulted in passive components being reduced to one half or one quarter of their original size. Considerable reduction in the size of thermionic valves also took place. For example, miniature battery valves were developed during the War which needed only 50 milliamperes at 1.5 volts to heat the filaments, and moving coil loud-speakers no larger than a matchbox.[44] A further consequence of wartime effort was a great increase in industrial expansion. For example, between 1939 and 1945 the UK radio industry alone was estimated to have grown to about two and a half times its pre-war size.[45]

However, in spite of strenuous efforts made by the industry during this time, British valve manufacturers were unable to satisfy national requirements. For example, during 1943 valve production was only able to meet about 70% of demand. During that year, 35.5 million valves were produced, and a further 17.5 million imported from the United States and Canada.[46] Significantly, the shortfall was particularly acute in the area of technically advanced products such as magnetrons (recently invented in Britain) and miniature types, and valvemaking equipment to construct miniaturised valves was imported from America. This suggests that a significant problem faced by the industry was the inability to respond rapidly to changes in technological requirements, although it must also be remembered that the scale of effort needed in all areas of valve production compounded difficulties.

Some idea of the discrepancy between American and British production capacity in miniature valve production may be obtained from a statement made by the Chairman of the Production Planning Committee, who informed the Radio Board that the United States was expected to produce 22 million miniature valves in 1944, and 45 million in 1945, whereas the United Kingdom's production capacity in this field would extend to no more than 0.5 million miniature and midget valves in 1944, rising to 4 million in 1945.[47]

Post-War Developments

The state of British thermionic valve manufacture during the immediate post-war period is of particular importance in any evaluation of the semiconductor industry, since the thermionic valve manufacturing companies formed the basis upon which the new technology was to be built. What now follows is an analysis of the situation within the British vacuum tube industry up to about 1955, by which time the semiconductor industry had entered its phase of early development.

Immediately following the end of hostilities, valve production declined substantially, due to the collapse of military markets. Widespread redundancy occurred throughout the industry. By 1946, demand for valves had fallen to only 45% of that during 1944.[48] Furthermore, the Government now possessed large stocks of surplus valves. These were sold back to the valvemakers through a scheme jointly administered by the Government and the BVA, and by 1954, about 27 million of these devices had been disposed of to various manufacturers.[49] However, in spite of this surplus, valve production soon recovered, largely due to a post-war demand for domestic radio receivers, and from about 1947 onwards, there existed an expanding market for television tubes.

As a consequence of the outcome of the War, a unique but temporary opportunity existed for British manufacturers, favouring the export of devices to Europe and the Far East. This was because no shortage of production capacity existed within the industry, and competition from German and Japanese manufacturers was virtually non-existent. Furthermore, mass-production methods had been considerably refined during this period, device types rationalised, and product quality generally improved. (These technical improvements were of course not confined to the indigenous industry, but also benefited overseas rivals).

Compared with the pre-War situation, the domestic and industrial valve industry in the immediate post-War period was both efficient and competitive. In 1947, £1.5 million worth of valves had been exported, compared with a figure of £349,000 for 1939, and this was to increase to over £3.7 million in 1951.[50] However, by the early fifties substantial competition had re-appeared, particularly in the form of imports from Holland (which were mainly BVA imports of Philips origin) and Germany, as can be seen from the following table:-

VALVE IMPORTS [51]

(Quantity x million)

Country of Origin:	1950	1951	1952	1953	1954	1955
Holland	2.16	4.64	4.29	3.16	5.79	6.58
Germany	-	.04	.11	.57	2.90	5.92
USA	.01	.07	.24	.10	.18	.10

The rapid increase in valve imports from Germany was mainly due to the adoption of frequency modulation broadcasting by the BBC in 1955.[52] Frequency modulation had been in use in Germany for about seven years previously, and required valves of a type which were not then being produced in the United Kingdom. The major suppliers were Telefunken and Siemens. Most of the imports from Holland were manufactured by Philips, a member of the BVA. Unlike the situation prior to the Second World War, competition from the American thermionic valve industry had virtually disappeared, largely due to the improved efficiency and increased production capacity of British valve producers.

The number of valves manufactured within the United Kingdom during this time considerably exceeded imports, and was as follows[53]:-

Year	1950	1951	1952	1953	1954	1955
Total manufactured in UK (x million)	26.32	39.66	44.07	41.15	50.21	64.33
Valve imports as a % of output.	8.6	13.8	11.4	9.9	18.0	22.0

Valve exports during the early fifties exceeded imports, but from 1952 onwards, due to rapidly increasing demand, production facilities of both valve and component makers became heavily overloaded, and by the middle of the decade the situation had reversed. This situation reflected post-war recovery in European valve manufacture, and in particular imports of high-frequency German valves for Frequency Modulation (FM) applications. A further factor was the increasing demand from the armed services, particularly in the area of guided missiles, which had now become important.[54] Export figures for the period under consideration are given in the following table, together with total yearly import figures for comparison.[55]

Year	1950	1951	1952	1953	1954	1955
Valve exports (x million)	7.61	11.18	9.67	7.29	7.45	7.62
Valve imports (x million)	2.28	5.48	5.04	4.1	9.31	14.12

These figures indicate that by 1955 the level of valve imports, including those produced by Philips, had reached the pre-war level of about 20%, and a balance of payments deficit existed from 1954 onwards.

Economies of Scale in Valve Manufacture

During the mid fifties it was suggested that in order to offer about 40 main types of valve, a manufacturer would need to produce at least 20 million valves per year, in order to achieve full economies of scale. Even allowing for a considerable margin of error on this figure, it appears that only a very few firms could survive within the United Kingdom at that time, since annual production amounted to only about 60 to 70 million devices. This situation suggests that if one particular manufacturer could achieve a dominant market position, this position would be progressively reinforced as its production capacity increased, other factors remaining constant. It is significant that in Britain one company, Mullard Ltd, had by this time achieved market dominance. A high degree of monopoly therefore existed within the industry from the nineteen- fifties onwards.

In the case of television tubes, a similar situation existed, although rationalisation was easier, due to the fact that fewer types needed to be manufactured. Here also, the largest market share was held by Mullard Ltd. Special valves, such as Magnetrons, Klystrons and Travelling-wave tubes were produced on a much smaller scale, and economies of scale were consequently more difficult to achieve. As a result, these devices were relatively expensive. They are also technically more complex, and research and development effort since the Second World War had been concentrated in this area. Setting up a valve manufacturing facility during the post-War period was extremely costly, and with the invention of transistors, the incentive to move into what was likely to become an obsolete technology became progressively less attractive. This factor would have favoured the existing monopoly of production capacity.

The Influence of Mullard Ltd upon Post-War Valve Manufacture

An important development during the nineteen-fifties was the relative growth of Mullard Ltd, which greatly strengthened its position as the major manufacturer of valves and television tubes in Britain. In addition to the factory at Mitcham, dating from 1927 and considerably extended in 1935, another valve manufacturing facility was set up at

Blackburn in 1939. A further plant entirely devoted to cathode ray tube production was built at Simonstown in 1955. An account of Mullard's subsequent activities within semiconductor manufacture is given in Chapter 6.

In view of Mullard's dominance in electron tube manufacture by the mid-fifties, it is hardly surprising that the Monopolies and Restrictive Practices Commission, reporting on the valve and cathode ray tube manufacturing industry in December 1956, should have given particular attention to the activities of the Company. Although accurate figures regarding production and sales are not available, it has been estimated that before the Second World War, Mullard Ltd accounted for 40% of total trade within the U.K. thermionic valve industry. By 1954, this figure had increased to nearly 60%.[56] At that time, the Company's valve production was more than four times that of its nearest British competitor, and its television tube production was approximately 50% greater. Furthermore, Company profitability substantially exceeded that of its rivals, as can be seen from the following data.[57]

Domestic and Industrial Valves

Year	*Mullard Sales. (£ x million)*	*Profit % on cost.*	*All other Manufacturers (£ x million)*	*Av. Profit. % on cost.*
1951	4.34	35.3	5.23	9.1
1952	4.88	34.8	6.52	12.7
1953	5.87	31.4	7.60	10.7
1954	7.69	25.9	6.95	8.5

Most of the profit differential in favour of Mullard Ltd was due to sales within the domestic market. Sales of industrial valves and to Government departments were much closer to average, or even below average for the industry. Although some manufacturers were incurring losses at this time, Mullard were consistently profitable in all sectors of activity, as may be seen from the following figures.[58]

Domestic Valves

Profit % on Cost

Year	*Mullard*	*Other Manufacturers*	*Range (3 Firms)*
1951	29.5	3.9	-3.6 to 8.5
1952	28.8	2.9	-5.1 to 6.4
1953	27.8	- 6.1	-28.5 to 0
1954	30.4	- 3.1	-37.7 to 4.4

BVA Industrial Valve Sales to Government Depts

Profit % on Cost

Year	*Mullard*	*Other Manufacturers*	*Range (4 Firms)*
1951	32.7	21.6	1.9 to 52.6
1952	54.6	8.2	-9.6 to 22.4
1953	61.0	12.7	-30.2 to 22.2
1954	36.1	8.0	-43.0 to 18.2

For some valve manufacturers, rates of profit varied widely from year to year, whereas for others they did not. However, on average, profits of valve manufacturers declined (apart from Mullard) to a considerable extent over the period 1951 to 1954. The above figures indicate that the most profitable area for the smaller companies lay in supplying specialised devices outside the domestic mass market, by then largely dominated by the Mullard Company. Already an emphasis lay in satisfying military requirements, which from at least the early 50s onwards became progressively more important. Due to previous wartime activities, close links had been established between the MoD and a number of valve manufacturing companies, setting the scene for subsequent co-operation in transistor manufacture.

The dominant position held by Mullard at this time, in mass-production for the domestic market, presaged the situation which was to develop within the British semiconductor industry, following the entry of a powerful American competitor, namely Texas Instruments Inc.

Cathode-Ray Tube Production

Small-scale production of cathode-ray tubes (CRTs) began within the United Kingdom during the early thirties. For example, EMI began work in 1930, and Ferranti Ltd started experimental research two years later. Other firms engaged in the field at this time included Cossor, Pye and Ediswan. Mullard began producing CRTs for television in May 1937. Despite the number of firms entering manufacture, pre-war sales of TV sets amounted to only about 19,000.[59]

Following the end of the Second World War, television tube production began relatively slowly, fewer than 29,000 television sets being produced by October 1947. During the early post-War years, production costs were high, and it was some time before mass-production techniques allowed economies of scale to operate.[60] With large capital resources compared with its competitors, Mullard, backed by N.V. Philips, were in a better position to ride out losses during the period needed to get efficient production methods established. It has been suggested that at this time Mullard actually sold tubes to setmakers below cost in order to encourage a rapid increase in receiver sales. Such a policy would also raise barriers to entry for any rival tube manufacturer during the period when unit costs of production were high. Certainly, Mullard Ltd. were making tubes at a loss during the 40s,as shown by the following data.[61]

Mullard TV Tube Production

Year	1947/8	1948/9	1949/50	1950/51
No. of TV tubes produced	22,000	50,000	N/A	N/A
Profit/ loss	-£81,000	-£150,000	in balance	into profit

In 1951/2, Mullard made a profit of 25.4% on tube sales, this margin however falling to almost half in the years immediately following. During 1954 the Company sold one million TV tubes, this figure rising to 1.29 million the following year, and amounting to 58% of the total UK market. However, a substantial proportion of these tubes were imported from Holland, the figure for 1955 being estimated at 0.27 million.[62] Mullard tube production in that year was stated to be 50% greater than that of the next largest manufacturer in the United Kingdom, Mullard then being perhaps the biggest producer in Europe.

Tube Sales and Import/Export Figures

As in the case of thermionic valve production, tube manufacture increased rapidly during the fifties. Imports however exceeded exports during this period, as can be seen from the data below: [63]

Year:	1950	1951	1952	1953	1954	1955
No. of tubes produced: (x1000)	626	778	875	1,177	1,677	2,240
Quantity exported: (x1000)	6	7	12	18	14	17
Quantity imported: (x1000)	174	224	171	274	412	286

Although a balance of trade deficit existed in tubes, it rapidly decreased as a proportion of total production during the 50s, and imports in 1955 were little more than one tenth of United Kingdom production. It is notable that the number exported was extremely low, remaining almost static during the period under review. With the exception of certain types of tube made by Mullard, differences between British and Continental TV tubes were such that it was difficult to use them interchangably. Although this fact restricted the import of foreign tubes,[64] it also restricted the ability to export, and now doubt reinforced the essentially defensive and inward looking attitude of British component manufacturers. In the case of the major manufacturer, Mullard, being part of the Philips organisation, the strategy was to concentrate on supplying the British market.

It is significant that almost all tubes imported came from Holland, and were manufactured by Philips.(400,000 in 1954, 270,000 in 1955). The rapid increase in television sales which took place during the early fifties had caused an acute shortage of television tubes.[65] Again, Mullard, with considerable capital and technical expertise was best placed to exploit this situation. This shortage no doubt encouraged smaller manufacturers to stay in business longer than they might otherwise have done.

Mullard's success in dominating the British television tube market had certain features in common with Texas Instrument's subsequent domination of the British semiconductor market. Both companies were foreign owned, with their principal research and development activities being carried out overseas, and the resulting "knowhow" was made readily available to their British subsidiaries. In both cases, this resulted in a technical lead (although this was more pronounced in the case of Texas Instruments). Also, investment in capital and manpower resources far exceeded that of their local rivals. The resulting efficiency and scale of mass production techniques employed ensured that unit costs fell to levels which enabled them to dominate their respective markets.

Some factors affecting the development of the industry

This section summarises the major factors influencing the performance of the British thermionic valve industry, insofar as they have some bearing on the subsequent performance of the semiconductor industry.

The British thermionic valve industry grew and developed within a system of tariff protection, the founder firms being protected by the dominance of the patent pool. This situation had a precedent in the earlier incandescent lamp industry, where the commercial history of the manufacture of electric light bulbs has been described as "a tale of monopoly, attempted monopoly and price agreements".[66] In Britain the Edison and Swan United Electric Light Company Ltd. held a monopoly of manufacture until the original carbon-lamp patents expired in 1893. Consequently, potential competitors were driven to the Continent. The possibility of achieving a similar situation within the field of thermionic valve manufacture could hardly have failed to have occurred to entrepreneurs such as Marconi, who was quick to follow a similar policy.

With the exception of the unusual conditions imposed on the industry by the Second World War, the patent pool retained its importance until the late forties, by which time the industry had entered its mature, monopolistic phase of development. During the inter-war period, in spite of the tariff wall and the pool's activities, valve manufacturers found it difficult to prevent substantial imports of cheap American valves, which were being produced more efficiently and on a much larger scale. In view of this difficulty, it is extremely unlikely that the British thermionic valve industry would have survived (with the possible exception of Mullard Ltd.) during this time, under conditions of free trade. Following the Second World War, the Mullard Radio Valve Company moved into a position of near monopoly, both in valve and cathode ray tube production, due to the employment of efficient mass-production techniques, backed by substantial investment. This situation was analogous to that of Texas Instruments during the subsequent transistor era, who with their superior mass production techniques and advanced device technology, rapidly achieved market dominance in Britain.

A characteristic of the industry during the inter-war years was the lack of component standardisation, and this was to cause continuing problems during the ensuing war when considerable efforts were made by Government to address the problem. Because of the organisational structure of the valve companies, the low level of technical contact between them had resulted in minimal diffusion of technical expertise. This problem still remained to some extent in the post-War years, indicating a long term resistance to change. The inability to switch rapidly to the production of more technically demanding products, (such as miniature valves) under wartime conditions, and to expand production on a sufficient scale, points, amongst other failings, to a lack of both flexibility and dynamism. This appears evident when comparing the performance of the industry to that in America. Although brilliant inventions, such as the cavity magnetron, suggest that the inventive powers of the research departments in industry, Government and the universities were of a high order, it proved impossible to produce the required devices in sufficient quantity. This inability exposes a weakness in production-development, which was to remain throughout the subsequent microelectronic era.

It is significant that both during the inter-war years and in the period following the Second World War, valve exports were always on a modest scale. Although it might be argued that in the inter-war years overseas competition was fierce, with cheap American exports available in Europe and Japanese valves being widely sold in Australia and the Far East, the situation had completely changed by 1945. From then onwards, for several years, a large potential export market lay on the European continent, with little competition present, yet valve exports still remained low. This situation was to be repeated during the early stages of germanium transistor manufacture, suggesting that British component manufacturing firms were content merely to manufacture for the home market, and felt little urge to expand and compete over a wider area. Since this inward looking policy appears to have been one of long standing, it suggests that marketing attitudes, formed during the days when the industry was extremely protected, remained heavily entrenched. Failure to adapt to the totally different commercial conditions following the Second World War therefore appears to have been to a large extent a result of management inertia.

With the exception of Mullard Ltd., (significantly a part of the Philips organisation) the overall picture which emerges during the mid fifties is therefore that of a cautious, inward-looking industry, resistant to change, and slow to respond to the new economic conditions following the Second World War. Most importantly, apart from Mullard Ltd., the industry had ceased to be profitable, except for the manufacture of specialised valves, suggesting a situation of marginalisation which was to become even more significant during the following decades of transistor manufacture. Being forced to compete from the outset in conditions of technical lag within the new semiconductor technology could not have been helped by the psychological disadvantage of competitive failure within the valve industry. With this uninspiring background, the temptation must have existed from the start to look for a non-competitive niche within transistor manufacture.

Valve Manufacture within the US

As British thermionic valve manufacture moved into a monopolistic stage of development following the Second World War, a parallel development was taking place within the United States. A brief comparison with the position of the American valve manufacturing industry shows that a high degree of monopoly existed in that country by the mid-fifties. By 1956, two manufacturers, Sylvania and the Radio Corporation of America (RCA), held about 50% of the vacuum tube business. A third manufacturer, General Electric, held a further 20%, although this was confined to in-house sales and TV tube production. Only a further five significant valve producers existed.[67]

Total vacuum tube sales within the United States for 1956 amounted to $855 million, and of this total $345 million were produced for the replacement market.[68] By this time, both valve and television tube manufacture had reached the mature phase of production, television tube sales amounting to about $240 million. The replacement market was now 40% of output, a substantial increase from 1950, when tube replacements had amounted to only 6%. Price competition had by this stage become minimal, although strong competition existed at cost level. Little research and development was being carried out, except on special military types. Research effort was concentrated on cutting costs within the area of valve production, rather than improving valve characteristics. Most research in the area of colour tube manufacture was done by RCA, and it is significant that in about 1956 Mullard began to manufacture colour television tubes under licence from that Company.

The American thermionic valve industry was not profitable. For example, Raytheon lost at least $10 million in five years on television tube manufacture, this loss only being sustained by profits in other areas of the electronics business.[69] The situation within the industry was therefore (apart from size) not dissimilar to its British counterpart. In both countries, thermionic valve manufacture had moved into a monopolistic phase, and had reached a technologically static state, although in colour TV production American manufacturers were somewhat more technically advanced.

Experiences and attitudes formed during the time of valve production were to place these manufacturing firms, both in Britain and America, at a disadvantage when entering the transistor field. This may well have contributed to their subsequently poor performance compared with the new horizantally integrated companies which were soon to emerge. As was the case in Britain, American thermionic valve companies, employing minimum research and development effort, operated with management structures schooled in supervising a technically static product. Senior production managers, trained in an earlier technology, could hardly fail to be at a disadvantage when making decisions within the new environment of transistor manufacture. Consequently these firms were not well placed to begin successful mass production of technically more complicated and advanced devices operating on totally different principles, and where the rate of technical change was unprecedented.

As in Britain, the American valve manufacturers were relatively unsuccessful in adapting to transistor manufacture, and in particular to the rapid technical changes which encompassed silicon device production and integrated circuit technology. However, unlike the United Kingdom, other factors were present enabling the United States to move quickly and successfully into semiconductor manufacture. These factors will be examined within the following chapters.

The Role of Patents

Developments within the thermionic valve industry took place under quite different conditions to those in subsequent transistor manufacture, and the patenting policies pursued within each industry reflect this fact. The Marconi company held a virtual monopoly on patents prior to the formation of a patent pool in 1922, which was set up at the time of formation of the BBC, and included the principal valve manufacturers. However, patents by their nature are a wasting asset, and by the beginning of the thirties a number of patents held by the Marconi patent pool had ceased to run. Furthermore other companies outside the patent pool now held important patents on both valve design and circuitry. Companies with these patents tended, often after considerable bargaining and litigation, to join the pool. For example, in Britain, STC patents were included in the pool from 1929 onwards, the Hazletine Corporation of America contributed patents in 1933, and after prolonged litigation was joined by Mullard (Philips) in 1939. The latter company had held important patents which were sufficient to allow radio manufacturers to construct sets without recourse to the Marconi patent pool, and furthermore, royalty payments were lower, being only 1s 6d per valve holder. The A4 licence lapsed in 1938, and its replacement, the A5 licence, which now included Philips, set royalty payments on a fixed percentage basis.

Although the addition of new patents to a patent pool acts to strengthen it, increasing the size of the pool means that revenue raised from patent rights must be distributed among an increasingly large number of members. Technical change in the thermionic valve industry was relatively slow compared with later semiconductor developments, therefore valve patents were of much greater value, being much less likely to become rapidly technically obsolescent. This fact assisted the BVA from its founding in 1924 until the Second World War in its policy of exerting control over setmakers through the patent pool. However, this control was by no means complete, largely due to low cost imports of American valves which increasingly forced the BVA to reduce prices to setmakers.

Possession of key patents by the BVA patent pool played a significant part in the development of the British thermionic valve industry, by protecting it against foreign competition during the inter-War years. In contrast, because technical changes in semiconductor manufacture having been both rapid and continuous, patents have not played such an influential role.

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52. Frequency modulation (fm) involves varying the frequency of the transmitted signal whilst keeping its amplitude constant. The advantage of this method of modulation is that under certain conditions, signal reception is less likely to be affected by interference or noise than with the earlier system of amplitude modulation.

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Chapter 3

Aspects of Early Semiconductor Development in the UK & USA

Introduction

This chapter reviews the technical development of the transistor from its origins to the invention of the integrated circuit, and also outlines the principal factors determining the rate at which semiconductor devices replaced the thermionic valve. The consequences of the different rate and manner of development of the semiconductor industry in Britain and America is then addressed. It is argued that the differing market requirements in America and Europe gave a significant advantage to American semiconductor manufacturers, and thereby contributed to the European (and therefore British) technical lag. In this respect, American military procurement programmes were to play a highly significant role. In spite of a relatively good record of technical innovation, given the resources available, it proved impossible for British semiconductor manufacturers to overcome this problem of technical lag. Infrastructural factors contributing to the subsequently poor performance of the industry are analysed, in order to obtain some understanding of the problem.

Genesis of the Transistor

During the period between the invention of the thermionic valve in 1906 and the point contact transistor in 1947, great efforts were made in the field of thermionic valve technology, which resulted in constant and extensive improvements in the performance of vacuum tube devices. Indeed, so successful was the thermionic valve as an electronic amplifying device during the greater part of this period that investigation within the field of solid state technology was relegated to no more than a fringe activity both in academia and industry.

Nevertheless, the thermionic valve amplifier still suffered from severe limitations, particularly in certain fields, for example, in applications where the requirements demand minimum size, weight and power dissipation, together with high reliability. In the period immediately following the Second World War, these limitations were becoming particularly acute in military applications, and specifically in the fields of airborne equipment and the developing science of rocketry, where devices were subjected to severe mechanical stresses.

Earlier, during the Second World War, much research had been directed towards overcoming these limitations by the miniaturisation of thermionic devices. However, it appeared that a lower limit in size was being approached and certainly by this time there existed a pressing need for a device capable of carrrying out the function of a thermionic diode which was small, robust and reliable. Specifically, the problem had arisen in the field of radar, where thermionic diodes were unable to perform satisfactorily as microwave detectors, due to their high inter-electrode capacitance. A possible solution to the problem lay in the employment of solid state devices, and renewed attention began to be given towards crystal detectors, which had been largely neglected since the early twenties, due to the success of thermionic valve as an amplifier.

Work on crystal detectors began at Birmingham University in 1940, following a suggestion early in that year by Prof. M.L. Oliphant that such devices could function as frequency mixers at centimetre wavelengths.[1] Within a few months successful "cat's whisker" crystal detectors were being produced by H.W.B. Skinner at TRE using silicon from GEC. This information was communicated to British Thomas Houston (BTH), who subsequently became the first British company to manufacture solid state silicon diodes.

Parallel work at GEC during 1940 resulted in the production of silicon-tungsten cats-whisker crystals. Crystal diodes manufactured at BTH and GEC were sent to the United States at this time, the BTH version forming the basis of Bell Laboratories design, and widely adopted by other American manufacturers.[2]

Research at this time was also directed towards the controlled synthesis and purification of silicon and germanium in order to improve the characteristics of semiconductor crystals. The first devices were designed using commercial silicon from GEC of about 98% purity (extremely impure by subsequent standards), and varied considerably in their characteristics.[3] In order to obtain more consistent results, further material purification was undertaken by the General Electric Company (GEC). Although at this stage the effect of the addition of minute impurities upon the rectifying properties of crystal diodes was not understood, the use of the more highly purified material resulted in improvements in device characteristics. Consequently, by 1943, silicon with 1 part in 100,000 boron was being used and germanium point-contact diodes were being made with peak inverse voltages of 100 volts.[4] However, research at this time largely proceeded on an *ad hoc* basis.

This work carried out within the United Kingdom assisted in stimulating further development within the United States from about 1942 onwards. It is significant that although Britain was somewhat ahead technically in material preparation during the initial stages, this situation did not long continue, due to the sheer scale of the American effort. As many as 30 or 40 laboratories were delegated the task of examining semiconductors for use in the field of radar. Referring to this period, C. Weiner comments "The significance of war-time semiconductor developments in setting the stage for the invention of the transistor cannot be overemphasised".[5]

Immediately following the cessation of hostilities, further development in this area within Britain all but came to a halt. However, this was not the case within America, where investigations into the properties of semiconducting materials continued, notably at Purdue University (where the germanium oxide process for the development of high purity germanium was developed) and the Bell Laboratories of AT&T, where J.H. Scaff and H.C. Theurer developed a directional freezing technique to produce polycrystalline ingots of silicon and germanium of improved purity. Further work on silicon was also then being done at the University of Pennsylvania.[6]

The first transistor was invented in the course of a research programme, which began in 1946 at Bell Telephone Laboratories, New Jersey. It was constructed on 23rd December 1947 by W.H. Brattain and J. Bardeen. The invention was announced to the press on 1st July 1948, although a patent application had been filed in February of that year.[7] Success in improving the characteristics of semiconductor diodes had led to increasing interest in the possibility of producing a solid state amplifying device. However, the actual discovery of transistor action took place as a result of an investigation of the surface properties of germanium, and not as a result of a deliberate programme to use a semiconductor surface to make a transistor. Consequently, despite the inventors' understanding and experience in the application of solid state theory, a great deal of initial work had to be done in order to explain how transistor action took place. This work was carried out in secret and patents were not filed until February 1948. The resulting device, called a "point contact" transistor, proved extremely difficult to manufacture. It was electrically noisy and unreliable,and a satisfactory theoretical model could not be found to explain its behavour. However, it appears that already at this early stage its inventors thought of the transistor as a replacement for the thermionic valve, using it to construct an amplifier and oscillator immediately after its invention.

Interest at Bell Laboratories in the possibility of more satisfactory alternatives was now intense, and in July 1949, W.S. Shockley, also at Bell Laboratories, invented the germanium grown-junction transistor.[8] However, Shockley mentions that "a satisfactory realisation of the junction transistor was not achieved until the Spring of 1950 and real excitement about it did not develop until early in 1951".[9] Although more reliable and generally superior to the point contact type, it suffered from the disadvantage of a lower frequency response, and for this reason was at first seen as being complementary rather than as a replacement for the earlier type. A further significant development took place at General Electric in 1952, with the invention of the germanium alloy transistor, described by R.A. Law *et. al.*,[10] also J.S. Saby.[11] This device operated at higher frequencies than the grown junction transistor, and was easier to fabricate on a mass-production basis, assisting greatly the diffusion of the new technology.

It appears that, already during the early fifties Bell Laboratories thought of the invention of the transistor primarily as a replacement for the thermionic valve. Because of the emphasis placed upon microminiaturisation of thermionic valves at that time, awareness of its potential is certainly not surprising. Military interest was present from the start, although Government requirements were to have greater significance following the invention of the silicon grown junction transistor in 1954. The invention of the germanium grown junction and germanium alloy transistors, enabled mass-production techniques to be employed, thus resulting in a continual decline in cost per unit compared with the thermionic valve. This made the newly invented product progressively more attractive, stimulating interest both in America and overseas. Research in semiconductor materials and early technical developments in transistors has been extensively covered in the literature, both in the United States and elsewhere.[12]

A major factor leading to the invention of the transistor was the establishment of multidisciplinary research teams. This development was particularly important in the case of the transistor, since work in this field encompasses physics, metallurgy, chemistry and electronic engineering, therefore crossing traditional academic boundaries. By the end of the Second World War there existed within the United States teams of scientists experienced in the field of solid state device technology, well acquainted with the theoretical concepts of quantum mechanics and experienced in working with colleagues trained in allied disciplines.[13] It is significant that the invention of the point contact transistor was the product of such a team, and that such a team was in industry.

Subsequent research and development in the semiconductor field mainly took place within manufacturing firms, rather than universities and Government Research Establishments. An important reason for this was that, unlike the situation within the thermionic valve industry, a technical plateau was not reached, and research and development was a continuously on-going process, closely bound up with the manufacturing process itself. The traditional boundaries between research, development and manufacture ceased to exist, and a strong inter-relationship between all aspects of the enterprise emerged. Consequently, research and development played a much more central role in the manufacture of semiconductors than in the case of thermionic devices. Another factor assisting the shift of research from the universities to industry was the cost of procuring the increasingly sophisticated apparatus and services needed to carry out work at the leading edge of the technology. This problem was further magnified in the case of the relatively underfunded British universities, and even Government Research Departments. For example, as late as 1982 the head of the Physics Group at RSRE stated that their facility for making integrated circuits was very poor in comparison with industrial facilities[14]. The result was that these organisations were under financial pressure to direct their activities away from mainstream research, towards fundamental work on the fringe of the prevailing technology, where the rate of technological change was slower[15].

Transistors versus Valves

Even at its earliest stage, the transistor possessed great advantages compared with its thermionic counterpart. It was mechanically stronger, it did not need a hot filament to heat electrons in a vacuum, it only required a low voltage supply and consequently dissipated less power and therefore less heat. As an example of the significance of this advantage, M.G. Say, writing in 1954, stated that "some 20,000 junction transistors could be operated on the power needs of one sub-miniature valve".[16] This factor was a particularly important consideration in the newly developing computer technology, and from the early 50s a rapidly growing computer market existed which the transistor, if successful, could completely transform. Nevertheless, actual replacement of thermionic valves by transistors within the computer manufacturing industry did not really get under way until about 1960.

A further advantage possessed by the transistor was that it appeared to possess an extremely long life. For example, as early as 1952, seventy to ninety thousand hours was forecast by J.D. O'Connor.[17] This was of particular importance, because as circuitry became more complex, it was necessary that the reliability of individual components be improved in order to avoid constant repair, which not only decreased efficiency, but acted as a limit governing circuit complexity. In addition, improvements in device lifetimes coupled with decreased size ensured that parallel redundancy could be employed with greater advantage in systems where weight and size, coupled with reliability, was an important factor, for example, in rocketry and airborne equipment. Also, because only a low voltage power supply was needed, voltage stress upon other components was less, resulting in their longer life, and consequently overall system reliability was increased (This was particularly important in the case of electrolytic capacitors, which could now be constructed to operate at much lower working voltages). Another important gain was that when used as an electronic switch, progressive decrease in device size resulted in more rapid switching times. This fact was to be particularly useful in computer design.

Apart from the abovementioned advantages, there were also obvious disadvantages. Early transistors, particularly the point contact type, suffered from high noise levels, and a thorough understanding of this problem was certainly not in sight at the time.[18] Both point contact devices and the junction transistors then being made could only handle small powers, which greatly restricted their use, and their bandwidth was considerably less than that of the equivalent thermionic valve amplifiers.[19] Consequently, they could only amplify a limited range of signal frequencies. Also, they were more liable to damage by electrical transients and their range of temperature operation was limited.

Additional problems were that in the initial stages it was difficult to manufacture transistors on a production line basis with uniform characteristics, and when it was necessary to "match" the characteristics of these devices, electrical testing was labour intensive and therefore costly. Furthermore, the operating characteristics themselves tended to be electrically unstable, particularly in the case of the point contact type, which was extremely prone to oscillation when used as an amplifier,[20] and also drifted with time, being especially affected by temperature changes. Reverse leakage currents were high, and increased with temperature, causing changes in the operating characteristics, necessitating temperature compensating biasing circuitry.

Yet another problem, which discouraged the initial acceptance of transistors as replacements for thermionic valves was that the operating characteristics were quite different from those of valves. Designing electronic circuitry using the new circuit element therefore required additional skills, and undoubtedly caused problems for engineers whose experience until then had been restricted entirely to valves. This situation could only be remedied by educating existing engineers in the new technology, and training a new generation of circuit designers.

Replacement of the Thermionic Valve by the Transistor

Early estimates of the rate of valve replacement by the transistor were highly unreliable, varying from extreme caution to over optimism. As an example of the latter viewpoint, Philips had predicted that the valve would be totally replaced by the transistor by 1965.[21] This did not of course occur, the rate of replacement being not nearly so rapid as expected, and in fact the Company's valve production remained profitable up to and including 1972. An important factor acting in favour of continuing profitability in this case was that overheads such as research and development and capital equipment replacement were no longer necessary. Furthermore, the technology was well understood and the production engineering effort needed had therefore become minimal.

During the initial period of growth of the semiconductor industry, the manufacture of vacuum tube devices did not rapidly decline. Within the United States, thermionic valves reached their peak in numbers in 1955,[22] but output did not fall seriously until the second half of the following decade, although more and more of this production was merely for the replacement market. Between 1954 and 1956, the peak period of thermionic valve manufacture, about seventeen million germanium and eleven million silicon transistors were sold in that country, worth about $55 million. During the same period, the much larger number of 1300 million valves were sold, worth about $1000 million. However, the situation had significantly changed by 1969, when production of semiconductors within America reached a value of $1218 million.[23]

From the mid sixties onwards, progressively greater inroads were made into the thermionic valve market, as the power handling capacity and frequency response of transistors rapidly increased. Already, by 1961, bipolar transistor sales in America had reached the same level as sales of thermionic valves, although in Britain this situation did not occur until 1975. The reason for this difference was that the largely valve-consuming consumer market was dominant in Europe at this time. This was not the situation in America, where the predominatingly semiconductor-using computer, calculator and military markets was more significant, and developed more rapidly. Furthermore, the nature of demand for the computer and consumer markets differed. During the latter part of the sixties and early seventies consumer demand was mainly for discrete transistors and linear integrated circuits, whilst the now rapidly growing computer market largely demanded digital integrated circuits.

Replacement of thermionic valves by semiconductors therefore proceeded not only at a different rate but in a different manner in Europe, when compared with the United States. This was to have a major effect both upon marketing policies and future technical developments in all producer countries. Furthermore, the American technical and production lead in silicon, gained through the military and space programmes, was greatly to assist the rate of valve replacement from about 1960 onwards in the key fields of computing and telecommunications, where reliability was an important factor.

Although small-signal devices for applications such as domestic receivers and hearing aids began to be marketed in quantity from about 1955 onwards, it proved more difficult to meet the more stringent requirements demanded within the fields of computing and telecommunications. This was because of reservations concerning long-term reliability. Also, these early devices were unable to handle sufficiently high voltage and power levels, function at high frequencies, or switch sufficiently rapidly. A further problem delaying the introduction of solid-state devices has been their susceptibility to damage from switching transients.

Improved transistor performance in power, frequency response and bandwidth resulted in the progressive supplanting of the thermionic valve in an increasing number of applications.[24] For example, advances in production technology, including the widespread use of diffusion techniques, enabled transistors to operate at greatly increased voltage levels. From about 1965 onwards, these technical improvements resulted in reverse breakdown voltages being reached in excess of a thousand volts. This improvement in voltage breakdown value increasingly enabled transistors to replace valves in a range of high voltage applications, for example, scanning line circuitry in television receivers and also increasingly in transmitters. [It is important to note that in spite of impressive advances, even today specialised areas still remain in which valves and other vacuum tube devices have not been displaced. These include power output stages in large broadcast transmitters and various microwave applications, an example being the high frequency tetrodes currently being used by the British Broadcasting Corporation for high power transmissions, where their superiority over solid state devices in withstanding transient voltages confers a considerable advantage.]

Aspects of Early (Germanium) Transistor Development

In view of the subsequent spectacular progress of solid state device technology, it is easy to overlook opinions being expressed during the mid-fifties, when the future potential of the transistor still remained, at least to some observers, a subject for debate. Initial acceptance in the field of transistor applications took place perhaps more slowly than expected. For example, as late as 1954, Say and Molloy wrote "It is too early to foretell the extent of the crystal valve (transistor) and how far it will affect the use of the thermionic valve. The general opinion seems at present to be that it will displace its established competitor only in some special cases".[25] Loeb, writing in September 1956, remarked that it "seemed highly probable in 1950-51 that by 1954-55 transistors would have found their way into a considerable number of applications, and they would feature as a standard component in many items of commercially available equipment ... Except in the field of hearing aids- relatively unimportant in this connection- until the beginning of 1955 nothing of this kind had happened in this country and little more seemed to have happened in the United States".[26] The reason for this state of affairs may throw some light on the difficulties facing the early development of the industry.

Apart from the relative technical merits of valves versus transistors, other factors may well have delayed the introduction of the transistor. For example, during this early period, technical progress was extremely rapid, and users appear to have been reluctant to commit themselves to large orders for devices which would be technically obsolescent by the time their product reached the market. Only with the development of the germanium alloy transistor, invented at General Electric in 1952, did it become possible to mass produce quantities of devices with consistent electrical characteristics, thus making possible a supply of reliable low and medium frequency devices for the radio industry. Consequently, from 1955 onwards, portable radios began to be marketed, principally in America and Japan, and this event perhaps more than any other alerted the public to the development of the transistor.

Due to the mastery of mass production techniques, particularly in the fabrication of germanium alloy transistors, unit costs fell rapidly. This development greatly assisted valve replacement, although it was some time before transistors were able to compete directly in terms of cost. For example, in America in late 1953 the best transistors cost about $8, compared with $1 for the corresponding valve equivalent.[27] A year later, the average price had fallen to between $2.25 and $5.50. By 1955, the American industry's production capacity was already well in excess of its ability to sell the product. In that year, 1.25

million devices had been sold, although the production capacity was estimated at about 15 million. At this stage, production entry costs were low, the major expense being device development. Thereafter, production volume increased rapidly, about 50 million transistors being manufactured in the United States in 1957, and a further 4 million in Britain. By 1957, the average value of a germanium transistor had fallen to $1.85, still more expensive than the valve, but certainly much more competitive than before. By 1962, the average value had fallen to $0.82.[28] Due to technical lag, prices were significantly more expensive in Britain, typically double that in America, consequently tending to inhibit valve replacement, and therefore limiting the growth of the British semiconductor market.

In order to obtain the full benefits of microminiaturisation, it was necessary to develop smaller, passive components such as resistors and capacitors for use in transistor circuitry. This was made more possible because they only needed to withstand much lower voltage stresses (for example, about 6 to 12 volts rather than high tension voltages of 150 to 300 which were required for thermionic valve circuitry). Consequently, in response to this need a considerable amount of effort resulted in the necessary components being produced within the fifties.

A difficulty facing the industry during its early stages was that transistor manufacturing engineers could only be recruited from those who had worked in an entirely different field, and this situation could not fail to influence early attempts to find solutions to technical problems in terms of a familiar but different technology. Whether this factor acted as a brake on initial progress, by delaying attempts to find more satisfactory solutions, appears impossible to evaluate. An example within the author's experience was that expertise in the field of glass to metal seals was immediately put to use in encapsulating devices in glass, a technique which was subsequently abandoned.

The complex problems of device manufacture involved a knowledge of semiconductor surface physics, and encompassed an understanding within the fields of chemistry and metallurgy, therefore crossing traditional academic boundaries, and this range of knowledge was not possessed by the large majority of those entering the field at this time, nor did these early recruits possess the "hands on" familiarity which can only be gained from experience. It was therefore important greatly to increase the number of graduates with a theoretical understanding of solid-state physics. In America, the need for this type of training was clearly recognised. The first course in semiconductors was run at Harvard in 1951, and by 1955 there were about a dozen universities offering courses in solid-state technology.[29] In Britain, Edinburgh and Southampton Universities, together with Middlesex Polytechnic, set up small-scale device manufacturing facilities during the sixties. However, due to the rapid progress being made in device technology, and also the cost involved, it was difficult for these facilities to keep up with industry.[30]

The Impetus of Military Involvement: Development of the Silicon Transistor

Due to the limitations of the thermionic valve, a strong demand existed, from the late 40s onwards, both in British and American military circles, for a suitable replacement device. The need was particularly urgent in applications such as airborne equipment and rocketry, where components are subjected to severe mechanical stresses, and payload is at a premium. It is therefore not surprising that military interest was immediate. Golding mentions that senior American defence personnel received a preview of the transistor a week before the original press announcement (which co-incided with scientific publication) in July 1948, and, following this "funds were immediately allocated to expedite transistor development and production".[31]

The urgent need for such a device can be gauged from the fact that the US Navy estimated at that time that 60% of its electrical equipment was not working satisfactorily because of receiving valve problems. Although replacement of valves by transistors was not yet possible on a complete scale, the United States Air Force (USAF) estimated that 40% of its electronic equipment could be transistorised with considerable savings in size and weight, with only low voltage power supplies now being needed.[32] Consequently, all Western Electric's initial production was purchased by the US Government, together with virtually all devices being produced by other manufacturers. Levin quotes a report published by the Defense and Business Services Administration of the Department of Commerce (1960), indicating that the average unit price of devices sold to the military was roughly twice that received from private sector customers, reflecting the Government demand for devices of the highest quality.[33]

A problem with the early germanium transistor was its inability to operate at temperatures in excess of about 70 to 80 degrees Centigrade. Military requirements dictated that transistors be required to operate at temperatures well above this figure, and this need stimulated Gordon Teal, then working for Bell, to attempt to grow silicon crystals, since that material offered the potential to produce devices capable of meeting the required specifications. Teal started work on this project in 1951, transferring to Texas Instruments in the Autumn of the following year. This work resulted in a breakthrough, and Texas began production of silicon grown junction transistors in 1954, enjoying a manufacturing monopoly of three years. The importance of this development can hardly be overestimated, since it immediately gave Texas, and therefore the American semiconductor industry, a significant technical lead in silicon solid-state device manufacture, which was to be maintained for approximately thirty years.

Transistor and Integrated Circuit Development

(a) Pre-Planar Device Types

A characteristic of the early days of transistor manufacture was the multiplicity of device types. Limited production of the germanium point contact transistor began at Western Electric (Bell) in 1951,and small quantities of germanium grown junction devices were produced by Bell in 1952. Also within that year General Electric (GE) began to market yet a third type, the germanium alloy transistor.[34]

Germanium alloy devices, assisted by their relatively simple method of construction, soon became the dominant type in terms of numbers produced, unit costs falling rapidly. Large numbers of this type continued to be manufactured both in Britain and America until the late sixties. For example, Texas Instruments (Bedford) was producing well over 300,000 germanium alloy small-signal transistors per month in 1966,[35] and Mullard (Southampton) was also at this time producing significant quantities.

The first silicon transistors were manufactured by Texas Instruments (Dallas) in May 1954. These were of the grown junction type, and because of their ability to operate at higher temperatures than germanium devices were of considerable interest to the military. From this time onwards, semiconductor research effort within the United States largely concentrated on silicon rather than germanium, with the aim of improving device characteristics and achieving component miniaturisation.

By the late 1950s, a wide variety of transistors were being produced with greatly improved characteristics, including significant advances in power-handling capacity.[36] At the beginning of the decade, transistors could only handle powers of about 50 to 100 milliwatts, but already by 1954 power transistors were being constructed which were able to handle up to 100 Watts.[37] These early power devices were however only able to operate at low frequencies, and being germanium were restricted to operating temperatures of approximately 70 to 80 degrees Centigrade.

Fundamental work at Bell Laboratories and General Electric during the mid fifties in the field of diffusion technology[38] led to the employment of diffusion techniques to form p-n junctions with a much greater degree of precision than had been previously possible. This information was made generally available at the Bell symposium held in 1956. Consequently, it was possible to manufacture a much more uniform product, enabling the processing of large numbers of devices with virtually the same characteristics.

The application of diffusion techniques led to the development of the mesa transistor, described by Aschner *et. al.*[39] These devices were a significant advance on previous types, since the newly developed diffusion process enabled a far more precise control of p-n junction depth to be achieved.[40] The considerably narrower junctions obtained by this method resulted in greatly improved performance at high frequencies. Diffused mesa transistors were soon being manufactured with cut-off frequencies of over 100MHz. Already by 1957 silicon diffused junction power transistors were being developed able to handle up to 80 Watts.[41] These were also mesa alloy devices. The manufacturing costs of silicon power devices were initially high due to low yields. However, by the early 1960s, these problems were largely overcome, and costs fell substantially.

A development of major importance was the discovery in 1956 by Frosch and Derrick[42] that it was possible to grow a homogeneous layer of silicon dioxide upon a silicon substrate. This technique was used to provide the transistor with an electrically stable surface, greatly improving its characteristics, including reliability. Unfortunately, this technique could not be used successfully with germanium, and this fact, perhaps more than any other, determined the future evolution of device technology. Used in conjunction with the deposition of a silicon dioxide layer over the junction, the long-term stability of device operating characteristics could be greatly improved.[43] The importance of these two developments can hardly be overemphasised, since they were the key elements in making possible the construction of silicon planar transistors, and consequently the silicon planar integrated circuit.

(b) Silicon Planar Technology and the Integrated Circuit

The planar transistor constituted a significant advance in semiconductor technology, having improved electrical characteristics, and better long-term reliability when compared with its mesa predecessor. Furthermore, it could be manufactured at decreased cost, and its method of construction opened up the prospect of successful integrated circuit manufacture. Apart from certain applications, such as high voltage rectifiers and thyristors, the planar technique rendered all previous methods of device construction obsolete. The process is described as planar because it resulted in the semiconductor junctions being covered with an electrically stabilising oxide, producing a flat, or planar surface, rather than the junctions being etched and exposed, as in the Mesa transistor. Electrical contacts could now be made by vacuum deposition of a suitable metal upon the insulating oxide surface, allowing direct connection to adjacent devices on the chip.

In February 1959, an integrated circuit patent (although for a non-planar device) was filed by J.S. Kilby, of Texas Instruments (Dallas),[44] and in the same year J.A. Hoerni, employed by the Fairchild Company (based in Arizona), invented the abovementioned planar process.[45] The development of this process enabled R.A. Noyce, also of Fairchild, to achieve the major step of fabricating a practical silicon planar integrated circuit.[46] These advances constituted a watershed in the development of solid state devices and established the basic technology upon which the present industry rests.

The subsequently rapid advances in integrated circuitry owed less to basic scientific research and development and more to design and process engineering. This resulted in the focal point of technical effort becoming centred around the production process itself. The first integrated circuits to be produced were the digital bipolar type, and a succession of logic types quickly followed. However, by about the end of the sixties, the industry had stabilised on TTL logic, with ECL logic being used in applications where switching speed was at a premium. The principal logic families were as follows: [47]

Logic Type	**Firm**	**Year**
Resistor Coupled Transistor Logic (RCTL)	Texas	1961
Direct Coupled Transistor Logic (DCTL)	Fairchild	1961
Diode Transistor Logic (DTL)	Signetics	1962
Emitter Coupled Logic (ECL)	Motorola	1962
Transistor-Transistor Logic (TTL)	Sylvania	1964

All the above logic types were introduced by American firms, and the stimulus for this development was due to military requirements, principally in the field of computing. For example, RCTL and DCTL were used in the Apollo guidance computer and also the Minuteman II missile system, but had design weaknesses, and were soon supplanted. TTL was developed specifically for the Pheonix missile programme.

During the mid-sixties, in addition to digital circuitry, linear integrated circuits began to be developed, using bipolar transistors and other circuit elements. In Britain, both Ferranti and Plessey became engaged in manufacturing devices of this type, principally for military requirements. As early as 1962, Plessey had produced small quantities of solid state linear amplifiers, to be used in analogue computers. Their use eventually extended to other applications, including television receivers, radios, and stereo amplifiers. Because of the specialised nature of these circuits, production mostly tended to be confined to relatively short production runs.

In addition to the bipolar transistor, some mention must be made of an alternative structure, the field effect transistor (FET), particularly because of its importance in computer circuitry. Although the concept of this device predates the bipolar type, the first commercial FET was not produced until 1958. It was designed by S.Teszner, a Polish scientist employed by a French affiliate of General Electric. Named the Technitron, it was of germanium alloy construction.[48] However, this product was not a success, being rapidly overshadowed by later developments. The technitron was followed in 1960 by a more efficient device manufactured by Crystalonics, a small company operating within the United States. These were however junction field effect devices. A more important development, using the field effect principle, was the silicon field effect transistor known as the metal oxide type (MOS).

The MOS transistor was first made by S. Hofstein and F. Heiman of the Radio Corporation of America in 1962.[49] This device was particularly suited to integrated circuit manufacture, its construction employing silicon planar techniques. It was upon this design that a whole new development in the field of integrated circuitry was to rest. Although slower in operation, the MOS transistor took up much less space on the silicon chip than its bipolar counterpart, and its power dissipation was considerably lower. The major reasons for its widespread use in integrated circuit form have been decreased size and cost, and permitting the fabrication of much more complex circuitry.

From the late sixties onwards, MOS technology quickly found a major application as an electronic switch in computer memory storage, and its subsequent development has resulted in very large scale integration to a degree unachievable by alternative means of fabrication, and also a fundamental shift away from analogue to digital circuitry. The number of components it is possible to mount on a silicon chip of a given size has constantly increased since the development of the integrated circuit, and this has resulted in a corresponding reduction in cost per component. The effect of this trend has been quite remarkable. For example, a 1 kilobit DRAM, manufactured in 1974 cost one cent per bit. By 1985, 1 megabit DRAM's were being produced at a cost of a thousandth of a cent per bit.[50] Furthermore, the reduction in cost per bit during this period took place at a constant rate, giving equipment manufacturers confidence to plan ahead on the assumption that this trend (based on a rate of annual doubling in component density, known as Moore's Law) would continue. Constant reduction in device size, bringing with it increased reliability and improved switching speed, has been an important factor in ensuring the success of MOS technology.[51]

Product Innovation and Technical Lag

The British semiconductor industry responded promptly to the invention of the transistor. Within six weeks of the announcement by Bell, British Thompson Houston, Standard Telephone Laboratories and GEC had independently succeeded in reproducing a point-contact device. However, to manufacture a working point-contact transistor is an infinitely easier task than setting up a production line and producing quantities of devices with consistent characteristics. It is perhaps significant that although Western Electric, Raytheon, RCA and General Electric went into production in 1951, by the following year total monthly production amounted to only about 8400, most of these being made by Western Electric.[52]

The technology symposium held by Bell in April 1952 provided information on both crystal growing and device fabrication. It attracted a number of companies operating in Britain, namely AEI, Plessey, English Electric, Pye, STC (ITT), Mullard (Philips), and Ferranti. Almost immediately, a number of these firms began to manufacture transistors under licence. Dates when production commenced are as follows: [53]

YEAR	FIRM	DEVICE TYPE
1952	STC (ITT)	Ge. point contact *(later, Ge. alloy)*
1953	AEI(GEC-EE)	Ge. point contact Ge. alloy
1954	Eng. Electric (GEC-EE)	Ge. point contact
1954/5	Mullard	Ge. alloy
1957	Plessey	Ge. alloy

The second Bell symposium was held in January 1956 and made available information on diffusion technology, which had been developed since the 1952 Symposium. It was attended by the following British firms:- AEI, Pye, Ferranti, GEC, Plessey, and also by the well-established foreign subsidiaries, Standard Telephones and Cables (STC) and Mullard (Philips). In view of the military importance of this work, all non-American nationals attending Bell symposia were required to obtain security clearance. This work was also of considerable interest to the British military, and at least one company (Ferranti) received financial assistance to participate.

Technical lag in the manufacture of germanium alloy and germanium point contact devices did not present a problem to British manufacturers, and these devices were soon being made in quantity. Difficulties were however to arise with silicon, a more complex technology, and these problems were compounded by the rapid technical advances being made in the United States. It was only at this stage that structural weaknesses within the industry began to emerge, when manufacturers found themselves faced with significant competition from a technically more advanced product.

Texas Instruments, having produced the first silicon grown junction transistors in 1954, went into production in the United Kingdom at the Bedford plant in 1958. Also at the end of that year, Fairchild began to manufacture silicon diffused transistors within the United States. Due to the successful introduction of silicon technology, the situation within Britain immediately became one of technical lag, amounting to perhaps between one or two years. Work on silicon had begun at Plessey in 1953 under military contract, and silicon rectifiers were first produced at Caswell in 1954. Work on silicon under CVD contract also began at Ferranti in 1953, and during the following year silicon junction diodes went into production. However,it was not until 1958 that a range of silicon transistors were marketed by a British company. These devices were made by Ferranti, using the diffusion technology developed at Bell laboratories, and which had been made available following their 1956 symposium. The failure of British companies to manufacture silicon transistors during the mid-fifties was to have extremely important and lasting consequences for the industry.

This sudden technical lag, which emerged due to the development of the silicon transistor, was largely due to the activities of a small number of American firms, which received their original technical impetus from Bell Laboratories. It is significant that most major innovations within the American semiconductor industry were due to these few firms, and that the majority of device manufacturers played little part in advancing the technology. In fact, the American semiconductor industry largely remained, like that in Britain, a germanium device producing industry for many years. For example, quantity production of silicon discrete transistors in America did not overtake germanium devices until 1966. By that year, the average price per unit for a germanium transistor was $0.45 compared with an average silicon price of $0.64. By 1968, the average price of a silicon and germanium transistor had equalised. Production of Germanium devices then fell rapidly, and, except for specialised devices, was from then on mainly for the replacement market.[54]

From 1954 onwards, the leading edge of technical innovation lay with silicon device technology, and therefore excluded a considerable number of American device manufacturers, as well as those in Europe. A review of the situation by Dosi mentions that during the period 1952 to 1961, the large established electrical firms (for example, the thermionic valve manufacturers) accounted for 32% of major innovations, and Bell Laboratories accounted for around 40%. Also, the percentage of significant process innovations due to Bell during this period amounted to 56%, and that of thermionic valve manufacturers a further 22%.[55] The number of firms making transistors within the United States rose rapidly from eight in 1952 to twenty-six in 1956, reaching thirty-seven in 1961.[56]

The major impetus leading to and then sustaining the technological lead by the American semiconductor industry came in the first instance from Bell Laboratories, and later from a small group of companies which had been technologically "pump primed" by Bell, having been formed as spin-off companies by ex-Bell Laboratory personnel. The manner by which this process occurred has been described in detail elsewhere.[57] The only other companies with enough resources to enable them to contribute to major innovations were the thermionic valve manufacturers, such as RCA and General Electric.

The record of successful innovation illustrates not only the predominance of the American technical lead, but also the limited number of companies involved. This concentration of innovation is even more marked when it is remembered that most of the major innovators within these start-up companies had previously been Bell employees. Selection of major processes and product innovations cannot fail to be subjective. The list below is compiled from published data, but chosen purely on the authors assessment.[58]

Major Semiconductor Device Innovations 1951-1970

Innovation	*Firm*	*Country*	*Date*
Point Contact Transistor	WE	USA	1948
Grown Junction Transistor	"	"	1951
Field Effect Transistor	"	"	1951
Alloy Junction Transistor	GE/RCA	"	1952
Surface Barrier Transistor	Philco	"	1954
Silicon Junction Transistor	Texas	"	1954
III-IV compounds	Siemens	Germany	1955
Diffused Transistor	WE*	USA	1956
Mesa Transistor		USA	1956
Tunnel Diode		Japan	1957
Junction FET	CFTH	France	1958
Planar Transistor	Fairchild	USA	1960
Epitaxial Transistor	WE	USA	1960
Integrated Circuit	Texas/Fairchild	"	1960
RTL Logic	Fairchild	"	1961
TTL Logic	Plessey **	UK	1961
MOSFET	Gen.Inst./Gen. Microelectronics	USA	1962
DTL Logic	Signetics	USA	1962
ECL Logic	Motorola	"	1963
Schottky TTL	Texas	USA	1969
CCD	Fairchild/Philips	USA/Holland	1969
Microprocessor	Texas/Intel	USA	1970

* note: WE=Western Electric (AT& T).
** TTL Logic first manufactured by Sylvania (US), 1964.

The British Contribution to Semiconductor Device Innovation

A review of the major product and process innovations since the beginning of semiconductor manufacture illustrates the overwhelming success of American research activity in this field. Perhaps because of this success there has been a tendency to overlook the British contribution, and from much of the existing literature it might be possible to conclude that relatively little or no innovation took place within the United Kingdom. In fact, taking into account the relatively small size of the semiconductor industry in Britain, evidence suggests that it was extremely innovative, and that the failure of the industry to prosper had its origins elsewhere.

It is important to consider the various innovations made within the British semiconductor industry in the context of technical lag in silicon technology, and as a response to the particular problems faced by individual firms. In this respect, the industry was in a similar position to many American companies. However, situated far from the major centres of innovation, and operating within a different economic framework and culture, additional problems were present which operated to the disadvantage of the local industry. A number of these innovations are described below, and although the list is incomplete, they illustrate the considerable successes obtained by British industrial semiconductor research establishments.

The preparation of high quality semiconductor material has always been fundamental to the production process, and therefore it is not surprising that considerable efforts were made by various firms to produce high grade silicon and germanium crystals. In this respect, research in Britain met with considerable success, although little work had been done in this field between the end of World War II and the early fifties. By 1957, GEC were producing high quality germanium crystals weighing 5Kg on a routine basis, and it is claimed that crystal growing technology at their Wembley laboratories led the world at this time. Wembley had begun to produce single crystals of silicon successfully in 1955.[59]

The Plessey company's contribution to innovation includes early work on integrated circuitry, the Caswell Laboratories research programme being probably the first in the World to explore this field. They were the first company to develop the "flip-chip" concept, and invent multi-emitter integrated circuitry. Perhaps their most important contribution to device technology was the design of transistor-transistor logic (TTL), by P.M. Thomson.[60] This was subsequently to become the most widely used bipolar logic type. It appears however that its potential significance was not appreciated by Plessey, TTL logic being first commercially introduced by Sylvania and Transitron in 1964.

Ferranti began work on silicon devices at an early stage, developing a series of fast silicon DTL logic circuitry. The company successfully developed the collector isolation diffusion (CDI) process, (originally invented by B.T. Murphy et al at Bell Laboratories). introducing it to the market in 1971. This process was claimed to have advantages over TTL logic, offering compatibility with MOS circuitry. Although extensively used by the company, the process was not widely adopted, its use being mainly confined to military applications, including the F100L bipolar microprocessor, the first to be designed, built and sold in Europe.

Infrastructural Factors Contributing to Technical Lag

The inability of the British semiconductor industry to compete effectively in the marketplace over most of its existence suggests that long term factors must have operated to its disadvantage during this time. One such factor has been economies of scale. The relatively small size of the industry has led to it being disadvantaged in these terms, when compared with its much larger American counterpart. For example, lack of locally based sources of production equipment, silicon crystals and chemicals, of the required quality, have hampered the development of the industry, and contributed to technical lag. This situation is illustrated by the examples described below.

It is important to remember that in Britain no organisation capable of performing the role of Bell Laboratories existed, either to perform basic research, or to transfer "state of the art" technology to spin-off companies. Consequently, no Fairchild could emerge, nor could British firms benefit from the diffusion of technical personnel to existing producers in the way, for example, Texas Instruments benefitted from the acquisition of Gordon Teale. Also, research funding in Britain was on a relatively insignificant scale. Golding estimates semiconductor research and development expenditure within the United Kingdom in 1968 as follows.[61]

Firm	**Estimated R&D Expenditure** (£ x 1,000).	
	Company Financed	***Direct External Finance***
GEC-Eng. Elect.**	700	350
Ferranti	150	150
Plessey	450	250
Westinghouse*	100	nil
Lucas*	100	nil
Total.	1500	750
Philips ASM (Mullard)	850	300

* [Both Westinghouse and Lucas were principally involved in specialised in-house manufacture].
** [By 1968, AEI and Marconi-Elliott had been incorporated into the GEC-English Electric combine. The above list therefore includes virtually the whole of the

semiconductor manufacturing industry in Britain, with the exception of the American manufacturing subsidiaries].

The above expenditures are probably typical for the mid-sixties, and it is unlikely that they would have been greatly exceeded in previous years. Further factors inhibiting research efficiency are reviewed in Chapter four. These figures illustrate the relative insignificance of the research and development effort being carried out in Britain during the sixties, and contrast with the considerable funds available to American research establishments at that time. For example, Hogan estimates that between 1958 and 1977 the United States Government spent 900 million dollars in support of research and development, which averages over $45 million per annum.[62] Comparing this sum with the scale of the British Government's contribution of £750,000 for 1968, detailed above, there can be little doubt that Government assistance considerably helped the American semiconductor industry to maintain its technical advantage, and in the words of Mackintosh "grossly disturb normal competitive conditions and commercial criteria in this industry".

Apart from a consistent lack of funding, problems related to the industrial infrastructure imposed long term penalties on industrial efficiency, and contributed to technical lag. The quality of innovation in such a highly technical and rapidly changing technology as semiconductor manufacture is dependent upon a close and mutually advantageous relationship with suppliers, manufacturers and customers. Specialised manufacturers of such important equipment as diffusion furnaces, crystal pullers, thermocompression bonders or wire welding apparatus did not exist in Britain during the sixties, and these items had to be manufactured by the organisation concerned, or imported from the United States. In view of the small size of the British research and development effort, or indeed the semiconductor industry itself, little incentive existed for American equipment suppliers to form close relationships with British semiconductor companies. This problem was obviously compounded by geographical isolation. Consequently, the strong mutually beneficial networks, or skill clusters, which were set up in the United States were completely absent. This lack of dialogue between manufacturers and their overseas suppliers was a significant long-term disadvantage for British companies. Such a disadvantage did occur in the case of foreign multinationals operating within Britain, since they had access through their parent companies to the information networks already existing within their home country.[63]

There can be little doubt that the consequences of isolation from specialised equipment suppliers contributed significantly to technical lag. An even stronger case is made by Dixon,[64] who argues that the activities of American multinational subsidiaries have effectively prevented local supply networks from developing, since they rely directly upon their national suppliers, thus limiting the potential size of the indigenous market. He also suggests that this tendency has been reinforced by the practice of transferring promising research and development projects to the parent company, thus limiting the size of a potential British market for the latest equipment. As evidence, he cites the work on ion implantation carried out within an American-owned subsidiary in Britain being transferred overseas when the work began to show promise, including the staff and equipment.[65] A further example, known to the author, was the transfer of important TTL research (involving the deposition of silicon dioxide) from Texas Instruments (Bedford) to the parent company under similar circumstances.

Another factor contributing to technical lag in British semiconductor manufacture, was the the difficulty in obtaining materials of the high quality needed for research, development and production. As in the case of equipments, skill clusters play a significant part in supplying the day to day needs of manufacturers. Unlike their American counterparts, British firms frequently had to rely on supplies of silicon wafers from overseas.

Production costs invariably decrease with increase in wafer size, and to be competitive it becomes necessary to replace manufacturing equipment, in order to be able to process larger diameters. As these wafer diameters have constantly increased in size, it has often been difficult, because of remoteness from skill clusters, to synchronise the planning of production equipment with changes in wafer diameter. Since many production processes are dependent on wafer diameter, lack of synchronisation could well be costly in time and money. If wafer shortages arise, it is highly likely that companies furthest from skill clusters will be "last in the queue". Also, being furthest from the major centres of activity, they will be less likely to respond promptly to technical changes. This may result in material shortages, since, as demand falls, the major wafer producers will abandon production of smaller diameter wafers.

A further difficulty facing British semiconductor manufacturers was that of obtaining supplies of very pure high grade chemicals. These are essential for material processing, and if stringent specifications are not met, it becomes impossible to fabricate solid-state devices. This problem arose in Britain because of the relatively small size of the semiconductor industry. Since demand for these high grade chemicals was comparatively small, prices were high. Dickson, writing in 1981, stated that semiconductor chemical costs in the United Kingdom were three to four times as high as in the United States on a per unit production basis.[66] Furthermore, the number of chemical suppliers within the United Kingdom able or willing to supply small quantities of these high grade chemicals to the industry, was extremely limited. For example, at least until the early eighties, only one chemical company in Britain supplied liquid hydrogen, and semiconductor grade hydrofluoric and orthophosphoric acids. Should supplies became interrupted, production would therefore unavoidably be delayed. The alternative policy of obtaining supplies of dangerous chemicals from overseas involves additional transportation costs and possible delays.

The Nature of UK Semiconductor Development and its Contribution to Technical Lag

British semiconductor firms, like many of their American counterparts, did not forsee the rapid growth of silicon planar technology, and in particular integrated circuits. They were therefore disinclined to follow this approach to device fabrication. For example, at a Ministry of Defence meeting in February 1959, five British electronics companies were invited to request research funding for work in the field of "solid circuitry". Apart from Plessey, they were "uniformly sceptical" of the solid circuit concept, and as a result, the only contract for this work was placed with that company.[67] In 1961, AEI decided to refuse further support to the intended launching of a range of planar devices. A Plessey manager stated that in 1962, "senior members of the semiconductor research fraternity in the USA were expressing serious misgivings about planar technology and monolithic circuits, preferring beam-lead mesa devices with air-gap insulation".[68] As late as 1964, two senior engineers left Texas Instruments (Bedford) to join Plessey to work on Micro-alloy diffused transistor (MADT) devices, claiming that this process was potentially superior to planar for the production of high-frequency devices.[69]

In view of the subsequent success of planar technology, it is easy to forget that during the late fifties and early sixties it was by no means certain that planar techniques would rapidly dominate the industry. This lack of perception is understandable in view of the rapid introduction (and successive abandonment) of a variety of different production processes which had occurred since the invention of the transistor. To predict that a particular technology would result in the the superceding of all rival production techniques, and the establishment of a process which would remain basically unchanged for decades, would have required an exceptional degree of foresight. This prediction was made more difficult in any case, since the new technology emerged in centres geographically remote from Britain, and was consequently more difficult to evaluate. Although the industry in Britain has perhaps been justifiably criticised for failing to adopt planar technology sufficiently rapidly, it is important not to lose sight of the difficulties facing technical management at that time.

Rapid adoption of planar technology was also inhibited by firms being understandably reluctant to commit themselves to the expense of new processes which could be easily rendered obsolete within a short period. Plessey's experience with the MADT process certainly illustrates this danger. Apart from the capital cost of new equipment, new processing skills had to be mastered, during which time both production efficiency and product yields were low. Entering the new technology in a situation of technical lag (as was the case with British firms) imposed further delays, due to the consequent "settling in time", which was longer than usual, because of the unfamilarity of planar manufacturing techniques. Even at Texas Instruments (Bedford), who were receiving considerable help from the parent company, planar manufacture remained unprofitable for well over a year after the production lines were in operation.[70] Under these conditions, it was tempting, as Mullard did, to continue to produce large quantities of germanium devices, satisfying current demand, whilst neglecting to invest in a silicon planar programme. Only immediately prior to when the germanium market began to collapse in 1966/68, did that Company attempt to remedy the situation.

Lack of understanding on the part of British managements, regarding the future direction of technical and market developments, certainly assisted existing planar producers in obtaining a strong market lead. By the time the full import of this situation had been realised, it proved impossible to catch up in an environment where the existing producers were by then far down the learning curve. However, had there been a greater perception of the future course of events, it is doubtful if it would more than marginally have assisted British competitiveness. More important factors inhibiting success were the composition and size of British markets, and the inability to control overseas economic penetration.

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64. K.E. Dixon, Infrastructural issues in the UK Semiconductor industry (Birmingham: Technology Policy Unit, University of Aston, March 1981), p.7.

65. *Ibid.* p.9.

66. *Ibid.* p.12.

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68. *Ibid.*

69. These engineers were colleagues of the author at the time.

70. Information obtained in 1966 from production staff at TI (Bedford).

Chapter 4

Direct Governmental Involvement within the Semiconductor Manufacturing Industry

Introduction

This chapter examines the history of direct Government funding within the non-defence sector of the British semiconductor industry. Firstly, it outlines the framework in which Government policy towards the industry was implemented during the period under consideration. This is followed by a review of the activities of the main funding bodies concerned, namely, the Department of Trade and Industry and its successor, the Department of Industry. It then details the apportionment of funds from these Departments to industry, and reviews the setting up of INMOS. Also included is a discussion of the importance of the timing of aid, coming as it did when the industry was under considerable market pressure. Policy factors inhibiting the industry's performance are then analysed. Finally, the Government's approach to state funding is reviewed critically.

The Structure of Governmental Industrial Assistance - a Brief Chronological Survey

The first phase of Post-War Governmental assistance to industry began in 1949 when the National Research Development Council (NRDC) was established by Harold Wilson, then President of the Board of Trade. The purpose of the Council was to develop discoveries made by Government Research Establishments and Universities, and to foster the patenting and commercial exploitation of British inventions. It provided risk-sharing finance for high-risk products, and the industrial application of patents arising from

Government work. During the following decade, relatively small sums of money were made available to the semiconductor industry under this scheme. Assistance in device development was almost exclusively channelled through Ministry of Defence Committees.[1] This phase of limited intervention lasted from about 1950 until the mid-sixties.

In 1962, the National Economic Development Council (NEDC or "Neddy") was established under the Macmillan Government, as a response to evidence that British manufacturing industry was in relative economic decline. The Prime Minister was attracted to the idea of setting up an organisation on similar lines to the French "Plan Calcul" which he saw as a means of reversing the existing economic trend. The British Government's approach, unlike that of the French, was however one of consensus between state and industry rather than compulsion. The NEDC consisted of a Council, usually chaired by the Chancellor of the Exchequer, and was comprised of Cabinet Ministers, and representatives from industrial management and the trade unions. A second tier contained about fifty committees, also tripartite in nature. In addition a secretariat (the Office of the Development Council) acted in an advisory capacity to the various committees.[2]

A distinct shift in policy was presaged by Harold Wilson's speech to the Labour Party Conference in Scarborough, held in 1963. in which he spoke of "the Britain that is going to be forged in the white heat of the scientific revolution".[3] Upon taking power in October 1964, one of the first acts of the incoming Government was to set up the Ministry of Technology, under Frank Cousins, which was charged with the direct responsibility for increasing production and efficiency. The Ministry was also instructed to assist in speeding the application of new scientific methods of industrial production.

Work now began to implement a "National Plan", the major priority being to improve the balance of payments and achieve economic growth. This plan, implemented in

September 1965, was mainly the work of Sir D. McDougall, formerly Director-General of NEDC until October 1964. Responsibility for planning was to rest with the Department of Economic Affairs. The role of the NEDC was diminished, the function of the tripartite committees now being to find ways of improving industrial efficiency, and meeting the objectives of the National Plan. The Science and Technology Act, dating from 1965, established Research Councils, gave the Government wide powers to support Research and Development and also finance applications work.

The Labour Government's immediate priority in the technological field, as seen by Harold Wilson, lay in computers. Wilson stated that on the evening he took office, he informed Frank Cousins that he had, in his view, "about one month to save the British computer industry from extinction".[4] With the initial emphasis upon the computer crisis, little direct action was taken at the time to assist the semiconductor industry, which was now passing through a critical phase of its development.

Against a background of renewed pressure on the pound, the National Plan was abandoned in mid-1966. The economic "stop-go" policy of the 50s was re-instituted, and a prices and incomes policy established. Government policy towards industry now reverted to short-term goals. In July 1966, Frank Cousins resigned as Minister of Technology, and was replaced by Tony Benn. Rationalisation of sections of the economy was felt to be necessary, and the Industrial Reorganisation Corporation (IRC) was set up to assist in the process. Also during that year, the Electronics Economic Development Committee (EDC) was instituted, its interests including components and electronic equipment. However, it was not until the early 70s that the Committee set up a number of Sector Working Parties (SWPs), suggesting some lack of urgency.

Further fundamental changes in industrial policy took place in 1970, following the June election of a Conservative Government under Edward Heath. Planning projects initiated under the previous Government were abandoned, and the IRC disbanded. The Ministry of Technology was broken up, and the Department of Trade and Industry (DTI) established, and made responsible for industrial funding. The general thrust of economic policy was now towards free market economics, and NEDC activities were relegated to maintaining a channel of communication to the TUC and CBI. An influential development was the creation of the Central Policy Review Staff (CPRS) in 1971, under Lord Rothschild. However, faced with cash-flow problems within the private sector, the Heath Government again carried out a radical reversal of policy in 1972. This included the introduction of the Industry Act (1972), which was strongly interventionist with an emphasis on efficiency and growth.

The incoming Labour Government in 1974 took the view that production improvement in industry would be obtained by industrial co-operation through the framework of the NEDC. Within that year, the DTI was split into two separate departments, the Department of Industry, (DoI) under Tony Benn, and the Department of Trade,(DoT) under Peter Shore. Since that time, most direct forms of financial assistance to the electronics industry have been provided for by the DoI. It was now believed that the formulation of industrial policy would best be achieved through discussion with industry, rather than the "top-down" planning approach as envisaged in the previous National Plan. The impact of multinational companies was reflected in the 1975 Industry Act, which gave the Government powers to prevent the transfer of control of British firms to foreign manufacturers. An important result of this Act was the setting up of the National Enterprise Board (NEB) as a public corporation, with the aim of promoting industrial efficiency and international competitiveness, and also to provide productive employment.

In 1976 a further body, the Advisory Council for Applied Research and Development (ACARD) was set up to advise Ministers on aspects of applied R&D in both the public and private sectors. It also published reports concerning the future development and applications of technology[5] including a report during the late 70s on the applications of semiconductor technology. Members of ACARD were recruited from industrial management, education and the trades union movement.

The following year the Electronics Development Committee (EDC) established a micro-electronics working group to bring together makers and users of microcircuits. Its terms of reference included acting as a high level forum of opinion, capable of influencing Government policy, and also to support and co-ordinate the SWPs. Setting up this Committee must therefore be seen as a further attempt to provide industrial input into the decision-making process. Membership of the EDC for the Electronics industry included managerial staff from Thorn Electrical Industries, Marconi, Ferranti and GEC, in addition to Government advisers and trade union representitives.[6] During its lifetime, the Electronics EDC issued numerous reports, dealing with a wide range of matters concerning the semiconductor industry, including its position with regard to overseas competitors.

The election of a Conservative Government in 1979 led by Margaret Thatcher introduced yet another change in Governmental policy towards industry. The previous industrial policy strategy was now abandoned, and a long period of industrial disengagement by the state began, control of the economy taking place through measures involving control of the money supply. The policy of state investment through share ownership, which had been vital to the creation of INMOS, and the continued existence of Ferranti, was to be brought to an end.

This policy involved reorganisation of a number of departments and committees.The Industry Act (1980) reduced the power of the National Enterprise Boards, which were now unable to extend public ownership into profitable areas of manufacturing. However, most direct financial assistance to the electronic industry was still provided by the DoI.

From the beginning of 1981, the Electronics EDC was reconstituted and its Sector Working Parties restructured to become an industrial policy forum, with the aim of establishing a medium-term policy for the industry. An important aspect of this policy was to ensure that Government and EEC policies were supportive and consistent with the industry's commercial and technological objectives. In September 1981, the NEB and the National Research Development Corporation (NRDC) were merged to form the British Technology Group. With greatly curtailed powers in its new role, the principal objective was now to transfer technology efficiently from Universities and research departments into industry.

It was within this constantly changing political and organisational environment that Government policy towards the semiconductor industry was made, and the industry compelled to operate. In an industry where, by its nature, development-production cycle times may be lengthy and the long-term view particularly important, this uncertain situation imposed an additional burden upon firms, who were, from the start, under considerable pressure from foreign competition.

Governmental Policy - Organisations and Attitudes

Government awareness of the semiconductor industry and its problems seems to have been slight prior to the initiation of the Microelectronic Support Schemes in the early 70s. Unlike the computer industry, which received immediate priority from Harold Wilson under the National Plan, the essential building blocks from which computers are constructed were given scant attention. Microelectronic devices appear to have been seen in a decidedly secondary role compared with the perhaps more impressive equipments, when viewed from the standpoint of the politician or Government official, or indeed the general public. This attitude does not appear to have been confined to the Cabinet, the

Ministry of Defence apparently showing little interest in transistors or integrated circuitry until about 1960.

The first Government Department to become involved in semiconductor technology was the Ministry of Aviation, RRE, which issued an industrial Research Contract for the development of integrated circuits in April 1957. This contract was initiated by G.W.A. Dummer, who had set up an RCRDC Committee to investigate constructional techniques in 1956. The contract was transferred to the Committee for Valve Development (CVD) in 1960, the Admiralty then becoming the principal source of external funding of R&D throughout the period under review.[7]

From an early stage a somewhat reluctant attitude existed within the Procurement Executive to fund large-scale work in silicon technology. For example, the abovementioned contract was originally proposed at £7 million, but then whittled down to a £100,000 study, to be funded at £10,000 per annum.[8] Since this project was initiated by the Ministry of Aviation, and involved both active and passive devices within an integrated circuit, it crossed the technical boundaries established between the Air Ministry and the Admiralty in 1940. In view of CVD's primary interest in valve technology, it is perhaps not surprising that this contract was accorded a low priority. This decision was certainly a major policy error, and resulted in valuable time being wasted, and a clear technical lead by Britain being lost overseas. It strongly contrasted with the American effort, made under the space and defence programmes, which resulted in the five major device manufacturers producing five million integrated circuits, as early as 1963.[9]

An undoubted influence upon Governmental attitudes towards the industry, was that until the 70s, engineering projects within the UK were unable to sustain high volume transistor production. No major equipment programme existed until that time to make use of semiconductor devices. To break the deadlock, D.H. Roberts (Plessey) suggested in

1963 that an order for one million integrated circuits be placed with the object of establishing large-scale high-volume production,[10] but this "pump priming" idea was rejected by MOD, on the grounds that the UK military market could not absorb anywhere near this number.[11]

In 1965, Plessey produced a presentation for the Government entitled "Microelectronics - its impact on the UK electronics Industry", which recommended setting up a centre to develop and manufacture special microcircuits for industry within the United Kingdom.[12] The initial cost of this proposal was estimated at being £5 million over a five year period. Although this proposal received support from the MoD Research Establishments, both Plessey and Government were reluctant to fund such a project. Doubts were also expressed that no market existed for the proposed product. Consequently, this initiative came to nothing.[13]

Pressure from the MOD led the NRDC to take an active interest in development-production of ICs from 1968 onwards. Funds made available by NRDC were however small. They assisted Plessey, Ferranti and Marconi, the biggest orders being for the British Aerospace "Rapier" missile. Support amounting to nearly £5 million was given to these three companies, in the form of loans, the money to be recouped through device sales by 1980. (In the event, this money was never repaid). Under this contract Ferranti received, for example, over £1.2 million.[14] Money was also made available by the Ministry of Technology through the Advanced Computer Techniques Project, under which firms could claim half their development costs for approved contracts.[15]

The short-term approach towards the economy dating from the collapse of the National Plan ensured that interest in funding civil developments at Government level received little encouragement. For example, Lord Zuckermann, then the Chief Scientific Adviser, produced a report in the spring of 1969 suggesting how to divert some military effort into the civil field. Governmental attitude at the time may be gauged by the fact that soon afterwards the Prime Minister dismissed the report, stating to colleagues "I am afraid there is no political capital in this because nothing we decide will have any effect until years after the next Parliament gets going"[16]. This remark, made at the most senior level of Government by the leader of a party most associated with the concept of economic planning, is revealing in showing a sense of priorities largely dictated by political expediency. It is difficult to believe that such an attitude, held by the Prime Minister, could not have had considerable repercussions at various levels of Government.

The most important step to date towards industrial funding by Government took place with the establishment of the DoI Research and Development Requirements Boards set up under the 1972 Industry Act. These Boards then became largely responsible for Government policy. They were usually chaired by senior industrialists, and had strong industrial representation. Their function was to determine the objectives, composition and balance of most non-aerospace R&D funded by the DoI.[17] The Boards were able to directly commission R&D, or support projects undertaken by individual firms. They operated through consultation with both the public and private sectors, including "NEDDY" EDCs and SWPs. The R&D Requirement Boards allowed the first significant industrial input to decision making to be made by electronics manufacturers, one Board dealing specifically with electronic components. Their importance may be illustrated by the fact that in 1982, they spent about one third (£55 million) of the Science and Technology budget.[18]

The decision to establish a committee structure, which was eventually to lead to the establishment of the R&D Requirements Boards, originated in the late 60s, when a series of reviews was carried out within the Ministry of Technology. These reviews involved academics, industrialists and Ministry officials. They were instituted by Tony Benn, who stated that he wished to break down the barriers between research and industrial production.[19] It has been suggested that previously to setting up the boards, research programmes were "more or less invented within the establishments".[20] Their programmes were then endorsed by a series of advisory committees and finally by the Government Chief Scientist (Sir I. Maddock). The result of setting up the R&D Requirements Boards was a shift towards stronger control of the research establishments, and for the first time an influential industrial input into the formulation of policy.[21]

The first co-ordinated across-the-board attempt to assist the industry was launched in 1978 by the DoI, under the provisions of the 1972 Industry Act. Its most important provisions were the setting up of the Microelectronics Industry Support Scheme (MISP) and Microprocessor Applications Project (MAP) programmes in July 1978, and also the Electronic Components Industry Scheme. The MISP scheme was initiated as a five year selective support programme, with the following aims.[22]

(a) to expand production of silicon ICs.

(b) to develop a UK capability for the design and manufacture of ICs for specific uses.

(c) to support UK companies supplying equipment or services to the microelectronics industry and to support the manufacture of other semiconductor devices important to microelectronics.

Realisation by Government of the importance of the industry came largely from semiconductor firms lobbying Ministers and officials at various levels. Informal contacts may well have carried more weight in this respect than recognised structures set up for consultation. Conversations with industrialists and also published evidence suggest that perhaps the majority of the semiconductor manufacturer's representitives on NEDO Committees felt they had no real influence on Government policy during their existence.[23] However, this feeling was not unanimous. Ivor Cohen (Managing Director, Mullard Ltd.) and Kenneth Walton (Director of ITT) disagreed on the grounds that the Committees provided information, and enabled them to have a greater input on Government policy than by individual lobbying.[24] A criticism (made in 1982) by a senior NEDDY official was that attempts to persuade managements to change attitudes "had become muddled up with the issues of employee consultation and trade union power".[25]

An event stimulating Governmental action appears to have been the financial collapse of Ferranti in 1974/5. This resulted in the Company's rescue by the NEB, during the lifetime of the Heath Government. The Industry Act (1975) establishing the National Enterprise Board, gave the Secretary of State prohibitory powers to stop, under certain circumstances, "transfer of control of important manufacturing undertakings to non-residents". It is evident that the Government regarded Ferranti as a strategic asset, in view of its commitment to the British defence industry. Certainly any attempt at a takeover of Ferranti by any foreign manufacturer would have been resisted in the National interest at that time.

In January 1978, the Government Chief Scientist Prof. John Ashworth, together with ACARD, set up a working party to look into the development of microelectronics.[26] In order to raise public interest, Ashworth recorded a television programme "The chips are down". To achieve maximum impact, he arranged for the programme to be screened at about the time the ACARD report was released. The television documentary was shown to James Callaghan, who consequently became the first Prime Minister to recognise the importance of semiconductor technology, to the extent of directly consulting leading industrialists, in order to obtain a first-hand evaluation of their problems. During his period of Office (1976-1979) a significant attempt was made to co-ordinate a national policy within the fields of microelectronics production and applications, involving Government, industry and education.

Apart from the MISP and MAP programmes, perhaps the most important decision taken in this field under the Callaghan Ministry was the establishment of INMOS, the semiconductor manufacturing firm set up as a subsidiary of the NEB, with government financial backing, in order to produce standard integrated circuits of an advanced type. Ian Mackintosh, a prominent semiconductor manufacturer and consultant advising the British Government, argued convincingly at this time that normal commercial criteria had been so distorted by US and Japanese government support that European companies had no hope of competing without comparable government backing.[27]

The INMOS venture met with opposition from the DTI and members of the Cabinet, on various grounds including that in its initial stages the proposed company would have to rely upon American personnel and manufacturing techniques. Furthermore, the money might be better invested in existing companies. Predictably, further opposition came from British semiconductor manufacturers, for whom INMOS was an unwelcome rival, not only competing commercially but also for government funds. Only the personal support of James Callaghan and other senior figures in government enabled the project to get under way.[28]

An objective of the Thatcher Government, elected in 1979, was to create an economic climate in which the financial needs of industry could be met from private investment. Consequently, the NEB was instructed to sell off its assets. Changes in the composition of the NEB at this time created further complications, members holding markedly different views regarding the future of INMOS.[29] However, in line with Government philosophy, efforts were soon being made to find a buyer, and following the Company's move into profitability in 1983, it was purchased by Thorn-EMI the following year.

Non-Defence Government Support Policy

Small scale commercial support for the semiconductor industry began through the National Research Development Corporation (NRDC). This organisation was involved at an early stage in funding the computer industry. For example, both Ferranti and ICT received loans under the Advanced Computer Technology project, launched at the end of 1963, which awarded cost-sharing contracts for the development of all aspects of computer systems.

During the late sixties the Labour Government, somewhat belatedly, was persuaded that additional support was needed in order to build and maintain a viable microelectronics industry, and the NRDC was chosen as the major source of funding. Consequently, industrial investment by the Ministry of Technology was initiated in 1964 through the Advanced Computer Technology Project. The sum allocated to semiconductor manufacture under this scheme amounted to about £0.8 million per annum, the work being carried out on a cost-sharing basis. The firms most involved in this project were Ferranti and Plessey.

The establishment of the Ministry of Technology was the first significant step towards increasing financial support for the semiconductor industry. This Department was set up in November 1964 by the Wilson Government, with the stated aim of strengthening Britain's technological industry and assisting the diffusion of advanced technology. This move received support at the time from the professional institutions. For example, the President of the Institution of Electronic and Radio Engineers wrote "The Government's initiative in founding a Ministry of Technology was widely welcomed as an excellent first step in securing better co-ordination of the Country's scientific and technical effort which hitherto has been dreadfully patchy and isolated".[30] Golding mentions that from that year onwards, semiconductor firms received contracts amounting to approximately £100,000 per year for the development of devices and techniques.[31]

Following a report published by the NRDC in 1966, the Ministry declared its willingness to support British firms engaged in the production of integrated circuits. The Department of Technology was certainly aware of the importance of stimulating the development of these components at that time. For example, the Minister of Technology, addressing industrialists in March 1967, declared his willingness to support British firms engaged in the production of integrated circuits, stating that "Integrated circuits will come to be at the heart of the whole of electronics, and, if we do not meet the challenge here, it will be tatamount to abandoning our world position in this industry".[32] Outlining the strategy to be adopted, the Minister saw little point in increasing expenditure upon R&D unless there was a worthwhile economic return in the form of increased output. He saw the future growth and competitive power of the industry in (a) successful innovation (b) identification of the areas in advanced technology most likely to pay off (c) planning resources so that the maximum power is brought to bear at the right time. Furthermore, these proposals would be most likely to be successful if integrated circuit manufacture "were concentrated in a very few industrial groupings, perhaps two or three".[33]

The above response came at a time when the British integrated circuit market had already become dominated by overseas producers. For example, in 1967, only about 25% of the market was accounted for by British semiconductor manufacturers. Of these, Marconi-Elliott held 11% of the total market. The principal foreign producer, Texas Instruments, held 25%. Plessey, in spite of an early start, due to the award of a Government Research Contract in 1957, held only about 1% of market share.[34] Certainly, failure by Plessey to invest substantially in this project was a greatly missed opportunity. The Company held an extremely lucrative Government contract for the supply of transformers at the time, and it has been suggested that this matter was given considerable priority over integrated circuit production.[35]

Non-defence involvement in the specific area of production technology dates from 1968, when Ferranti and Elliott Automation obtained relatively small grants for yield improvement on a 50% cost-sharing basis. Under this contract, Ferranti received £186,000 over two years, the money being used to improve the efficiency of integrated circuit manufacturing plant.[36] A limited approach was initiated in 1969 when the Department of Trade and Industry (DTI) set up the Micro-Electronics Support Scheme (MESP). Under this scheme, £5 million was made available over a five year period for approved development projects. In 1974, a further five year allocation of £12.5 million was granted, this figure to be matched by a similar contribution from participating firms. Repayments were to be made by a levy on profits rather than sales. In parallel with this assistance ran the Electronic Components Scheme, with a budget amounting to £20 million, about £2 million of this sum being allocated for IC development. The companies assisted under the above two schemes were Ferranti, GEC and Plessey.

By the late-seventies, anxiety was being expressed by the DoI and various Government committees regarding Britain's failure to compete effectively in the field of microelectronics technology. A report published in November 1977 by the ERC's Solid State Physics and Devices Working Party recommended "the setting up of a National 5 year VLSI project, to provide a design technology and marketing base"[37] in order to enable the industry to compete internationally. The DoI, in a report to the SWP on Monolithic Silicon, also argued for "a minimum but essential five-year objective" to develop the microelectronics industry. A further report by the NEDO Electronic Components Sector Working Party in June 1978, expressed concern at the balance of trade defecit in integrated circuits. It concluded that "without an effective strategy for a British microelectronics industry the situation would worsen further".[38] It recommended concentration upon the manufacture of selected multi-application devices rather than attempting an across the board approach and argued for the creation within the United Kingdom of "a design and production capability which would be competitive internationally by 1983." The report also expressed concern at the degree of state support provided by competitors. For example, the French Government had allowed about £70 million over the next five years in direct support for their microelectronics industry, the United States Government was expected to provide between £200 and £300 million over a similar period, and the Japanese four-year integrated circuit programme (including VLSI) was estimated at about £300 million.[39]

From 1977/8 onwards, a co-ordinated attempt was made by Government through the Science Research Council, together with the DoI, to assist the microelectronics industry, on an across-the board basis. At the request of the Prime Minister, the Central Policy Review Staff were now engaged in co-ordinating studies of the social and employment effects of microelectronics. Their Report, published in November 1978, stated that the Government did not accept a situation where Britain had to import all its microelectronic components, since in a fast-moving technology total reliance on overseas suppliers would put equipment users at a disadvantage. Technical competance would be greatly enhanced by technology transfer, which an indigenous industry would provide.[40] In February 1979, a Sector Working Party report published by ACARD, recommended setting up "a design and silicon processing capability in a preferred range of MOS and bipolar processes which by 1983 would be competitive with the best of our international competitors".[41] This report was to result in the decision to fund the INMOS project.

A further scheme, the Microprocessor Application project (MAP), was launched in July 1978, with the aim "to render financial assistance in order to encourage UK industry to apply microprocessor techniques over a wide range of processes and products". This project followed industrial support of £20 million, which had been made available in 1977 by the Department of Industry (DoI) for the electronic components industry. Under the MAP scheme, £55 million was allocated for industrial support.[42]

This announcement was followed during the same month by publication of the Microelectronics Industry Support Scheme (MISP), with the general object of "assisting the development and manufacture of those microelectronic devices where a close interaction between user and supplier is needed". The MISP programme made the sum of £70 million (later reduced to £55 million under the Conservative Government) available over a period of five years. About £15 million of this amount was to be towards the design, development, testing and production of non-microprocessor devices. Grants could be up to 50% on cost-shared contracts for research projects; up to 25% or in certain circumstances 50% for development of products and processes, and up to 25% for investment in production plant, equipment and building.[43] A further scheme, announced early in 1979, allocated £6 million for a five-year programme to assist the development of microelectronics in education.

Under MAP and MISP, total investment in the integrated circuitry, (including support for INMOS, ITT, GCE-Fairchild, Plessey and Ferranti, plus additional sums including £25 million for re-training), has been estimated at about $500 million (£250m).[44] In addition to this amount, a further £30 million was allocated under MAP in 1982. These schemes also gave support to selected foreign companies operating within the United Kingdom. For example, ITT received $2 million in Government support for its 60K memory programme, and National Semiconductor obtained approximately $10 million through MISP and the Development Planning Agency, in order to open an integrated circuit plant in Scotland. A second phase of MISP (MISP II) was launched in 1984. This programme, extending until 1990, was designed to support the development of custom and semi-custom integrated circuits and their utilisation. Under this scheme, £120 million was made available to support up to 25% of approved projects[45]

In response to increased overseas research effort (and in particular the announcement in April, 1982, by Japan of the intention to develop a new advanced generation of computers)[46] a five year programme (the ALVEY project) was set up to sponsor research in the field of information technology (IT). Beginning in 1983, it was funded by a budget of £350 million, more than half this sum being provided by government, and supported by the DTI, MOD and SERC. Its object was to double the level of information technology during the lifetime of the project, and to meet specific goals. The MOD contributed approximately £40 million, most of this money coming from the CVD budget supporting R&D on electronic components. The major share of the funding (£90 million) was allocated for the development of VLSI and a further £30 million for computer aided design (CAD). Any centre of IT research within the United Kingdom, public or private, was allowed to participate, and 113 firms did so, although many formed part of larger groups[47]

Major companies *taking part in the ALVEY programme* included GEC, Plessey, Ferranti and ICL. INMOS would not join, however, on the grounds that they were technologically ahead, and attempts to get GEC and INMOS to collaborate were unsuccessful. During the lifetime of the Programme, GEC withdrew from a number of projects, and it has been suggested that the company took decisions "without really any consideration of such things as collaborative research programmes".[48] Nevertheless, it is generally agreed that a major achievement of this programme was the degree of collaborative research achieved between Government, private industry and the universities.

During the 80s a shift in Government policy towards funding semiconductor projects took place, less emphasis now being placed upon programmes aimed specifically at assisting British firms, but with more stress upon participation in jointly funded European projects. For example, the European Strategic Programme for R&D in Information Technology (ESPRIT), was launched by the European Community in 1983. Its first phase (ESPRIT 1) running from 1983 to 1988, was concerned in creating the framework for collaboration between diverse national organisations. The second phase (ESPRIT 2) running from 1988 to 1992, involved the formulation of projects around specific goals. Government funding by EC members, including both phases, was estimated at $4200 million, this being 50% of total investment.[49] Sums of this nature certainly illustrate the rapidly escalating cost of microelectronic circuit research and development, and the need for inter-European co-operation in assisting work on such a scale.

A consequence of the Governments shift in policy towards the funding of inter-European projects was diminishing support for post-ALVEY developments. In June 1985, the Minister of State for Industry and Information Technology invited industry to assemble a working group to consider planning a sequel to the ALVEY programme , and to produce a report with the minimum of delay. Consequently, in February 1986, the so-called IT86 Committee, was formed under the chairmanship of Sir Austin Bide,[50] and subsequently published the "Bide Report" in November 1986. Its recommendations included an information technology application scheme, involving £125 million of government funding. In addition, a £300 million government contribution would be made to a £550 million research scheme extending over five years. Hardware investment would be the largest part of the government's contribution and amount to £250 million. The plan would involve an integrated approach with Britain's European partners, and also include a comprehensive education and training programme.

Although the Government had pressed for an early report, action was not taken until January 1988. By this time, a change in Government policies and objectives had taken place, with renewed emphasis on "free market" ideas. This new policy, administered by

Lord Young, then Secretary for Trade and Industry, amounted to continued support for ESPRIT 2 through the EEC budget, and in fact this was increased to £200 million. However, DTI funding now amounted to only £29 million for a further three years of research, mainly to be carried out in partnership with companies[51]

INMOS

The third principal avenue of state intervention has been through the setting up of a private company (INMOS). This Company was unique in being a semiconductor manufacturing firm set up through state intervention. The decision to do so was taken at a time when British component manufacturing firms operating in the private sector had withdrawn from this highly competitive activity, in the face of overwhelming competition from the American semiconductor industry.

The project was initiated by R.Petritz and I.Barron, who were specialists in their respective fields, namely device and computer engineering. Government advisors included *I.M.Mackintosh, an industrial* consultant with wide experience in device technology, and individuals within Government establishments. Although the idea was conceived during the office of the Labour Government, the incoming Conservative administration continued to support the scheme, although somewhat reluctantly.

INMOS was established in July 1978 through the British Technology Group (formerly the National Enterprise Board). The new company received the highest level of Government support set aside for the microelectronics industry during the period 1978/9, amounting to an initial £25 million for early development, followed by a further £50 million to be allocated in two £25 million parts, this sum being for building production plants and for research and development programmes.[52]

Following the decision to proceed, a research and development facility was set up at Bristol, England, together with a production plant at Colorado Springs, the latter more easily to take advantage of American technical expertise. A further production plant was scheduled to be sited within Britain, but a delay of about six months occurred as the result of a change in fiscal policy, following the election of a Conservative government in May 1979. However, the incoming administration eventually agreed to allow payment of the final £25 million instalment on condition that the new production plant was constructed in South Wales. In spite of the INMOS management's preference for Bristol, the government, with strong personal support from Margaret Thatcher, selected Newport (Mon.), thus qualifying for both regional grants and EEC subsidies.[53]

Production began at Colorado Springs in 1981/2, initial efforts being concentrated on both memory and microprocessor devices. Early products included 16k static and 64k dynamic RAM's. The early years of production were unprofitable and by May 1984 Government support totalled £65 million in cash and £35 million in loan guarantees, most of which had been spent on the plant at Colorado Springs. Evidence exists of poor co-ordination at this time between the Department of Industry on one side and the MOD, the British Technology Group, and the Science and Engineering Council on the other.[54]

From its very beginnings, INMOS operated under an atmosphere of uncertainty. State control of the Company found no place in the incoming Conservative government's policies, and upon taking office, early attempts were made to find a purchaser. A number of British firms were approached, including GEC, but they declined to become involved. However, during the first quarter of 1983 Inmos moved into profitability, and in July of the following year it was purchased by Thorn-EMI, the directors estimating pre-tax profits of £3.7 million for the previous six months. The agreement provided for a transfer of NEBs holding of 76% of issued share capital against a payment of £95 million in cash on completion.[55] Personnel changes following the takeover included five new non-executive directors being appointed , all of whom were executives of EMI. The four existing executive directors, including the founders, Dr. R. Petritz and I. Barron continued to hold office.[56]

In 1985, EMI purchased further share holdings, bringing the total issued share capital in their possession to 94.7% by July 1985.[57] The Company suffered small losses during 1985, due to the then current world-wide depression within the computer industry. At this time the workforce was reduced and management reorganisation carried out. However, in spite of these difficulties, a new range of CMOS RAMs was introduced during the summer of that year. Instead of an anticipated recovery, a sharp decline in the market took place in 1986. New products launched during that year included the transputer (October), which, together with related products, accounted for over 50% of the firm's orders during 1987.

An important event in 1987 was the transfer of volume production from Colorado Springs to the Newport location, and the decision to withdraw altogether from DRAM manufacture. This change in policy involved ceasing to produce 64k and 256k DRAMs, although static RAMs continued to be made. One consequence of the move to Newport was an estimated delay in static RAM production by nine months.[58] Especially unfortunate was that this event involved the new 256k device, designed to be the fastest in the industry, with a switching speed of 20ns.

Although INMOS again went into profit in 1988, it was sold to SGS-Thomson in the following year, but with Thorn continuing to maintain a 10% holding.[59] Immediately following the transfer, it was announced that heavy financial investment in INMOS would take place, and that it was planned to recruit 100 engineers to create another transputer range.[60] However, financial problems continued under the new management, and the

Government was approached with the object of obtaining further aid, a minimum figure of £30 million being required. Although the Government was prepared to offer some assistance, it would not agree to this level of support. In December 1992, SGS-Thomson sold a 70% interest in the INMOS Newport fabrication plant to the Hong Kong electronics group QPL International for only £7.77 million.[61]

The greatest achievement of the Company was undoubtedly the production of the T414 transputer, described as the first genuine computer on a chip. This parallel data processing device was not only significantly ahead of the competition, but also of its potential users. A problem however was that in its initial form its sole programming language was Occam, and this lack of flexibility was a major factor in limiting sales. Criticisms were also made of a "distinctly arrogant marketing stance" by the Company at this time.[62] The T800 transputer was introduced in 1987. More powerful, with twice the on-chip RAM, its production ensured a continuing growth in transputer sales, which reached 200,000 devices in 1989.[63]

Government strategy in setting up INMOS must be seen as complementary to ensuring the maintenance of a viable indigenous electronic equipment industry, as part of a general effort to maintain Britain's position as a technically advanced manufacturing nation. The Electronic Components Sector Working Party of the National Economic Development Office, reporting in June 1978, identified the following three interdependent objectives for the British microelectronics industry: [64]

> *"(a) Supporting the U.K. user industries, (b) improving the competitive performance of the industry itself and (c) protecting national security where access to local technology is vital."*

The abovementioned report stated that "in particular, the DoI support schemes must take account of the need for long-term planning within companies by agreeing with them areas of development and production targets". It also referred to the need to expand volume production of selected multi-application circuits within the United Kingdom. These conclusions were reached in the period immediately following the domination of the digital mass-market by the major American semiconductor companies. It marked a considerable shift in attitude since the mid-sixties, when it was felt both by Government and industry that semiconductor manufacture in Britain could be competitive, and able to ensure a supply of components sufficient for the country's needs.

The subsequent history of the company was one of lack of commitment, both in financial backing and also in Governmental support for the concept of a state assisted market leader, offering technological strategic advantages. With the emphasis upon free market economics from the early 80s onwards, INMOS was seen as an embarrassment to be sold off as rapidly as possible. Nevertheless, financial aid was given, although grudgingly. Inmos did not fit in well with EMI-Thorns activities, and the prospect of investing considerable sums of money in a company of this type seems most likely to have been the major factor for their decision to sell to Thomson-ATES. The final sale by Thomson to QPL International, and consequent asset stripping, forms a sad end to a unique enterprise.

The Microelectronics Programme: Support Within a Hostile Environment

The Microelectronics Support Scheme, launched during the early seventies, was conceived as an attempt to assist the industry to become internationally competitive. In retrospect, what it did achieve was to enable the indigenous semiconductor manufacturers to produce and market linear IC's on a profitable scale. It did not and could not have enabled these manufacturers successfully to enter the highly competitive bipolar market. Although fairly substantial funds were allocated to the industry under this project, effort was diffused and subjected to rapid policy changes by different governments.

The decision to invest in microelectronics came at a time when the industry was already being forced out of the integrated circuit market, by a flood of low-priced devices imported from the United States. Between September 1969 and the September 1970, the average price of integrated circuits fell from over £1 per device to a third of that figure, or even less. Retaliatory price cuts by British producers had little effect other than to increase their financial problems.[65] Consequently, this situation led to a considerable reduction in output. Ferranti, for example, were forced to cut their production by 50% at this time. This dire situation may be illustrated by the following data.[66]

British Trade in Integrated Circuits 1967-69 (£1000)

	1967	*1968*	*1969*
Exports including re-imports:	107	872	2450
Imports:	1992	2602	6410
Sales:	4500	7800	15400

In interpreting the above figures it must be remembered that perhaps the majority of home sales in integrated circuits at this time were made by American companies operating within Britain. It can be seen that a substantially increasing trade deficit was occurring precisely at the time when Government intervention within the non-defence sector was beginning to get under way.

This situation, coupled with the fact that the research and development structure ot the British semiconductor industry was by this time firmly oriented towards defence requirements, left them with no alternative but to abandon bipolar IC manufacture. Consequently, from then onwards, Plessey and Ferranti concentrated primarily on producing custom ICs for military and telecommunications applications, with GEC following a similar policy.

It is important, when considering the policy of British device manufacturers, to remember that turnover in semiconductors only formed a small part of their operations. For example, in 1980, total GEC Company turnover amounted to $4214 million, only $30 million of which was accounted for by semiconductor sales. In that year,the respective figures for Plessey were $1100 million and $20 million.[67] Although substantial, semiconductor manufacture was therefore hardly central to these firm's activities and this fact was reflected to some extent in their commitment.

Evidence for this view exists in the case of GEC, whose participation in semiconductor manufacture has been subject to interruption and often minimal commitment during the past three decades. For example, the firm temporarily left the industry under the ASM agreement in 1962, on the grounds that considerable investment would be needed to maintain a significant presence. Furthermore, after acquiring Marconi Microelectronics and Elliott Automation during 1967/8, GEC closed down both these companies fabrication plants, thereby virtually ceasing semiconductor manufacture within the organisation. Again, Plessey unsuccessfully attempted to sell their semiconductor manufacturing plant in the 1977, discussions taking place with the National Enterprise Board, GEC and the American company General Instrument Microelectronics.[68] Also, after considerable financial losses unconnected with their semiconductor division, Ferranti sold this division to Plessey in November 1987.

The policy of industrial mergers within the electronic industry, encouraged by the Industrial Reorganisation Corporation, was aimed primarily at strengthening the computer sector. It led, paradoxically, to a weakening of the semiconductor manufacturing base, due to the subsequent closure by GEC of Marconi Microelectronics and Elliott Automation.

This consequent weakening of the industry was unplanned, unforseen and unintended. The alternative faced by Government during the late 60s was, therefore, either further investment in existing companies, or start up a new company, specifically dedicated to mainstream semiconductor manufacture. In the event, both options were followed, and aid to existing companies was granted through the abovementioned Microelectronics Programmes, with additional funding to establish INMOS.

Government support within the non-defence sector was therefore a response to a situation where the British semiconductor industry found itself under increasing pressure within both local and World markets. A similar situation existed on the Continent, where not only the semiconductor industry but also the computer industry was effectively dominated by American manufacturers. An OECD report, published in 1968, questioned to what degree disparities in the components industry affected a given countries military capability, and concluded that the answer depended upon "the type of relationship each one enjoys with the U.S." and goes on to state "the question is to know how far this dependence on outside sources of supply can go and to what extent the higher cost of nationally developed hardware are justified by the maintenance of a national capability in certain important fields".[69]

The OECD report also pointed out various disadvantages that lack of a local components industry would bring. For example, a trade defecit on components, a possible inability to obtain advanced components when needed, difficulty in designing equipments when lacking close co-operation between supplier and user, and the inability to make an original contribution to the field. It was felt that Government support should be given nationally to assist the components industry, and it was also suggested that a Continent-wide European market would help to overcome the existing fragmentation.

This report, coming when it did at a time of crisis in the British semiconductor industry, undoubtedly played a part in increasing an awareness of existing problems, and also by assisting in the formulation of Government policy. Not only did Government attempt at this time to give the industry a market orientation through DTI involvement, but Government Research Establishments were now encouraged to assist in the process. Due to the existing relationship between industry and Defence requirements, progress in this direction was reluctant and slow.

As industrial funding by the DTI became increasingly available during the late 70s through the implementation of the various microelectronic support schemes, the industrial influence of that department correspondingly increased. The emphasis now moved towards commercial activities, and the prospect of co-operation on a European scale. One consequence of this was that from the beginning of the 80s, British semiconductor companies began to look towards building relationships with European firms, for example, Siemens and Thomson. Following the setting up of INMOS, there was some feeling of neglect among management within British companies.

By the early 80s it was obvious to Government that previous policies had not resulted in appreciable technology transfer between the Research Establishments and industry. Renewed efforts were therefore made by the incoming Conservative administration to address the problem. The need for closer co-operation with industry in project planning, in order to assist the marketing of defence equipment overseas, was emphasised by the Prime Minister in a speech made in September 1980, stating "The prospect of overseas orders will be a factor which will play an increasing part in deciding our own operational requirements".[70] The need for closer co-operation between industry and the Research Establishments in marketing overseas defence equipment was emphasised in the following statement issued by the Permanent Secretary to Directors and Heads of Divisions in November 1981:-

> *"It is therefore imperative that all staff involved in the procurement process should not only be fully conscious of the importance that Government attaches to maximising sales of Government equipment, but should fully understand the need to engage in constructive discussion with industry in the definition and evolution of future projects with this end clearly in view."*[71]

The work of Defence Establishments was thus given a decided stimulus in the direction of market orientation.

This new policy raised the problem that concentration upon market objectives might deflect Government research away from the aim of producing devices and equipments specifically geared to British defence needs. This matter became one of concern, and was discussed by a Select Committee on Science and Technology in February 1982.[72] Certainly a conflict of interest existed between the need to satisfy specific operational requirements, and the demands of overseas markets. In view of the high proportion of MOD funding, the Service Departments obviously regarded their interests as paramount. One perhaps unforseen consequence of the policy shift was that the role of the Government Research Establishments now required to be redefined. Conversations with senior RSRE personnel suggest that this was never clearly done.

Commercial Exploitation of Defence Contracts

By the beginning of the eighties, Government attention was becoming increasingly focussed on encouraging firms to use MOD contracts more actively as a springboard to enter commercial markets, and at the same time direct Research Establishments towards an increasing awareness of market requirements. A report commissioned by NEDC and published in February 1983,[73] expressed concern regarding "the UK's ability to harmonise defence procurement with broader industrial objectives, and , in particular, to obtain technological spin-off." Furthermore, "the EDC was not alone" in feeling that too little commercial advantage was being derived from the major MOD investments.

At a seminar, held at the MOD July of 1982, and also attended by representitives from industry,[74] it had been pointed out that the MOD's spending amounted to about eight times the DoI's support for industrial R&D, and that a significant portion of DoI science and technology funds was being channeled into defence related industry.[75] Statements by the Secretary of State for Industry and other speakers were critical of the record of firms in exploiting technology obtained from Defence Contracts. A specific criticism was that often companies appeared to concentrate too much on obtaining the next Defence Contract at the expense of seeking civil benefits from previous defence work. It seemed, therefore, that little had changed in this respect since the early days of MOD involvement.

Positive suggestions emerging from the abovementioned seminar were that there should be more scope for joint projects with industry, and that Defence Research Establishments should take on more commercial repayment work. This would bring them into closer contact with a wider spectrum of industry, and thus making them more aware of the techniques required to meet commercial markets. It would also be advantageous to set up commercial units in R&D establishments to expedite the results of their own developments, and for defence contractors to look specifically at commercial opportunities arising from their defence work.

Faced with these suggested improvements, the Government attitude remained one of caution, and might well be summed up by the Defence Secretary, Michael Heseltine, in a speech made in September 1983. He stated that "There are no magic solutions to the problem of spin-off. It has proved elusive in other countries as well, including the United States. Britain's particular problems stem from attitudes and institutional structures which are deep-rooted and long standing. We hope for a radical change and strive to achieve it, but the likelihood is that improvement will be slow and measured in percentage points rather than steep changes".[76]

The Government's policy towards procurement was made plain in answer to a Parliamentary question raised on Dec. 21st 1984, which referred to the planned cuts in expenditure, including about £2 million in the then current microelectronics programme. The Parliamentary Undersecretary of State for Trade and Industry, Mr. John Butcher, stated that although the Government were anxious for the Departments and Government funded bodies to buy British products whenever possible, they would not specify that they must be bought "simply because they were British".[77] This was because such a policy would result in products being specified as compulsory which were not relevant in the international market. Interestingly, he quoted the example of the telecommunications industry where "a cosy buyer-seller relationship emerged and where our international market share plummeted during that relationship".

Factors Involving Government Policies Directly Inhibiting Industrial Performance

Before considering specific policies which have contributed to the poor economic performance of the semiconductor industry in Britain, some mention should be made of the relatively low status of industry within Government circles. This also appears to have been reflected in the status accorded to the DTI, one example being that Leon Brittain's move from the Home Office to the DTI in 1984 was seen by most commentators as a demotion.[78] Such an attitude can hardly have failed to have a significant effect upon the priority accorded to industrial assistance during the period under review. Departmental lack of status may be reflected in the fact that during the sixties and seventies there were no less than twelve Secretaries of State for Industry. In any event, such frequent changes suggest a general weakness existed in leadership and departmental policy over this period. Furthermore, the quality of Departmental leadership is open to doubt. For example, during the sixties and seventies, of the large number of politicians who held the post, only John Davies had first-hand knowledge of industry.[79]

In view of the abovementioned record, it is not surprising that recruitment into the DTI has been less popular than the more prestigious Departments, such as the Foreign Office, Home Office and Treasury. A further complication tending to weaken the influence of the Department of Industry has been the effect of the structural changes which have taken place,[80] firstly by the Department being split into the separate Ministries of Trade and Industry in 1974, and then being brought together again under Cecil Parkinson in 1983.

One organisation which appears to have strongly affected the rate at which new technologies were developed was the Procurement Executive. CVD was essentially an Admiralty organisation, and it has been suggested that its attitude towards device development was unduly influenced by the requirements of the Senior Service. Certainly during the early stages of device development, the prime military application for solid state devices lay in the fields of aircraft and missile systems, and there is evidence of a somewhat reluctant attitude on the part of CVD to fund work in semiconductor technology.[81]

An event inhibiting industrial performance was the abandonment, during the mid-fifties, of research on silicon by RRE and SERL. This event unhappily co-incided with the decision to purchase supplies of silicon grown-junction devices from Texas Instruments. This was not so much a policy error, as suggested by Golding,[82] but a logical move when viewed within the narrow confines of MOD strategy. However, when considered within the wider aspect of the future of the British semiconductor industry, the consequences were highly disadvantageous. This was because the decision could not have failed to have delayed and diminished any contribution to the development of planar technology, which would otherwise have been made by Government establishments. It is also extremely doubtful whether the considerable financial assistance extended to foreign concerns manufacturing within Britain was on balance an asset, when the advantage of military device procurement was weighed against damage to the commercial prospects of the indigenous industry.

One likely reason for the reluctance of Government Research Establishments to become directly involved in silicon technology, was the initial and possibly ensuing capital cost of planar manufacture, involving clean rooms and expensive equipment. Certainly the Treasury, and possibly CVD itself would have looked askance at the considerable sums involved. As a result of the decision to concentrate on GaAs, research output in silicon technology from the Establishments was almost completely absent during the critical period of integrated circuit development and manufacture.

Another problem was claimed to be the substantial slowing down in decision making due to purely administrative delays on part of the Government. For example, a specific complaint, dating from about 1963, was made by Plessey regarding the existing procedures introducing a considerable time-lag in arriving at the point at which a contract was made.[83] The firm's representitives pointed out that because of the time lag caused by these procedural delays commercial spin-off was adversely affected. Holding a specific contract "on ice" might well suit the requirements of the MOD, but from the point of view of an individual firm it could be highly disadvantageous. This was because of the rapidity of technical obsolescence, and also the necessity to deploy teams of scientists and engineers until the project re-commenced.[84]

A further factor which led to difficulties was the manner of awarding development contracts to individual firms. Until the early 80s, MOD Development Contracts were normally awarded to selected firms on the basis of estimated costs plus "incentives" (i.e., cost-plus contracts). Under this system, costs were calculated and a profit margin then added. However, in order to get components or equipments into service it was then necessary to negotiate a Production Contract during some stage of the development process. The procedure was to place a Production Contract for a limited number of components or devices at an agreed price, this being turned into a longer term Production Contract at a later stage.[85] In the event of a long production run, the system worked strongly in favour of the company which had received the Production Contract, and particularly in the case of firms within the semiconductor industry, which is subject to rapidly falling unit costs, and rapid technical obsolescence.

The disadvantages inherent in the system of awarding cost-plus contracts were not confined to the Ministry of Defence.It has been stated that the Post Office found "The firms got richer by minimising capital employed: that way they were able to convert the 13% return on cost, allowed by the Treasury formula for cost-plus contracts, into a higher return on capital employed. It provided no incentive to invest, to innovate or raise efficiency".[86]

Evidence exists that long-term Production Contracts were extremely lucrative, earning far higher profits than might have been expected if the same devices had been sold in the open market. This knowledge can hardly have failed to provide a further incentive to component manufacturers, often faced with considerable market pressure, to favour long production runs of devices under Government contract. (Unlike the situation within the United States, financial information relating to these contracts is security classified, therefore it is impossible to publicly analyse the situation quantitatively). It is likely that a non-commercial attitude on the part of manufacturers would be reinforced by the belief that CVD indulged in speculative development.[87] Golding and others suggest that a significant proportion of Government support went into the development of devices for which no subsequent market developed. This situation could hardly fail to result in high production costs.

By the end of the 70s there was an increasing tendency for the MOD to approach a specific company possessing some particular expertise to co-operate in a particular defence project, thereby operating the principle of what has been described as "rough justice"[88] rather than putting out a Development Contract to competitive tender. The argument against competitive tender at the production stage was that when a Development Contract was placed it often became necessary to proceed to the production stage without delay, and this might well involve starting production before development was complete. The manufacturer holding the Development Contract would have the advantage of being already tooled up, at least in part, and already familiar with the project. Also, since development work was usually done on a cost-plus basis, there would be little profit at that stage.[89] Without the incentive of a Production Contract, firms might well be reluctant to take on development work.

The operation of a policy of "general understanding", (i.e., that a firm completing a Development Contract would be most likely to get the corresponding Production Contract), seems to have been followed on the grounds that firms would otherwise be reluctant to accept further Development Contracts.[90] The operation of this policy suggests that close informal contact could well arise between the MOD and the particular company in question, and evidence for this situation exists.[91] Under this system it is highly likely that once these informal contacts were established, there would be a strong tendancy for further contracts to be awarded to the same firm on a preferential basis. Although there is no direct evidence of this, it is interesting to note that data showing the percentage of the total number of Research Contracts awarded to the principal semiconductor manufacturers between 1965 and 1978 reveals the dominance of the same few large companies during that time.[92]

Under the above arrangement, it would be extremely difficult for any new company to enter semiconductor production, given the prevailing market conditions, since existing companies were only able to stay in business through Government work. The most likely way of doing so would have been to attempt the same strategy as INMOS, and aim at a narrow, technically advanced market. It is not surprising that, under these conditions, given the shortage of both capital investment funds and skilled semiconductor personnel, start-up companies failed to emerge.

From the early 80s onwards, the MOD, under the new Defence Secretary Michael Heseltine, moved strongly towards a policy of purchasing by competitive tender. The practice of automatically awarding production orders to firms already in receipt of development contracts was to cease. One important aspect of the new approach involved moving away from "cost plus" contracts (which virtually guaranteed steady profits) towards fixed price contracts. Under the previous system, little incentive had existed for companies to increase the efficiency of their operations, and it was felt that the new scheme would not only do this, but also assist their competitive edge within the marketplace. This change increased the element of risk to participating firms, but also offered the opportunity for increased profits. Evidence exists that this move was regarded with disfavour and even consternation by participating contractors.[93] Consequently, the take-up rate of fixed price contracts was low following their introduction.[94] Far from stimulating the industry to move more strongly into the commercial field, this policy reinforced the already existing trend of withdrawl from semiconductor manufacture.

The degree of success achieved by this policy may be gauged by the fact that in the period 1982-3, only 20% of MOD contracts were subject to competitive tender, although, as the Defence Secretary pointed out, there was now much more competition amongst sub-contractors. The proposed separation of Development and Production contracts at that time was certainly not popular with industry, and drew the following comment from Donald Rowley of the Electronic Engineering Association "I cannot imagine a more dangerous policy for the defence and economy of this country if adopted for complex engineering projects".[95]

A factor possibly affecting industrial performance was the dissemination of advanced technical data by Government Research Establishments. This may have led to unfortunate, although no doubt unintended consequences. Publication of non-classified Government research carried out within the United Kingdom was generally made available on a World-wide basis, and was in no way confined to indigenous firms. Since this work was of a highly technically advanced nature, it may well have been of more assistance to overseas commercial rivals operating at the leading edge of technology. An even more disadvantageous situation existed whereby under British-American defence agreements, several instances occurred where American semiconductor research personnel obtained more immediate access to CVD reports than their British counterparts.[96]

A widely recognised characteristic of British electronics industry, has been the relative lack of personnel mobility between individual firms, when compared with America. What is perhaps less well known is that contacts between MOD personnel and their counterparts in industry were, at least until about 1970, even more rare. A House of Commons Select Committee Report, published in March 1969, stated that there were no cases of officers being seconded to industrial firms for a period, the nearest situation being the employment of certain officers for two or three years within an engineering firm "engaged on the whole business of inspection of military equipment", thereby obtaining an insight into "the way industry works and handles its problems".[97] Nor were industrial personnel being seconded from industry for a limited period to work within MOD establishments.[98]

The above situation was certainly one of long standing. For example, a NEDO report, written in 1983, spoke of hostility towards moving personnel within contracting companies between defence and civil fields, and stated that a large and widening culture gap between civil and defence oriented companies existed, even within the same group.[99] However, visits by individuals between firms and Government establishments were stated to be fairly frequent, resulting in close contact at various levels.

A significant barrier to Government Research and Development spillover into industry was that RSRE imposed a two-year embargo on scientific personnel who wished to join a private company, in order to work in the same area of research. Individuals did however occasionally leave the establishment to work within the United States, thereby placing British industry at a disadvantage in terms of diffusion of knowledge. Perhaps to a somewhat lesser extent, the Establishment benefitted from exchange of personnel with American research institutions. Finally, a further and important disincentive to leaving Government employment was the loss of a Civil List Pension.[100]

Government Funding: A Conflict of Aims?

State funding of the semiconductor industry has always been on a departmental basis, rather than part of a co-ordinated plan. It is understandable, therefore, that different departments, with differing priorities, should place a varying emphasis upon how the money was spent. Superimpose upon this situation frequent changes in Government policy, and it is not surprising that industrial management exhibited a degree of cautious scepticism. What is particularly important is that the basic structure of industrial funding was set up by the MOD, and was already in operation well before the DTI became involved. This structure set a pattern which was to involve an increasing dependence upon CVD contracts, and a corresponding reluctance to compete in commercial markets.

An important aspect of this lack of co-ordination, is what appears to be the contradictory role played by the MOD and the DTI during the early years of DTI involvement. The primary aim of the MOD was always to ensure that a reliable supply of components of the right type were available for the construction of military equipment. This aim might be achieved by procurement through indigenous suppliers, or buying from overseas. British semiconductor firms are few in number, and their manufacturing operations relatively small compared with either their Japanese or American counterparts. Any decision reached by firms to supply devices primarily for the MOD, would result in research and development effort being directed primarily to this end. This can hardly have failed to have been the case since for at least the first two decades of device manufacture, between 40% and 50% of total research and development funding within the industry came from the MOD.[101]

Operating in an increasingly competitive situation, it was an attractive policy for British firms to concentrate on manufacturing specialised devices for Government use. However, the resulting penalty was increased difficulty in gaining access to rapidly developing commercial markets, since the non-military spin-off was limited. Also, the activities of foreign suppliers were assisted by the MOD. (For example, during the late 60s, Texas Instruments (Bedford) were receiving 60% Government funding for integrated circuit development, compared with a sponsored element of only 18% allocated to Ferranti)[102] This was in order to make up the shortfall of advanced silicon components, needed to construct and maintain service equipments. The resulting strengthened competition, offered by British-based foreign companies, further compounded the problems of British firms, when attempting to operate within the commercial sector. The overall effect of Government funding during the formative years of the industry was therefore to weaken the ability of British firms to compete.

This was the existing situation at the time when the DTI began substantial funding, with the aim of building a viable microelectronics industry, able to compete successfully within rapidly growing commercial markets. The problem faced by the DTI was therefore not only one of financial assistance, but of obtaining a radical change in strategy from firms previously geared to an entirely different set of priorities. This change, although conflicting with that of MOD objectives, had nevertheless to be implemented in such a way that it would not override MOD requirements.

This conflict of priorities did not arise within, for example, the American Semiconductor industry, where commercial integrated circuit requirements were met directly by fall-out from the extensive military programme. Commercial success was assured by a combination of rapidly falling unit costs, together with a substantial technical lead. Discussing the part played by military funding of integrated circuits within the United States, Noyce points out the two-fold nature of this assistance. Firstly, that although the new technology was developed mainly through company sponsored research, it did receive a measure of direct subsidy. This subsidy was in fact considerable.For example, between 1967 and 1969 Texas Instruments alone received $229 million in American Government support, amounting to 60% of its total R&D effort.[103]

Noyce describes the military agencies interest as "not only in using integrated circuits but also providing the market and motivation for suppliers to complete the development and establish production capability to supply this waiting market".[104] This situation was in direct contrast to that in Britain, where the vital area of production technology has been consistently neglected. One reason for this was that because of short production runs to supply military needs, it was not possible to develop sufficient expertise in mass-production techniques. State procurement within the United States had, for military reasons, been primarily aimed at silicon technology. Familiarity with this material assisted the rapid move into integrated circuitry, which found a ready commercial market, as unit costs fell with increasing production.

Within Britain, in direct contrast, the major effort made by the MOD was largely directed towards more esoteric projects, connected, for example, with infra-red technology, group III-IV compounds, and cryogenics, all with extremely limited commercial application. (This policy was of course in line with the early assumption that the British semiconductor industry was able to compete successfully in the manufacture of commercial devices without Government assistance). This matter only began to receive attention within Government circles during the late 60s. Golding remarks that following 1968, CVD began to play a more active role in promoting commercial spillover, but points out that this action was "to some extent counterbalanced by the R&D levy which applies to any commercial benefit derived from Government financed development of devices and techniques". In this context, he quotes a House of Commons Estimates Committee in which British semiconductor manufacturers claimed that the existence of this levy placed them at a significant cost disadvantage compared with their American rivals.[105]

Up to at least the mid-sixties, Treasury policy was to avoid investment of public money in projects which would primarily be of value to the commercial market. For example, the Head of Field Experiments, Atomic Weapons Research Establishment, stated in 1963 that "unfortunately the Treasury does not support the principle of "priming the pump" of commercial enterprise". and also that the Treasury considered it "a wrong practice to put money into projects that could also have a considerable commercial potential".[106] He also pointed out that "this hidden form of subsidy was frequently the reason why a British firm was at a disadvantage in the competitive field". Conversations with leading industrialists and senior Government research staff strongly confirm this view.

Any attempt to rival the American challenge by military funding would have been out of the question, taking into account relative economic strengths, the existing technical lag, and the availability of resources within the United Kingdom. An imitative military strategy would have suffered from the disadvantage that civilian fall-out from such a programme would have been strictly limited. As Dosi points out, "imitators always find new devices already diffused from the military to the civilian sector in the leading country".[107] Should a policy of imitation be pursued in the absence of trade barriers, the most technically advanced devices would already be available for import to local equipment manufacturers. These devices would be available in quantity at prices perhaps well below manufacturing cost within the importing country, effectively destroying the home industry. This situation did indeed arise in Britain with, for example, the importation of TTL logic gates in the early 70s.

In the absence a policy involving selective but effective import controls, it is likely that the only available strategy which could be pursued with any degree of success, was that actually adopted by British semiconductor manufacturers. This involved producing specialised devices for military contracts, with the resulting penalty of limited commercial and industrial spin-off. Any attempt at "creaming" specialised markets through military contract work had only limited success, largely because of the long lead times involved.

Far from any commercial spin-off, the result of research activities within Government establishments led (although no doubt unintentionally) to the restriction of commercial effort. This was because the work was targeted specifically at specialised materials and devices with little commercial application, and also because funding of commercial semiconductor research and development by the MOD formed such a large percentage of the total amount spent. (For example, in 1968, research and development within the Plessey Electronics Group was funded as follows: 50% by Government, 25% by private venture capital, and 25% by contract work for British and foreign companies[108]. It has been estimated that total expenditure upon semiconductor Research and Development in Britain for that year was as follows: Government Laboratories $4.1 million. Government financed industrial research $3.5 million. Company financed, $6.4 million. The latter figure would include private funding of projects by customers).[109] By at least the early eighties, it was recognised in Government circles that under these conditions, the most effective spin-off which could occur was through defence sales.[110]

Changes in Government policy towards the Research Establishments, made during the 80s, were framed with the stated intention of assisting manufacturers to move more strongly into the commercial and industrial sector. This proved impossible for the British semiconductor industry, locked in as it was to the small-scale production of linear circuitry for military requirements. Coupled with an increasingly tight fiscal policy, there could be no question of significant growth. In this environment, the belated attempt to alter the long-standing structural relationship between Government Research Establishments and industry, failed to succeed in stimulating industrial performance.

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Chapter 5

Government Involvement within Non-Industrial Semiconductor Research

Introduction

The microelectronics industry in Britain has been assisted not only by direct Government aid to manufacturers, but also indirectly through its Research Departments, and other agencies. This chapter complements chapter 4, by considering the latter case. It describes how industrial aid was organised and implemented through the procurement policies of the Ministry of Defence. This outline is followed by a review of the relevant work carried out by the major Government Research Establishments, and also that resulting from Post Office activities and government-assisted university research. The views of both the Research Establishments and industry towards government policy are then summarised, and the concluding paragraph draws general conclusions from the data presented in both chapters 4 and 5.

The Role of the Ministry of Defence

Military sponsorship in the electronic components field began in 1938 when the Inter-Services Committee for the Co-ordination of Valve Developments (CVD) was set up by the Royal Naval Scientific Service in order to co-ordinate the development of thermionic valves for military equipment. The Committee was also responsible for procuring a satisfactory supply of electronic components for all three armed services and civil aviation. This objective could be achieved either by procuring components from suppliers within the United Kingdom or elsewhere. The Royal Navy was then the principal user of thermionic valves, and it seemed to be a logical step at the time to place these responsibilities under the Admiralty.

Although the Ministry of Supply became the principal purchaser of valves during the War, CVD, based at the Admiralty, continued to be responsible for valve procurement, through the Inter-Services Technical Valve Committee. However, in 1940, a reorganisation resulted in the Ministry of Aviation, through the Radio Components Research and Development Committee, (RCRDC), being made responsible for placing development contracts for passive components and materials. These committees functioned through a controlling committee, and a number of specialist sub-committees. The function of these specialist sub-committees, together with associated research advisory panels, was to administer research contracts. These research advisory panels appear to have been almost entirely composed of government scientists who were experts within their particular field.

The basic CVD structure remained essentially the same during the 50s and 60s, but the emphasis changed from co-ordinating government research towards a more active role in determining its direction.[1] In 1972, the title was changed to Directorate: Components, Valves and Devices (CVD) tardily reflecting current technical developments. Government funding of the semiconductor industry took place almost entirely through CVD until as late as 1976.[2]

Operations by CVD within the United Kingdom have consisted of carrying out research through government establishments in co-operation with industry, in order to develop devices principally for use by the Armed Forces. Contracts were awarded to selected firms in order to manufacture an agreed quantity of devices. It has not at any time been the function of government research institutions to set up production lines for manufacturing purposes. Instead, funding has been made available to support the Government Research Establishments, and also to award grants to selected firms to carry out research and development on specified projects. The policy has been to award industrial contractors (i.e. semiconductor manufacturers) General Valve Development (GVD) contracts, permitting them to spend an agreed annual sum without further authorisation by the Treasury.

For at least the first two decades of transistor manufacture, Government Research Establishments were entirely confined to the role outlined above, and did not consider the need to promote commercial spin-off from their activities as being part of their function. Sir S. Zuckerman, Chief Scientific Adviser to the Government, summed up this situation in 1969 with the following comment: "If the results of Defence R&D can be exploited for commercial ends, including exports, the economy benefits; but this is a secondary objective of this kind of work"[3].

Despite a cutback in funds during the early 70s, which led to concern on the part of semiconductor industry executives, the total CVD budget for 1979, amounting to approximately £20 million, was approximately the same in terms of purchasing power as ten years previously.[4] This suggests that a fairly stable situation existed during at least this period regarding the CVD funding of industrial contracts. Consistent long-term funding of this nature could well induce a feeling of complacency in the recipients, with little incentive to seek alternative sources of profit within the commercial field.

From the early eighties onwards, increasing emphasis was placed by government on the need for commercial spin-off from MOD research activities. The MOD took the view that this was principally a problem for industry, rather than the Research Establishments and that successful spin-off was "market led" rather than "technology driven".[5] The Department also argued that since over 80% of Defence R&D expenditure went on product development programmes within industry, and because it was normal practice to vest the intellectual property rights of the technology in question with the firm concerned, then private industry was already in possession of the technology arising from these programmes. It therefore followed that lack of spin-off was primarily due to the inability or unwillingness of industry to exploit defence technology.[6]

MOD Procurement: The Organisational Framework

The organisation of MOD project work, and the manner in which this activity involved industrial contracting, had a profound effect upon the efficiency of industrial research activities and their general direction.

Industrial contracting by the MOD was organised as follows. The Establishments co-operated with the private sector by inviting Research Proposals (RP's) to be submitted to CVD by individual firms. These proposals might amount to supporting the continuation of co-operation on some particular project, or could involve an entirely new field. They could be initiated by the firm concerned, or by the Research Establishment itself. Research Proposals, if accepted, resulted in CVD sponsorship of development projects. CVD financial support under this system was dependent upon the satisfactory progress of a particular project, and usually reviewed on a yearly basis.

Development projects (known as VXs) usually consisted of two stages. Firstly, a feasibility study, to determine whether it was possible to meet the required military service specifications, and secondly, to demonstrate the ability to make these devices at an acceptable quality level. Success at this later stage usually led to the firm being granted a certificate by CVD entitling them to manufacture the device under government contract. However, there was no guarantee that an order would be placed at any time to purchase these devices, since this decision rested with a different department within the Procurement Executive.[7] Consequently, a degree of uncertainty was introduced into the whole operation.

Unlike the situation within the United States, no funds were usually made available for production development, as this was considered to be the responsibility of the firms concerned, who were expected to re-coup their expenses from profits made by device sales. Since production runs involving government procurement contracts tended to be short, unit costs remained high, ensuring that devices supplied under these contracts were correspondingly expensive. These costs reflected in turn in higher equipment values, leading to a disadvantage in export markets.

Procurement policy during the early years of semiconductor manufacture was of vital importance in shaping the future course of the industry. Faced with an initial technical lag within the United Kingdom, and limited research and development effort in silicon technology, there appears to have been little prospect of obtaining adequate supplies of components of the required type from British semiconductor firms, despite MOD contracts being negotiated at an early stage. A vitally important decision was therefore taken to procure supplies of silicon devices as rapidly as possible, by encouraging the most technically advanced firm in the field to construct and market these components within Britain. Reviewing this situation, Malerba states "public procurement followed a policy of low risk purchasing involving the purchase of established components which had already been successfully launched in the United States".[8]

Government purchasing policy was outlined in the 1967 White Paper entitled "Public Purchasing and Industrial Efficiency". This was stated as being to obtain "what is needed, at the right time, and in such a way as to secure the best value for money". This policy was restated in 1983 as being that of "buying British defence equipment unless a foreign product offers substantial advantages of time scale, cost or performance".[9] Evidence suggests that at least in the case of the MOD, this procedure was implemented with regard to suppliers.[10] Within the narrow constraints of MOD requirements, it was no doubt a sound and effective approach, although as later events were to show, this purchasing policy was to have dire consequences for the future of the British semiconductor industry. What is evident is the compartmentalised, ad hoc nature of this governmental decision, in the absence of an overall, long-term industrial strategy.

It is notable that at least as early as 1959 , development contracts were awarded to both Standard Telephones and Cables (STC) and Mullard, the one an American, the other a Dutch controlled company.[11] Right from the beginning, therefore, Government encouragement and assistance was being given to foreign companies, from politically friendly countries, manufacturing within the United Kingdom. The sole criterion for placing orders appears to be have been that they were capable of producing sufficient quantities of electronic components of the type required, in order to meet equipment needs.

MOD Procurement: The Strategy

A basic object of MOD policy was to acquire a reliable and adequate source of components for military equipments, and this led the CVD to assist industry in research and development activities. At least until the late 60s, it was not the Department's practice to use this assistance as a commercial springboard, although it was not unsympathetic to this occurring. An indication of the prevailing attitude towards industrial spin-off, was that a Research and Development levy was placed upon any commercial benefit derived from MOD funded activities. This levy was not fixed, but open to negotiation, and was criticised by industrialists on the grounds that it placed them at a disadvantage when compared with American competitors.[12]

Apart from any considerations of technical lag, the temptation to procure devices from the United States was considerable, since due to military pump-priming, American manufacturers were able to supply technically advanced components at extremely low prices.

Consequently, large orders were placed in America by the late 50s for devices which were in short supply, such as silicon grown junction transistors. Furthermore, encouragement was given to foreign suppliers to locate their manufacturing operations within the United Kingdom. Under these circumstances the obvious course, and indeed that soon to be pursued by British semiconductor firms, was to manufacture highly specialised devices outside mainstream production which could be sold to the Government at premium prices. The result of Government procurement policy, during at least the first two decades of manufacture, was therefore effectively to steer the indigenous industry towards the production of devices which had limited commercial application.

MOD interest in semiconductor research had begun at an early stage. The reason for this, was that problems had arisen as a result of attempts to microminiaturise thermionic valves for use in military equipment. This led CVD to fund investigations into alternative means of producing reliable electronic alternatives. Like their counterparts in the United States Department of Defence, MOD Research Establishment personnel were certainly quick to realise the significance of the transistor, and already by 1952 semiconductor materials and solid-state physics were major subjects of investigation. (For example, the need for a more reliable electronic switch in guided weapon systems resulted in Treasury support for a Ferranti team to participate in the Bell Technical Symposium held in April 1952, and also to fund the licence fee from Western Electric, which was necessary for that company to manufacture transistors commercially). Government assistance through MOD, at least in Ferranti's case, was certainly important in initiating work in this area, it being problematical whether the company would have been able to afford such a venture using internal resources.[13]

Towards the end of the 70s the DoI began to consider supporting research projects of major importance to the civil sector, but possessing a significant defence electronics content, providing that they could not be assisted by the MOD due to lack of funds. The company concerned would usually be expected to contribute to the funding, although in exceptional cases where the work has wide civil value, and also did not directly benefit the company, up to 100% support might be considered.[14] In addition, further funding from the DoI was possible on projects where MOD assistance could no longer be justified. An example of this would be where it was desired to modify components, in order to make them more suitable for export markets. Alternatively, subsidies might be given in order to pursue production engineering activities no longer required by the MOD.[15] Due to increasing DoI financial support, and the influence of the Research Requirements Boards, a shift in emphasis took place from the beginning of the 80s in the direction of more industrially oriented R&D, particularly in the microelectronics field.

Government R&D Establishments

The leading Government Research and Development Establishment involved in semiconductor work has been the Royal Signals and Radar Establishment (RSRE), based at Malvern, Worcestershire. This establishment was formed in 1975 by the amalgamation of the Royal Radar Establishment (RRE), Malvern, with the Services Electronics Research Laboratory (SERL), based at Baldock, Herts. and the Signals Research and Development Establishment (SRDE), at Christchurch, Dorset. RRE had itself been formed in 1952 by the amalgamation of the Radar Research and Development Establishment, mainly working for the Army, and the Telecommunications Research Establishment, supporting the Royal Air Force. RSRE became the principal centre for all aspects of electronics, computing and physics research. Its policy, according to its Director, was to concentrate on "speculative research which industry at the present time at any rate would feel it could not attempt to do".[16]

Like other Government Establishments, RSRE underwent substantial re-organisation and redefinition of objectives, reflecting changes in government administration and policy. Previously to coming under the Ministry of Aviation in 1959, RRE was part of the Ministry of Supply. In 1967 it became a Ministry of Technology establishment, changing to the Ministry of Aviation Supply in 1969. Following further Government reorganisation, it was placed under the Ministry of Defence in 1971. As RSRE, it came under the Department of Trade and Industry in 1980, this move reflecting its newly perceived industrial role. Finally, in 1990, It became part of the Defence Research Agency, emphasising still further its commercial outlook. In April 1992 the Electronics Division was split into ten "business sectors" two of which are largely based in Malvern. At the same time further staff redundancies resulted in a 50% cut in support staff on a nationwide basis.[17]

In 1965, RRE had been described as " a Ministry of Aviation research establishment with broad responsibilities for the application of electronics to equipment for the three fighting services and for civil aviation".[18] More specifically, RRE was engaged in "the conception of military and civil systems"[19] and, in addition to "fundamental work in the study of physics of materials and techniques which may be expected to be expected to be applied to electronics",[20] its remit extending to "such further work as is necessary to demonstrate that a new technique has a worthwhile potential capability".[21]

RRE comprised two main technical departments, these being (a) the Physics and Electronics Department, sub-divided into a Physics Group, mainly concerned with solid-state research, and an Electronics Group, acting as a link between basic research being carried out within the Physics Group and (b) the Military and Civil Systems Department, also divided into a number of groups, the largest being Applied Physics and Technical Services. The function of this latter Group involved the development of components and equipments and their packaging, and also their environmental testing.

Until its amalgamation in 1975, SERL did not engage in formal collaboration with RRE either at the working or management level, although co-ordination of programmes did occur. As part of CVD, they were engaged in the field of electron physics, and during the 70s were experts in the construction of electronic devices such as Klystrons and Magnetrons. Work was also being carried out in the solid-state field, including solid-state lasers and on Gallium Arsenide (GaAs), where in the latter area at least, practical liaison with RRE was close.[22]

The amalgamation of research establishments resulting in the formation of RSRE was carried out to reduce costs, and avoid duplication of effort. The complete rationalisation of the various Service establishments was, however, never fully implemented.

Other Research Establishments involved in semiconductor activities from 1959 onwards included the Royal Aircraft Establishment, Farnborough, the Atomic Weapons Research Establishment, Aldermaston, the Radio Research Station, Slough, the Atomic Weapons Research Establishment, Harwell, and the Post Office Research Station, Dollis Hill, London.[23] It appears, therefore, that although a centralised approach was adopted in concentrating research at Malvern, widespread awareness and interest in semiconductor technology existed at an early stage amongst Government research personnel.

Technological Innovation: Devices and Materials

From the earliest days of device production, the MOD showed an interest in various microelectronic circuit techniques, and concentrated its attention on work in this field, rather than assisting discrete device development. With the advent of the silicon integrated circuit, it was decided not actively to pursue this work, but to encourage industry to acquire experience in the basic processes needed in making silicon integrated circuits, and to establish techniques which could be utilised subsequently in developing specific circuits for equipment projects. It is evident that this approach aimed specifically at satisfying MOD requirements, and did not refer to the possibility of commercial spin-off.

Prior to 1961, CVD had initiated a small programme to produce specialised germanium transistors and diodes, together with thin-film microcircuitry. Major support for microcircuit research and development in industry began in 1961, and the total sum invested by CVD on a yearly basis in terms of research specific to integrated circuits was as follows.[24]

Year:	61/62	62/63	63/64	64/65	65/66	66/67	67/68	*TOTAL*
£x1000:	94	126	82	63	101	137	116	719k

Research and Development on general silicon technology (relevant to IC's and discrete devices) amounted to the following:-

Year:	59/60	60/61	61/62	62/63	63/64	64/65	65/66	66/67	67/68
£x1000:	7	8	25	12	25	65	124	149	85

TOTAL = 500k

In addition to the above, a further £444k was allocated to firms as CVD support under various VX development projects, bringing the total financial support for microcircuit research and development during the ten year period above to £1.633 million.[25]

The aim of the 1961 programme was to encourage firms to undertake a feasibility study, involving the production of a digital integrator in integrated circuit form. However, the requirement ceased to exist before the study could be completed. Nevertheless, reports produced by the six firms involved enabled the Working Party concerned to conclude that Ferranti and Plessey were the most technically advanced within this field.[26] It is therefore significant that when CVD initiated their first two major projects, they chose these firms [specifically, the Ferranti Micronor I, and a Plessey project involving two integrated circuits for intermediate frequency (IF) amplifiers.]

In 1962/3 CVD provisionally allocated £250,000 to be spent during the following year upon circuit development for specific equipments. Although considerable discussion took place within the Research Establishments, no firm recommendations were made and CVD transferred the money to other projects.[27] At the end of 1963, initial research studies were abandoned, and it was decided that CVD would only support integrated circuit research in response to formal requests from user establishments. Until at least 1968, these requests were minimal, and CVD funding during these years was largely restricted to investigating new techniques.

It is evident from the above figures that CVD support during the formative years of microcircuit manufacture was on a relatively small scale. Furthermore, this money was allocated to quite a large number of projects, covering a fairly wide field. These included work on specialised photocells and microwave devices, used largely in military applications, and with little mass production potential. The main firms involved in the above projects were Ferranti, GEC, Mullard (ASM), Plessey, Texas, and Standard Telephones and Cables (STC). In addition to these companies, Elliott (Microelectronics) and Marconi received a small amount of CVD support.

Comparison between the commencement of research projects initiated within Government Research Establishments and the corresponding successful innovation within the United States during the early 60s indicate a time lag of perhaps one or two years. RRE were certainly aware of and quick to act in response to technical developments in the United States. This is illustrated by the following table[28] indicating the time lag between initial commercial production of various devices and innovations and the date of their commencement at RRE, or alternatively when procured by MOD.

Innovation within the US	Initiation of Research Project by RRE or device procurement by MOD
Thin Films (Tantalum) (1959)	Jan. 1960 (RRE)
Thermocompression Bonding (Mid. Fifties)	End of 1960 (although 1956 at GEC Hirst Labs.)
Planar Transistor (Fairchild 1960)	Planar facility set up 1961 at RRE, although original concept took place here 1952 (G.W.A. Dummer)
Epitaxial Material (Bell Labs. 1960)	Material first received 1962 at RRE
Silicon Junction Transistor (TI, Dallas, 1954)	TI (Bedford) set up with UK Government assistance to produce Si. Junction devices for military (1957)
TTL IC's in limited production, TI (Dallas) (1962)	TI (Bedford) 11 months later, on UK Government contract
MOS (Fairchild, & GE) (1962)	Work commenced 1964/5 at RRE

G.W.A. Dummer, writing in 1965, describes work being carried out at RRE on a variety of microelectronics projects with an emphasis on thin film technology, and in addition sponsoring a number of development contracts.[29] These included sealed microminiature transistor and diode development, carried out by Mullard Ltd., together with a thin film development contract awarded to the same firm. Following the early work in silicon integrated circuitry with Plessey, a team was set up at RRE in Feb. 1960 to study semiconductor integrated circuit techniques. Contracts to study these techniques were also awarded to TI and STC. CVD were also supporting Ferranti at this time in the development of silicon mesa devices.[30]

It has been suggested that no viable programme existed in silicon at RRE because a role could not be defined.[31] Some work was carried out on support technology, but little real core work on circuit fabrication (which would have involved considerable financial outlay). Although the military perceived the importance of silicon integrated circuit technology at an early stage, priorities in other areas were considered to be greater at the time. This was because of its commercial significance, and the fact that supplies of advanced devices were available to satisfy existing needs. Other long research programmes, dating from the early 60s, were the fabrication of indium-antimonide and cadmium-mercury-telluride infra-red detectors. These programmes involved considerable collaboration with industry.

The resumption of work on silicon at RSRE in the early 70s was certainly beneficial to the industry, and a good working relationship appeared to have existed between them and the major semiconductor companies. Research of an advanced nature into other materials also yielded dividends. For example, help from RRE, together with MOD funding, greatly assisted Plessey in becoming world leaders in GaAs technology during the late 60s and early 70s, although the devices produced as a result (GaAs FET's) were too advanced for the existing market. However, such successes were on a relatively small scale, and did nothing to stimulate mass markets.

Fundamental work at RSRE on military electronic devices was hampered by a severe shortage of funds.[32] This problem became progressively greater as the cost of setting up fabrication plant escalated, due to increasing device complexity. Dr. W.Fawcett, head of the Physics Group at RSRE, stated in 1982 that their facility for making integrated circuits was very poor in comparison with industrial facilities, and for this reason any initiative in the military field should be linked to industrial schemes.[33]

SERL began to investigate silicon semiconductor technology in the early 50s. This work was however phased out in favour of germanium and group III-IV compounds by the middle of that decade. Work ceased on silicon because of the urgent need to produce a highly reliable pulsed neutron source for field use, which was to be used as the initiator for a nuclear weapon. A GaAs programme commenced in 1952, with the initial aim of producing a GaAs P-N junction transistor, and at the same time to carry out fundamental research into that material. This developed into a lengthy GaAs programme, which evolved as follows:[34]

	Research *Year*	**Development** *Year*
Varactor diodes.	1958	1969
Lasers.	1962	1969
Gunn dodes.	1963	1967
Low noise FETs.	1970	1976
IMPATT devices	1974	1977
Power FETs.	1976	1976
ICs.	1980	-

In addition to the above, work was carried out on a number of other projects, including photocathodes and image intensifiers. Collaborative work on epitaxial growth of GaAs began in about 1973 and was still in progress over a decade later.[35]

Baldock became the main European centre for GaAs semiconductor devices, and work continued on this compound because so much of the material physics was yielding interesting phenomena.[36] It was stated in 1983 that this project was kept going because of its potential use in IC fabrication. Major work on Gunn effect was done at RSRE at Malvern, although IBM obtained the patents some time after Gunn's departure to the United States. Commercial devices then soon went into production. Baldock were successful in being the first to develop Gallium Phosphide (GaP) light emitting diodes (LEDs).[37]

The Post Office

Apart from the Ministry of Defence Establishments, the most important public sector research and development facilities were owned by the Post Office. Under an Act of Parliament passed in 1969, the DoI held sponsorship responsibilities for the Post Office and its private suppliers. However, since telecommunications investment was part of the public sector borrowing requirement, approval had to be sought from the Treasury before any investment in this area could be made.[38] Perhaps inevitably, "the DoI not infrequently found itself in conflict with the Treasury over the scale of funding necessary for the development of the telecommunications network".[39]

Post office interest in semiconductor manufacture was stimulated by the requirements of their telecommunications activities. An important aspect of this work was the procurement of high reliability amplifying devices and switchgear. Although the Post Office bought devices on the commercial market, it safeguarded its activities by carrying out in-house manufacture.

Previously to producing transistors, the Research Centre at Dollis Hill had been engaged in the development and manufacture of high reliability thermionic valves. Work on semiconductors began at Dollis Hill during the 50s. The original material chosen was germanium, but interest quickly moved to silicon. Production of high-reliability silicon devices increased, and by 1975 had reached about 2-3 million units per year.[40] These were supplied to Standard Telephones and Cables, largely for use in submarine systems. Integrated circuit production at Dollis Hill was only in the nature of a demonstration of the possibility of manufacture.

When the Establishment moved to Martlesham (Suffolk) in 1976, there were about 1000 staff. Although the number increased appreciably after this time, device activity was run down, as interest shifted increasingly towards software and systems. By 1980, the Post Office was spending £5 million per annum on semiconductor research at Martlesham.[41] Following the establishment of British Telecom. in 1981, limited experimental work began the following year on high-speed CMOS devices, as part of the ALVEY and ESPRIT programmes.[42]

University Involvement in Government Research

The history of government sponsorship of university research in semiconductor technology has been one of continuing and growing co-operation, and has followed on from the highly successful work carried out in the field of valve technology during World War II. In 1963 there were about 700 postgraduates and staff within British Universities working in radio and electronics. This number formed a very significant fraction of the total electronics research effort in Britain at the time, which amounted to an estimated 2460 graduates. This latter figure included both industry and Government Research Establishments, including 1150 personnel employed in research and development within the Ministry of Aviation.[43]

Following experimental work in thin-film technology at RRE from 1958 onwards, a number of institutions rapidly became involved in government contract work within this field. These included the Universities of Strathclyde, Manchester, Birmingham, Southampton and Imperial College, London. In addition Cambridge, Manchester and Imperial College carried out research in electron beam technology, including selective etching and micromachining.[44] The wide extent of this work testifies to the importance which was then being attached by the MOD to the development of thin-film integrated circuitry.

The first University to set up a fabrication plant for a whole production line was Southampton, although Edinburgh also started solid-state work at the same time. A silicon device fabrication plant was set up at Edinburgh during the late 1970s under Dr. J. Robertson, and by the early 1980s, MOS and CMOS devices were being processed.[45] Work began under an SERC grant at Southampton in 1966, links then being established with Mullard (Southampton) and the Admiralty Surface Weapons Establishment (ASWE). Since then, other firms and Government Research Establishments have become involved. From the start, interest has been almost entirely confined to silicon. Bipolar IC's were first produced in the early 70s, and by the middle of the decade MOS devices were being manufactured. The increasing cost of device manufacture (i.e. clean rooms, equipment, etc.) has been met to some extent by Government and industry, including the abovementioned firms. From 1978 onwards, the Southampton facility has received an SCRC rolling grant to finance its work. Currently (1992), about 50 personnel are engaged in solid-state activity, the stated aims of the Department being to train semiconductor engineers and to advance the technology.[46]

Already by the end of the 70s widespread contacts existed between MOD Research Establishments and the universities. An example of highly successful co-operation was the work which led to the invention and subsequent development of the first stable liquid crystals suitable for devices, which was carried out jointly by RSRE, Hull University, and BDH Chemicals. The manufacture of these materials was then licenced to BDH.[47] By 1980, at least sixteen universities were engaged in MOD funded projects involving semiconductor materials or devices. Topics ranged from pure research, such as that being carried out at Cambridge on "Theoretical work on deep traps in semiconductors", to work of a more applied nature, for instance that being done at Birmingham on "Electrodeposited Heat Sinks for High Power Microwave Devices".[48]

Other work being carried out during the period under review included research into crystal defects in silicon under Prof. R. Newton at Reading University, in conjunction with AEI, and at Bradford under Prof. Symmonds. From 1971 onwards, work on silicon involving diffusion and epitaxy commenced at Liverpool University under Prof. Eccleston, in co-operation with Plessey. Studies into crystal defects in silicon were also carried out at Bradford University during the early 1980s under Dr. M. Morant in collaboration with GEC and Plessey under the ALVEY programme.[49]

Following the election of a Conservative government in 1979, a marked shift in policy towards university research took place. A Government Select Committee report published in 1983 stated that "universities should accept some of the discipline of market oriented work in order to achieve contract income"[50] and favoured exchanges of staff between universities and industry. Co-operation with the universities was strengthened under the ALVEY programme, a government sponsored five-year basic research programme launched within that year.[51] It included financial support for very large-scale integration and computer aided design, with assistance to both industrial and academic research institutions. The original academic contribution to the programme was fixed at £50 million but eventually rose to £70 million. Taking the overhead contribution into account, the total percentage of ALVEY participation associated with the universities amounted to 27%, a considerable proportion of the total effort.[52]

Co-operation between Government research establishments and the universities has been inhibited by a number of factors, and the most important of these appear to be as follows:-

- The necessarily secretive nature of much of the work being carried out in the research establishments. A conflict may therefore exist between security requirements, and the essentially open nature of academic research.

- The relatively rapid turnover in postgraduate research workers within the universities. Many microelectronics research projects are of a long-term nature, and the problem of continuity therefore arises.
- Problems involving the supervision of work. The physical distance often existing between the research establishments and universities cannot fail to cause difficulties in this respect. Research programmes of this type are of course initiated and supervised by senior establishment personnel, who are often accorded professorial status. Supervision of these projects would most likely be only part of the supervisors work, which would be mainly located in the research establishment concerned, and therefore subject to day-to-day pressures and priorities.

Government Policy: the Research Establishment View

Conversations with a number of senior Research Establishment personnel suggest that, in general, government policy towards the Research Establishments was to streamline research rather than to rationalise it, this being seen as a less costly option. Despite declarations of intent, and whatever government was in power, promises were never backed up with adequate resources, nor was there an understanding of how to implement stated intentions.

A strong feeling existed that choice of a research topic should rest with the establishment, rather than with the services, the Treasury or MOD administrators, on the grounds that their outlook was too short-term, and inevitably they thought in terms of equipment. Since any success in research is usually the result of years of sustained effort, moves made during the 70s towards outside control had resulted in "a strong element of the accountant's attitude requiring to be convinced of pay-off in a short timescale".[53]

Financial stringency during the 80s had resulted in restrictions in the recruitment of research personnel, and consequently the numbers within research teams may well have fallen below the critical level. Due to this policy, research momentum may well have been lost in certain fields. Low pay on entry had also led to difficulty in recruiting first-class graduates, the situation being exacerbated by a steady deterioration in salaries and terms of service.

It was suggested by senior MOD personnel[54] that a constant difficulty in influencing policy appeared to be that the views of Heads of Research Establishments were filtered through to Ministerial level via administrators with a typical "Oxbridge" Classics background, and with little interest in science. All administrators at First Secretary level and the majority at Second Secretary level have been recruited from this group. Perhaps understandably, administrators did not like scientists using technical language to argue a *case, suggesting that misunderstandings* at this level were highly possible. Little direct contact existed between politicians and the Heads of Research Establishments. What contact did exist was mainly through Parliamentary Select Committees, and occasional visits by Ministers to the Establishments.

Some efforts were made to change this situation, but with only minor success. For example, prior to 1976, the post of Chief Scientific Adviser had been held by Sir Alan Cotterell, supported by a small number of Scientific Officers in the Cabinet Secretariat. This arrangement has been described as having "not worked well, since others had decided what was or what was not "science"; in a classic Whitehall pattern the technical expert found himself largely excluded from mainstream policy making and limited to commenting mainly on technical issues".[55] Upon Cotterell's retirement in 1976, the post of Government Chief Scientist was created, "as an indirect result of the 1971 Rothschild Report on Research and Development."[56] The first appointment to this new post was Prof. John

Ashurst, a biologist from Essex University, who also became a member of the Central Policy Review Staff. In this position he was able to alert the the Callighan Government to the siginificance of microelectronics.

The above criticisms also appear to be borne out both by the Chairman of an ACARD working party,[57] who approvingly quotes a House of Lords Select Committee Report, published in 1982, which stated:-

> *"In a system of government which separates civil servants into generalists and specialists, the paucity of scientists and engineers coming through as potential Permanent Secretaries is a structural weakness ... there has been no progress since 1970 in increasing the proportion of recruits to the Administrative Group with qualifications in science, engineering and mathematics".*[58]

This situation would perhaps explain why it was felt that advice given by Research Establishment personnel appeared to carry less weight than that offered by either industry or academia. Consequently, much of the advice reaching Government came from those who were not in contact with advanced technical thinking, and without the experience of controlling research teams engaged in this type of work.

Recruitment of scientific personnel of sufficient calibre was claimed to have been hampered by restrictions on direct entry into the Establishments at an appropriate level. Evidence suggests that a chronic shortage of first-class scientists existed in the Establishments within the semiconductor field, and financial restrictions were a major reason for this situation. Co-operation with leading research institutions on an international basis, including the exchange of technical staff, was regarded as being extremely important. This policy was however difficult to implement, due to financial restrictions. For example, a scheme involving a fruitful exchange of personnel between RRE and the Massachusetts Institute of Technology was closed down during the 60s by the Service Committees and the Treasury, due to lack of funding.[59]

Although a close relationship existed between Government research establishments and the microelectronics industry, differences (some of a long-standing nature) did arise. One criticism was that although advanced products were made available to industry for development, firms were often reluctant to take up the challange. Getting devices into production was difficult, since someone had to put up cash for this, and a general reluctance existed among firms to do so. An important example of this reluctance was the refusal by Plessey to begin work in the field of integrated circuitry without a MOD defence contract.[60] When interviewed, the Director-General of Establishments, Research and Programmes, A., at the MOD expressed the situation thus; "The only way to get firms to take action was to initiate a military project - in general, firms strongly preferred to deal with research projects initated by the Ministry through cost-plus contracts".[61]

Predictably, opposition existed towards any suggestion that the MOD actually hand over Establishment R&D work to industry. The Defence Procurement Secretary, G. Pattie, commented in 1982 that "although such a policy would give industry a sharper edge, many firms shy away from the cost and the responsibility".[62] However, by this time the need to involve industry more closely in research activities was felt to be evident, and in the same article, the Procurement Secretary also argued for closer partnership with industry.

Consortia, involving RSRE and private firms such as Mullard and GEC, seemed to have worked well. This arrangement involved equal effort on the part of participating organisations, and the relationship between the participants was good. The essential feature was the pooling of research resources and information, allowing the possibility of competing more effectively with large foreign laboratories. University laboratories have also been involved in most consortia, wholly funded by research contracts. Examples of success where this approach was attempted include liquid crystals, infra-red detectors and solid-state microwave devices. Although this plan has worked well in transferring ideas rapidly into the industrial laboratory, it has had much less success in speeding up the manufacturing or marketing processes.

Perhaps the most important criticism of government policy during the period under review was of its short term nature, both in terms of funding and objectives, together with the commercially restrictive guidelines placed upon the Research Establishments. This resulted in an inability to take advantage of commercial openings. An example of this was a project set up under Dr. B. Mullen in the late 60s, requiring the Electronic Materials Unit at RRE to supply Indium Phosphide crystals.[63] Treasury approval was granted, and work began on the project, which ran for two to three years, involving a team of five or six Experimental Officers. Although profitable, and with excellent prospects of expansion, it was decided for financial reasons not to staff the project up to a level which would make it a financially viable production unit, although it continued to be run on a reduced basis.[64]

The chronic lack of funding for solid state device development may partly be explained by the view (expressed by some RSRE staff) that solid state development was not as important as radar, particularly in view of the lack of all-weather capability afforded by infra-red devices. The development of radar during the Second World War had been highly successful, and it has been suggested that senior staff, whose research experience mainly dated from that time, may have been reluctant to concentrate effort outside their specialised field. Also, the relatively greater amount of work done on the development of materials certainly contrasts with the comparative lack of effort in the more costly field of device technology. This fact supports the view that financial restrictions strongly influenced the direction of research within the Establishments.

Government Policy: The Industrial Viewpoint

Industrial attitudes towards government investment policy, and the general relationship between government and industry, are perhaps best gauged from statements made by senior managers, because of their close contact with the relevant Departments. Criticisms of Government centred on two major factors, namely, lack of continuity in policy, and inadequate financial support.[65] The views quoted below appear to be a typical sample of opinion, and largely agree with opinions expressed during interviews with representitives of the major semiconductor companies.

A frequent complaint was that, unlike Japan and France, the United Kingdom did not have a well developed National strategy. This view was expressed by, for example, Dr. Alun Jones, Managing Director of Ferranti Ltd. He also criticised the lack of continuity in policy, stating that:-

> *"we do not have a consensus that , whatever political party is in power, there is a generally accepted strategy of what is good for U.K. business which survives different Governments. This is a terrible handicap."*[66]

Furthermore, Government Departments were slow in seizing opportunities, and financial support was limited. For example, Dr. Alan Shepherd (Manager, Ferranti Electronic Components Division) stated in 1978 that government assistance from the DoI came at a time when the industry was suffering from world-wide recession, and therefore helped to smooth out its worst effects. However, these funds were not adequate.[67] (Ferranti were heavily committed at this time to government contract business, about 40% of their output being accounted for by government procurement, this figure rising to 60% if foreign government work was included).

Support for the above view also came from Dr. Derek Roberts (Managing Director, Plessey Microsystems Division) who observed that Government investment programmes had made:-

"A useful contribution to maintaining and improving the UK's capabilities in the IC business. However, they have not been of sufficient magnitude to actually break out of the limitations of a small marketplace and put in the really massive investment that is necessary for the UK to become a significant operation by World standards."[68]

He also felt that a more formal degree of technical interchange and collaboration between companies and governments within Europe was necessary to offset the advantages of high personnel mobility on the part of engineers which existed in the United States.

GEC did not see its role as a semiconductor manufacturer on the international scale, despite its size. Christopher Turner (Manager, GEC Semiconductors) stated in 1979 that if Government funding under the Microelectronics Support Scheme had not been available, "it is debatable whether the UK semiconductor companies would still be in existence".[69] If anything, this remark suggests a definite lack of committment, at least on the part of GEC, given the scale of their resources, since they received only about £3 million under this scheme.

Ministry of Defence equipment procedures were a subject of criticism, and in particular the practice of constantly changing specifications, which often resulted in considerable delay. It has been suggested that this factor contributed to lengthy delays in the introduction of the CLANSMAN radio system, on which Plessey started work in 1962, although the first sets were not delivered until 1974.[70] In addition to widely criticised delays in the procurement process, which contributed to loss of export orders, F. Chorley (Deputy Managing Director, Plessey Ltd.) felt that the policy of encouraging export sales of defence equipment, through acceptance of export oriented specifications (with the Ministry recovering cash through a levy on export sales) had failed. He added that competition for orders within NATO were prejudiced, because Plessey did not receive the same level of subsidies as foreign competitors.[71]

The Government decision to set up and support INMOS rather than increase funding to existing semiconductor companies predictably came in for criticism. For example, Plessey's Chairman, Sir. J. Clarke was highly critical, and the Company's Technical Director, G.Gaut, claimed that Plessey offered a far more viable alternative for the NEB's money than INMOS. He asserted that it was not only the Plessey Board, but others in the electronics industry who were dismayed by the proposal.[72] Gaut stated that in 1965 Plessey presented a report to Government (entitled "Microelectronics- its impact in the UK Electronics Industry) recommending setting up a microelectronics centre to develop special microcircuits for British industry, at an initial cost of £5 million, over a period of five years. This scheme had the support of technical personnel at RSRE. However, others, including staff at Plessey were dubious about such a venture on the grounds that a market did not then exist. In view of these doubts, expressed within the company perhaps most fitted to play the role of National product champion, it is not surprising that the government decided to support the setting up INMOS rather than invest in existing companies.

Conclusion

The abovementioned views, together with the evidence presented in chapter 4, strongly suggest that a major characteristic of government in its relationship with the microelectronics industry has been lack of long term planning and constant changes in policy. However, these changes in policy towards the industry appear to have been a by-product of wider policy decisions, rather than specifically targeted towards semiconductor manufacture. Unlike our major competitors, also faced with the problem of dominant American multinationals, successive governments failed to put forward a national strategy for the industry. The first co-ordinated attempt to assist the industry took place as late as 1978, and followed shortly after the imminent collapse of Ferranti in

1974/5. This suggests response to a crisis rather than a positive commitment to building a viable industry. Governmental co-operation with industry was tardy. Only in the late 60s were industrialists invited to participate in decision making through the Research Requirements Boards. Attempts to set up structures during the 70s in order to establish closer links between government and industry do not seem to have been particularly successful, as evidenced by the short-circuiting of formal channels of discussion by private lobbying of ministers and officials.

During the period under review, continual changes took place in the administrative structure of Government Research Establishments. It is difficult to estimate the resulting degree of dislocation and effect upon the planning of research programmes, but it would hardly have been insignificant. Furthermore, senior research staff were unavoidably occupied in restructuring programmes to the detriment of their technical work. The consequent problems and uncertainties were reinforced during the eighties by financial problems involving, amongst other matters, the reorganisation and reduction of staff, on lines suggested by the Strathcona Report.[73]

Cash limits precluded any major research in silicon device technology, and indeed until the late 60s any such programme directed at commercial markets would have been strongly discouraged. Although some work was carried out in the microelectronics field, it was largely speculative in nature and aimed at satisfying specific MOD requirements. Throughout the period, work on silicon was subject to a technical lag. Not until the mid 70s did the role of the Government Research Establishments begin to be questioned with a view to their assisting commercial activities.

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62. Article: "Cover Story", Engineering Today. (26th July 1982), p.20.

63. Private communication, B. Mullen (Head, Materials Section, RSRE).

64. *Ibid.*

65. In 1973, Plessey and Ferranti expressed scepticism (through their membership of the EDC) of the effectiveness of Government support in ensuring the viability of the UK microelectronics industry.(National Economic Development Office. Electronics: Industrial Review to 1977 (London: NEDO, 1973). para.3.37, p.18.

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71. *Ibid.*

72. D. Erskine, "How Plessey's voice remained unheeded", Electronic Times. (27th March 1980), p.12.

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Chapter 6

A Review of the Performance of Semiconductor Firms within the UK

Introduction

This chapter considers the development of the semiconductor industry within Britain from its beginnings until the mid-eighties. The major factor influencing the direction of this development was overwhelming economic penetration from American manufacturers, following the invention of the silicon grown junction transistor. This event established a technical lead which was never to be recovered by the indigenous industry. As well as describing the form of this economic penetration, the chapter outlines the development and response of the major British semiconductor firms, faced, as they were, with rapidly shrinking domestic markets.

During the first phase of semiconductor development, lasting until about the late fifties, germanium transistor production was dominant, with strong emphasis on the consumer market. Although the United States was by far the major producer, its industry mainly concentrated upon satisfying internal demands. European Manufacturers, including those in Britain, pursued a similar policy. The exception was Japan, which from the mid-fifties onwards began to export significant quantities of germanium devices to America, capturing 50% of the cheap portable radio market by 1959.[1] Defence industry requirements outside the United States were not sufficiently strong to exert a significant market pull towards an alternative silicon technology, although in Britain small numbers of silicon diodes were being manufactured, mainly for industrial applications.

The second phase of development began when United States military requirements included the need for large quantities of silicon transistors. This need was largely met by a small number of horizantally integrated firms, specialising mainly in semiconductor manufacture. These devices were then sold at premium prices until unit costs fell substantially, enabling their manufacturers to enter commercial markets with a cheap but technically superior product. Not only were these devices exported, but, because of demand, soon began to be fabricated overseas. This development had the additional advantage that labour costs in Europe and elsewhere were lower than in America. In the case of Britain, regional development grants were made available, thus assisting the process. Under these conditions, the American semiconductor industry rapidly achieved worldwide domination. This domination was reinforced by the invention of silicon planar technology, quickly followed by the integrated circuit, thus maintaining American technical superiority until at least the later seventies.

Overseas Investment in Semiconductor Manufacture within the United Kingdom

Apart from steadily increasing imports of semiconductor devices arriving in Britain from the late fifties onwards, foreign economic penetration took place through the construction of semiconductor plant within the host country. This development occurred in three stages. The first entrants were the long-established valve manufacturers, Mullard Ltd. and ITT Semiconductors. During this early stage, Mullard Ltd. dominated the commercial market in Britain by mass-production of germanium-alloy transistors. ITT, through its subsidiary Standard Telephones and Cables, followed a completely different policy, manufacturing small quantities of high reliability transistors, largely for in-house applications in telecommunications equipment. The second stage began with the arrival of Texas Instruments in 1957. This company played a key role in the subsequent development of the industry within Britain and must therefore be considered in some detail. The third stage of penetration took place largely within the central industrial belt of Scotland, with the arrival of a number of American semiconductor firms during the sixties. Although this latter stage of industrial penetration intensified pressure upon existing firms, it did not have the same amount of impact upon the development of the indigenous industry as the activities of Texas instruments.

The rapidly increasing degree of overseas penetration of the British semiconductor market up to 1977 is illustrated below.[2]

Firm Shares in British Semiconductor Market %

(Imports plus manufacture within the UK)

Year	1958	1962	1967	1968	1973	1977
Mullard	55	49	23	22	17	18
Texas	n/a	13	22	23	18	22
Fairchild	n/a	n/a	16	14	3.6	5.5
Motorola	n/a	n/a	5	6	14.4	10.2
Ferranti	n/a	10	5	5	4.5	1
Plessey	n/a	n/a	n/a	n/a	4	3
*GEC + Assoc.**	34	7	6	4	2.8	6
Estimated US owned %	2 to 5	17+	51+	56+	59+	64+

* (includes AEI, English Electric and Marconi)

Note: In 1958 and 1962 firms listed as % share *n/a* would have amounted to only a small fraction of the market.

The above estimates of import penetration may be somewhat low, in view of Willot's estimation that by 1978 American companies supplied 90% of the UK market.[3] What cannot be disputed is the rapid and significant trend towards market domination by overseas multinational companies during this period.

Mullard Ltd

Before the arrival of Texas Instruments, the principal semiconductor manufacturer operating within the United Kingdom was Mullard Ltd.. Because of the nature of the Company and European market demand, its policy was to concentrate on low-cost high-volume production of electronic components both for in-house use and external sales. Perhaps because of its foreign ownership it did not become involved in Government contract work to the extent of its British competitors.

Mullard's entry into semiconductor manufacture began in 1955, with the manufacture of germanium point-contact diodes at its Mitcham factory, followed by germanium transistors about one year later. These devices, designated the OC70 series, were originally developed at Eindhoven.[4] In 1957, transistor production was transferred to a new purpose-built plant at Millbrook, Southampton. The Company quickly became the leading semiconductor manufacturer in Britain, holding 55% of the local semiconductor market in 1958. Golding quotes a market research report at this time, which concludes "With the aid of its superior marketing arrangements and a wide range of models, Mullard is able to outsell transistors which have a superior performance, lower price, or both".[5] As the major producer of thermionic valves, Mullard already possessed an established and efficient network. In addition to R&D input from Redhill, further technical assistance was available from Nijmegen. Mass production techniques gained through valve manufacture were of considerable assistance, and expertise in such fields as glass to metal sealing were put to use in early forms of device encapsulation.

In 1961, Mullard purchased the assets of Associated Transistors Ltd. (ATL). This concern had been founded by EEV-Marconi, ATE & Ericsson in 1958, in order to supply those companies with transistors for in-house applications in the field of telecommunications. This purchase was followed in 1962 by the merger with GEC to form ASM (Assoc. Semiconductor Manufacturers). The effect of this move was to absorb the largest British competitor, and add substantially to the Company's research facilities. (by obtaining access to the Hirst Research Laboratories at Wembley).

Until the early sixties, it seemed that Mullard would repeat its achievements within the field of thermionic valve manufacture by dominating the British transistor market in similar fashion. Mullard's very success in the germanium field was perhaps a significant reason for their failure to realise the threat to their existing technology when it came from the development of the silicon planar transistor, and its subsequent successor the integrated circuit. After about 1962, the Company began to lose ground due to the arrival of these devices, which were not only being imported into Britain, but also at that time then began to be manufactured in quantity by Texas Instruments Ltd. at their plant in Bedford. By 1967, Mullard's share of the British semiconductor market had fallen to 23%, an indication of the scale of American market penetration.[6]

Three main factors appear to have contributed to Mullard's loss of market share. Firstly, during the early to mid-sixties, market projections for germanium transistor sales were unduly optimistic, and conversations with personnel at Southampton suggest that there was a lack of appreciation by sales staff of the significance of new technical developments.

Comparing events with the previous history of the valve industry, certainly no precedent existed for the rapid rate at which the new technology evolved. Marketing staff, largely trained in the more static environment of valve manufacture, could hardly have been prepared for the sudden impact of planar technology. Proven success in thermionic valve sales, in addition to the early success in sales of germanium devices, may well have induced an element of complacency.

The second factor was the delay in entering silicon production. This was to a great extent because Mullard had traditionally adopted a policy of waiting until a particular technology or process had become established. The Company then entered the market, using its experience in high volume production techniques to drive unit costs down to a very low level. Assisted by an excellent distribution system, it was then possible to flood the market with cheap components, offering equipment manufacturers prompt and efficient service. Unlike the situation within the valve industry however, technical advances in device manufacture did not reach a stable plateau, consequently the "wait and see" policy only resulted in additional time lag, coupled with decreasing market share.

The third major factor was Mullard's inability to catch up technically with its American rivals, due to lack of expertise within the new technology. Technical effort at the Millbrook plant was deficient in all aspects of silicon planar production, and there is evidence that the problems associated with the new technology were underestimated. Ambitious plans to construct high quality diffusion furnaces and thermocompression bonding equipment led to difficulties and delays during 1966/67. These difficulties were eventually resolved by buying in American equipment.[7]

Mainly as a result of such problems, a technical lag of about two years had been allowed to occur. This was to have grave consequences for the future development of de vice technology within the Company, which was consequently forced into negotiating licensing agreements with American device manufacturers. From the mid. sixties onwards, Mullard were forced to operate in a situation of technical lag within a rapidly evolving technology, and despite strenuous efforts, they were unable to retrieve the situation.

Although mask-making for discrete planar production began in 1963, and work commenced at Millbrook the following year on small-scale production of silicon discrete devices, it was soon abandoned. About eighteen months later activities were resumed on a larger scale, together with parallel work at Philip's Nijmegen plant. However, the devices then being produced (i.e., BFY 50 series silicon planar discretes) exhibited a consistently lower yield than those being produced at Nijmegen. In 1965, a number of DTL integrated circuits were produced for use in the construction of computers by the Marconi Company. Large scale WC200 DTL production began in 1967 under licence from Westinghouse.[8] Some of these devices were absorbed by in-house activities, such as the Electrologica computer, produced in Holland by a Philips subsidiary. However, the computer was not a success, and production of WC 200 devices ceased. Instead, Mullard switched to Fairchild 930 DTL. This appeared to be a sound move, since Fairchild was, through the introduction of this device, the recognised market leader. The subsequent success of TTL logic could then have hardly been forseen. Towards the latter part of the decade, Mullard began to produce their own version of 7400 TTL[9] and by 1969 this logic family accounted for just over half of the Company's total IC production by value.[10]

In 1967, the link with GEC was broken. However, during the same year, Mullard acquired Newmarket Transistors, the semiconductor manufacturing plant owned by Pye Ltd.

In addition to being Britain's largest exporter of radio and TV sets, Pye also manufactured various types of germanium alloy devices, and in addition assembled small numbers of small-signal planar types. In order to obtain government approval for the takeover, Philips were required to give an assurance to the Trade Secretary that Pye would continue to preserve a separate identity and maintain an export surplus in its trading activities.

In common with other manufacturers producing their own versions of TTL integrated circuits, Mullard suffered defeat by Texas Instruments in the 1969/71 TTL "war". Now that Texas Instruments 54/74 TTL logic had become dominant, Mullard were forced to withdraw from the mass market sector, dominated by standard bipolar logic. From now on, like other European semiconductor manufacturers, Mullard adopted a defensive strategy, concentrating on linear and custom devices, together with discretes.

Consequently, in 1972 a company reorganisation took place resulting in each group within the Philips organisation specialising to a greater extent than hitherto. As a result, Mullard (Southampton) concentrated on MOS devices and linear integrated circuits. In addition, some specialised integrated circuit design was carried out at the Mitcham plant.[11] One advantage possessed by Mullard over the smaller British companies was that, being part of a larger concern producing devices on a European scale, they were able to draw both upon additional funding and technical expertise. Against this, however, they were subject to the overall Company strategy, which might on occasions conflict with local interests. In 1975, Philips purchased Signetics. Not only did this strengthen their "state of the art" expertise in MOS, but re-established a foothold in the manufacture of bipolar TTL devices. Because of Philips late entry into large scale integration (LSI), production of these devices remained unprofitable until 1979. During the later part of the decade, Philips absorbed about 50% of its total semiconductor production for its own manufacturing requirements. Furthermore, the Company was almost self-sufficient in its needs, meeting between 80% and 90% of its component demand from in-house sources.[12]

During the late seventies and early eighties, Mullard continued to manufacture linear integrated circuits for specific customer applications, in addition to MOS products, including NMOS integrated circuits for teletext and view data, ROM memories and microprocessors for TV applications. Work during the mid-part of the decade included the production of silicon-on-sapphire (SOS) radiation hardened devices.[13] However, when the Philips Megachip project was announced in 1985, involving co-operation with Siemens, there was no mention of any role for the Southampton factory.

ITT Semiconductors

This is an American-owned vertically integrated company. Until 1982, when its British subsidiaries were sold to Standard Telephones and Cables (STC), it operated primarily in the field of telecommunications, with interests in component manufacture and defence systems. Its European headquarters were situated in Brussels. The British subsidiary, based at Woolwich, was formed in 1883 by Western Electric, and originally traded under that name. However, in 1925, the whole of Western Electric's European interests were purchased by ITT, an American telecommunications firm which had been founded in 1920. From this time onwards, the British section of the Company operated under the name Standard Telephones and Cables.

Interest in semiconductor manufacture began with the construction of point-contact transistors at their Ilminster (Somerset) plant in 1952. The Company had shown an early interest in computing, having started work on magnetic core storage development in 1949. However, during the early and mid-fifties, considerable research took place into silicon, largely funded by the Company and with little reliance on Government contracts.

In 1963, STC components was established, amalgamating the Rectifier Equipment Division based at Harlow (Essex) and the Transistor Division, based at Footscray (Kent). During the early sixties the Rectifier Division at Harlow was manufacturing silicon power rectifiers of varying size up to 500 amps and silicon controlled rectifiers able to handle 25 amps and rated at 400 volts.[14] The Footscray plant had originally been sited at Borehamwood, where small quantities of germanium rectifiers and photocells had been made. During the early sixties, the only type of transistors being produced at Footscray were small-signal alloy devices, mainly for in-house use, although a few of these were sold on the open market. No mesa transistors were produced, the Company going straight to silicon planar. Production of linear integrated circuits began in 1967, and by 1968 ITT were making Fairchild 930 DTL under licence, followed in 1973 by Fairchild 7400 series TTL. By 1970, ITT had become the third largest solid-state device manufacturer in Britain, with a turnover of about £16 million.[15]

As a major manufacturer of telecommunications equipment, the fortunes of STC were closely linked with the Post Office, and from 1972 British Telecomm.(BT). By 1975, BT was running at a considerable loss, and cut back sharply on its electromagnetic ordering programme. This resulted in large redundancies within STC and the closure of plants in East Kilbride and Larne. However, the rapid change from electromechanical to electronic switching exchanges then taking place stimulated demand for the manufacture of solid-state switches, and the Company consequently expanded into this area, purchasing Britain's biggest printed circuit manufacturer, Exacta Circuits, based at Galashiels and Selkirk.

In 1982, ITT sold a majority share holding of its UK subsidiary to STC, its British division. In 1984, STC made a successful takeover bid for the computer manufacturers ICL. In order to assist this move, ITT further reduced its existing shareholding within STC from 35% to 24%, to ensure that this move would be acceptable to the British Government from the viewpoint of national sovereignty.[16] In 1986, STC withdrew from the merchant semiconductor business after sustaining heavy losses, leasing its fabrication plant at Footscray to the US firm LSI Logic.[17]

As a specialised manufacturer of high-reliability devices for a "niche" market, ITT did not present significant competition to the influx of devices from overseas, or present a threat to the newly arriving subsidiaries. Conversely, it was not until about the mid seventies before ITT itself was threatened unduly by competitors activities.

Texas Instruments

The company most responsible for determining the future development of the British semiconductor industry was Texas Instruments Inc., based at Dallas, Texas. This was done largely through the activities of its subsidiary, Texas Instruments (Bedford). The parent company was founded under the title Geophysical Services Inc. in 1930, and was originally engaged in carrying out geophysical surveying on a world-wide scale. During the Second World War, Texas supplied airborne magnetometers to the American government, thus establishing links with the military. In the period immediately following the War, the Executive Vice President, P. Haggerty, stated that the Company policy had at that time three specific aims: to manufacture and service geophysical equipment; secondly, to re-enter the military equipment field as a supplier of electronic equipment; and thirdly to enter non-military markets to develop existing new technologies.[18] These aims were to be consistently pursued during the following years.

In 1951, the company was renamed Texas Instruments. At this time it was still a small concern, business turnover in 1949 being just over $0.5 million, with profits after tax of $263,000.[19] However, successful entry into semiconductor manufacture, stimulated by lucrative military contracts, soon led to rapid expansion. Some idea of the subsequent growth of the Company can be obtained from the fact that by 1972, World-wide turnover had risen to $1287 million.[20] Total revenues had further increased to $8.3 billion by 1988, the Company's European electronics revenue within that year reaching $1.1 billion.[21]

Following the Company's decision to manufacture semiconductors, events moved rapidly. A research laboratory was set up under G.Teal on Jan. 1st 1953, and by the end of that year, they were producing germanium transistors in quantity.[22] The real breakthrough came with the successful manufacture of silicon grown junction devices in 1954. This resulted in Texas being "effectively the sole supplier of silicon transistors at prices yielding profit margins which the Chairman of the Company described as 'exceptional'."[23] Company management was, and remained astute and well informed, the limitations of germanium being realised from the start. The decision to produce silicon devices was taken with the knowledge that if they were successful, substantial military contracts would result.

By 1957, Texas Instruments had become the principal semiconductor manufacturer in the United States (a position they were to hold until 1985) and in that year opened their first overseas production facility, Texas Instruments Ltd. at Bedford, England,in order to manufacture silicon grown-junction transistors. Golding states that "TI consulted British military authorities before finalising its decision in the knowledge of a prevailing concern at the high rate of silicon imports for military requirements in the absense of a domestic source of supply".[24] A further inducement was that Britain was the largest military market in Western Europe. Furthermore, the Company would be operating within a politically friendly country, speaking the same language, and claiming a "special relationship". Choice of the Bedford site was largely determined by the availability of low-cost female labour, and the same consideration was dominant in the later choice of TI's Plymouth location.[25]

TI Bedford was certainly a profitable operation, growth being such that a new plant was opened, also at Bedford, three years later, financed entirely from local earnings. The Company did not restrict its activities to supplying the profitable military market, but, with falling unit costs, took an ever increasing share of British commercial and industrial semiconductor sales. It consequently displaced Mullard Ltd., becoming the major British-based supplier in 1968 with a 23% market share.[26] By this stage, a catastrophic decline in the proportion of market share held by indigenous semiconductor manufacturers had taken place, largely due to the activities of the Company, and a market lead well and truly established before the added impact of integrated circuit manufacture. Company policy at Bedford always remained under tight control from the parent company in Dallas[27] and one aspect of this was product diversification. For example, by 1964, in addition to silicon grown junction devices, a range of silicon mesa, silicon alloy, germanium alloy, discrete planar and integrated circuit devices were being manufactured.

Late in 1958 and early in 1959, Texas presented briefings and demonstrations of integrated circuits based upon the work of J.Kilby, who constructed the first working device of this type in the summer of 1958. In 1959 and 1960, United States Air Force contracts were placed with the Company to produce integrated circuits. A significant breakthrough was the award in 1962 of the highly important Minuteman ll ICBM development and pre-production contract. This involved the development, design and fabrication of eighteen types of integrated circuit in six months.[28] Further Minuteman contracts were awarded during the following year and by October 1963 it was estimated that the Minuteman requirement accounted for about 60% of the value of all integrated circuit orders to date.[29]

The emphasis in this work was upon the large-scale production of high quality, high reliability devices within a short overall timescale, and successful achievement of this aim established the Company as the technical leader in integrated circuit manufacture on a

World-wide scale. A major spin-off from these contracts was that the production technology and technical expertise had been developed and was now available to mass-produce devices for commercial and industrial markets, both within America and overseas. As early as 1960, a British Government contract was awarded to Texas by RRE (Malvern) to set up integrated circuit production facilities in Britain as rapidly as possible. This contract assisted in establishing the production of series 51 diode transistor logic (DTL) devices in Bedford.[30] In addition, Texas supplied large quantities of DTL circuitry to the Government for the Rapier missile programme. Sciberras states that prior to the introduction of Transistor Transistor Logic (TTL), 46% of the Company's turnover was already accounted for by sales either to the British Government or their suppliers.[31]

A characteristic of Texas Instruments has been the rapidity of technical transfer between the parent company and its subsidiaries. For example, Dallas first produced series 51 bipolar logic in 1962, and in the following year manufacture of these devices began at Bedford· In 1964, Texas brought out their 54/74 series TTL, and in less than a year these devices were also being manufactured in Bedford.[32] They were initially produced for use by the military, and the speed of technical transfer indicates the importance of the British military market to the Company.[33] TTL logic became standard within the computer industry, and this logic type was to dominate the bipolar market from the late sixties onwards. Its successful introduction and subsequent marketing was possibly the major factor in both determining the strategy of the indigenous semiconductor industry, and contributing to its decline.

TTL logic had been successfully developed by Fairchild, but such was their success with their 930 series DTL logic that they did not market TTL until 1967. Because of Fairchild's position as market leader in DTL between 1965 and 1967, it appeared that they would retain this lead, and a number of manufacturers, including Mullard and Elliott second-sourced Fairchild logic products. However, the subsequent Fairchild 9000 series TTL performed disappointingly, production yields being low.[34] Other major American companies manufacturing TTL at this time, including Sylvania (Texas's main rival) also suffered from production yield problems and consequent marketing difficulties.[35] Texas instruments, second-sourced by National Semiconductor, successfully engineered the product on a mass production basis.[36] They aggressively reduced prices with falling unit costs, effectively capturing the TTL market, in what became known as the "TTL war". With the defeat of Fairchild by Texas in this "war", Mullard and Elliott (who had both second-sourced Fairchild DTL and TTL) were also forced out of the bipolar market. Ferranti, producing their Micronor 5 TTL on a relatively small scale, were unable to compete on cost.

It is indeed difficult to underestimate the importance of this development, although statements by rival manufacturers may give some idea of its impact. For example, the General Manager of Elliott-Automation, stated "within about two years it was almost impossible for those of us making other IC families to sell our products into new systems".[37] In the same article he remarked "In terms of absolute management commitment, design skill and marketing acumen the success story of the 74 series is, in my view, unmatched in the history of the semiconductor industry".

The problem facing the British semiconductor industry at that time was not however principally one of obsolete technology but the combination of an influx of high quality logic circuitry at prices with which it was impossible to compete. Again, F.E. Jones, Managing Director of Mullard Ltd., writing in 1970, and at the beginning of the TTL "price war" stated "It impedes all judgement on what to do in the future. I honestly can't see how anyone can make a living and pay reasonable wage rates with these sort of price parameters".[38] What had happened was that with cancellation of orders for the Minuteman missile programme, Texas possessed a considerable inventory of TTL devices. Consequently, large quantities of these devices came onto the commercial market, and prices tumbled. For example, between January and August 1970, the price of a TTL gate in Britain decreased from an already highly competitive $0.6 to $0.15-0.2. In that year, Texas held 50% of the European market for TTL.[39] The success of this policy (criticised widely as "dumping") was that in 1971 Texas Instruments made a gross profit of £3 million on sales of £5 million.[40]

Although Texas made considerable profits both in the early days of discrete and integrated circuit manufacture by selling to both British and American governments at premium prices, it did not rely upon this strategy once unit costs started to fall with increasing production. Instead, it changed tactics, progressively reducing its prices in such a manner as to keep a constant factor relative to falling unit costs. As market leader, the Company was consequently able to mass-produce its products at a point further down the learning curve than its rivals, and force them into a position where in order to compete they would have to sell their products at a loss. Consequently, competing companies were faced with the realisation that it might never be possible, even with considerable expenditure, to remain in the field.[41] Furthermore, this process was cumulative, since as market penetration increased, unit costs fell due to growth in demand, this fall leading to further market penetration.

In 1970, Texas consolidated their position in the bipolar logic field with the introduction of the Schottky TTL family, a modification of standard TTL with improved switching characteristics. As market leaders, they again proceeded with their policy of aggressive price cutting. For example, in May 1973, price reductions of 50% were announced by the Company on Schottky TTL and low power Schottky TTL, and in February of the following year additional reductions of between 20% and 50% took place.[42]

Following the Company's successful logic "war" major competition within Britain only came from other American companies, although from about the middle of the eighties Japanese imports began to mount a significant challenge.

Overseas Subsidiaries in Scotland

Apart from Texas Instruments, several foreign semiconductor firms established overseas subsidiaries in the United Kingdom. This settlement took place from the early sixties onwards, principally in the central belt of Scotland. Apart from sales activity within the host country, this development afforded access to other European markets. Advantages in moving to Scotland included a lower cost of living than in many European countries, reasonably good transport and communication facilities, and substantial Government grants, which under the Microelectronics Industry Support Scheme (MISP) programme could amount to to 40% of initial investment costs.[43]

Some idea of the magnitude of development grants awarded to overseas firms may be gained from the fact that during the third quarter of 1981, American semiconductor companies operating in Scotland received the following allocations:[44]

Motorola	£980,000
National Semiconductor	£297,000
Hughes Microelectronics	£28,000

In addition, the major US electronics company IBM, based at Greenock, received £1,089,000 during this period.[44] (As a measure of comparison, INMOS received £61,000 for development at its Newport plant).[45]

Other advantages which have been cited include the helpful attitude of the Scottish Development Authority, a stable and adaptable workforce, and the availability of a pure water supply for manufacturing processes.

Although the resulting influx of foreign investment put additional pressure on British manufacturers, it did not play a critical role in dominating the local industry in the same way as Texas Instruments through that company's relationship with the Ministry of Defence.

The firms involved were as follows:[46]

Name of Company	**Date of Arrival**	**Location**	**% of UK Market**				
			1962	**1967**	**1968**	**1973**	**1977**
Hughes Microelectronics	1960	Glenrothes	1.0	1.0	1.0	1.4	0.4
SGS-Fairchild	1962	Falkirk	n/a	16.0	14.0	3.6*	5.5
General Instrument	1968	Glenrothes	-	-	-	4.5	2.4
Motorola	1969	E. Kilbride	-	5.0**	6.0	14.5	10.2
National Semiconductor	1977	Greenock	-	-	-	-	5.1
NEC (Japan)	1984	Livingstone	-	-	-	-	-

* [This fall in market share occurred following the SGS break with Fairchild]

** [Imports from Europe and America]

Device production in what became known as "Silicon Glen" grew to account for a significant proportion of the total device output within the United Kingdom. By 1981, the Scottish share of semiconductor production within Britain had risen to 36%, and the Motorola plant had by this time become the largest semiconductor production facility in Europe.[47] At that time, INMOS was the only firm outside Scotland dedicated exclusively to the manufacture of standard chips.

In common with overseas subsidiaries elsewhere, there was a reluctance by these companies to set up research and development facilities at their production plants, in spite of efforts by the Scottish Development Authority to encourage them to do so.[48] However, by the eighties, General Instruments and National Semiconductor had each set up design centres. One reason for the reluctance of companies to export research facilities is that it is then easier (and cheaper) to cease offshore production, if desired. A further possible reason is a desire to limit advanced technical knowhow to the parent company (and country). Reluctance on the part of Fairchild to provide research and development facilities in Italy led to the break in 1968 between the partly government owned SGS and Fairchild.[49] There is evidence that slices were exported from these factories to Eastern Asia and also South and Central America for the labour-intensive assembly processes to be carried out,[50] thus following the pattern already established within America.

The Effect of Foreign Market Penetration on Device Development in Britain

During the first phase of device production, with its emphasis on germanium, the major limitation constraining the production of device types was the state of the existing technology. Early devices were restricted to low power, low frequency applications, and the problem of technical lag with respect to overseas manufacture was not yet apparent. From the early sixties onwards, however, the situation changed radically, and market penetration by foreign companies became considerable. Consequently, market penetration became the dominant factor in determining the development of device types within the United Kingdom.

The principal British semiconductor firms manufacturing devices for the open market were Plessey, Ferranti and GEC. [In addition, Westinghouse and Lucas were large producers of specialised semiconductor devices for largely in-house purposes, and therefore much less affected by international developments. They are consequently excluded from the following discussion.] All were vertically integrated companies, Plessey and Ferranti in particular having traditionally strong connections with the MOD. Because of this link, and in order to satisfy military requirements, it was necessary to move into silicon integrated circuitry at an early stage. Although relatively small, both Plessey and Ferranti possessed considerable technical expertise, and were strong in research and development. This advantage enabled them to enter the development of silicon devices with confidence and achieve a considerable measure of technical success.

However, Plessey, Ferranti and GEC were soon to be faced with increasing market pressure and a chronic technical lag. Under these conditions, they eventually pursued the strategy of aiming at a "niche" market, primarily supplying the MOD and telecommunications industry with limited numbers of specialised high-cost devices. Before this situation was finally accepted, unsuccessful attempts were made to compete in a wider market. Because of their importance as the major British semiconductor manufacturing companies, a detailed chronological survey of all three now follows, illustrating the effect of market pressure upon their industrial performance.

Ferranti Ltd

The Ferranti company was founded in 1898 by Dr. S.Z. de Ferranti, and remained a family owned concern until the mid-1970s. This form of ownership, perhaps unique for a semiconductor manufacturing concern, was to play a significant role in Company policy. Ferranti originally started to manufacture electronic components in the early thirties, when a range of thermionic valves was produced. During the Second World War, the Company produced a variety of high-frequency components including Klystrons, Magnetrons and miniature valves. These devices were then being mainly used in Ferranti manufactured equipment, especially radar.[51]

The abovementioned work provided a technological base upon which to enter the new field of guided weaponry, and consequently in 1949 Ferranti, in association with the Bristol Aircraft Company, obtained a contract to develop a guided weapon system which was eventually to result in the successful production of the Bloodhound missile. Problems arose during this project which involved the fundamental limitations of the miniature valves then being used, leading the company to consider an alternative solid-state approach. Consequently, in 1952, Ferranti representatives, assisted by financial support from the Ministry of Supply, attended a symposium at Western Electric (Bell), at which details of semiconductor fabrication techniques were made available. By September 1953 Ferranti, (again with MOD support) obtained a licence from Western Electric to produce semiconductors. Whether the Company would have gone ahead at this time without Government financial support is difficult to determine, in view of the demand upon resources this operation would otherwise have involved.[52]

Semiconductor Research and development started in 1953, under the direction of Dr.A.A. Shepherd, and concentrated entirely on silicon. This decision was taken primarily because of the physical limitations of germanium, and in order to establish a lead in silicon device technology.[53] The decision provided Ferranti with an early lead in silicon technology over most other British semiconductor manufacturers. The first European silicon junction diodes were being made by 1954. An attempt was then made to produce a silicon alloy transistor, but this was unsuccessful.[54]

This failure was to have highly important consequences, as it assisted in enabling Texas Instruments to establish itself, in 1957, as the sole successful manufacturer of silicon transistors within the United Kingdom at that time.[55] Silicon photovoltaic cells came into production by 1957. The following year a range of silicon transistors was marketed, including the ZT20 "Mesa", this being the first commercial production of this type in Europe. These devices were fabricated using the diffusion technology developed at Bell Labs. and announced at their 1956 symposium.[56] Ferranti had attended this event, and the ensuing work had again been supported by Government funding.[57]

By the late fifties, sales had increased markedly, and the Company was at last able to plough more of its own funds into an increasingly successful venture. The experience gained in silicon technology, including diffusion and oxide masking techniques, now enabled Ferranti to move rapidly into planar device manufacture. Research in integrated circuitry began in 1961 and in the following year the first British designed integrated circuit, the Micronor l, (using DTL logic) was produced under Government sponsorship for use in computers for the Royal Navy. This was a multi-chip circuit, but in 1965 its successor, Micronor ll had been developed, based upon RCA technology. This was also a DTL chip which was faster and had a higher loading than the Fairchild equivalent. It had been intended for use within the Ferranti range of miniature Argus 400/500 process control computers, which were to be used in the Bloodhound missile system. However, failure to produce a complete Micronor ll logic family led to lack of success in military markets. The next development was based on a fast logic circuit initially developed under CVD contract in response to a requirement from ASWE.[58] Even before the TTL "war" therefore, Company policy was to develop integrated circuit logic families with the military market primarily in mind, assisted by significant Government financial support[59] [Although Ferranti largely pulled out of the guided missile area following the Bloodhound controversy 1963/4, production refinement of the Bloodhound system continued for over twenty years].[60]

Although Ferranti's discrete component business had remained profitable during the early sixties, constant financial losses in integrated circuit production gave cause for anxiety. By the mid-sixties, Ferranti was under considerable financial and market pressure, having been forced to sell its mainframe computer business to International Computers and Tabulators Ltd. (ICT) in 1963.[61] This was because of the high cost of developing new designs, and the small size of the British market. Nevertheless, heavy investment continued in integrated circuitry, and in 1966 the Company accounted for 70% of the total output of integrated circuits manufactured by British owned companies. In 1967, Ferranti began to market a range of logic of its own design, based on 7400 series TTL, thereby becoming the first European manufacturer to enter TTL production. These devices were developed in only nine months.[62] MOS technology was introduced in 1969, in response to American pressure.

During the late sixties a crisis arose, due to a combination of factors. Firstly, there were few high technology projects within Britain able to absorb large numbers of integrated circuits. (This situation was worsened as a result of the cancellation of the TSR 2 programme). The Company was also faced with the financial consequences of the Bloodhound affair. Furthermore, in 1968, ICL switched to Texas Instruments as their main supplier for use within their 1900A computer range. This was the time of the TTL "war", and Texas were supplying a booming market within the United States with 54/74 TTL devices. They were already well down the learning curve before Ferranti even began to produce this logic range.

Following the 1970/71 recession within the industry, competition intensified, and in this harsh environment Ferranti were forced to abandon TTL manufacture altogether, the Texas version of this logic becoming standard. A further important factor operating against the Company was that throughout the sixties the proportion of Government sponsored Research and Development fell from about 50% at the beginning of the decade to less than 20% of the total cost at the end, putting an increasing strain upon already highly stretched resources.[63] An additional problem was that Ferranti originally overestimated yields obtainable at the diffusion stage of production, and this problem took about two years to solve satisfactorily.[64]

Government financial assistance through the Advanced Computer Technology Project became available during the sixties, enabling firms to claim half their expenditure on approved contracts. Although the amount allocated to semiconductor technology under this scheme was relatively small, it did enable Ferranti to improve their existing integrated circuit plant capability. This was an important precedent, since on this occasion public money was being spent within the previously neglected production-development area, in order to obtain yield improvement, thus following American practices.

A further contract, sponsored by the National Research and Development Corporation ran from March 1968 to March 1970, and involved a substantial loan to be paid by a levy on all integrated circuit sales. This funding assisted work on the collector isolation diffusion (CDI) process' although financial support from CVD was of more importance.[65] This technology had been developed originally by Bell Labs. and Fairchild, but neither company had been able to develop it fully. Its advantage was that it allowed increased packing density of components on the silicon slice, and was compatible with TTL. By 1971 Ferranti claimed to have made significant progress. However, this development was seen as a threat by the large American companies. For example, Fairchild, Texas and Motorola refused to second-source CDI, in order to prevent its widespread use.[66]

As a result of the TTL "war", Ferranti changed its strategy, giving up the attempt to compete within the high-volume digital integrated circuit market, and concentrating instead on manufacturing custom-designed devices, for which there was a growing demand.

The Company's initial response was to develop the Uncommitted Logic Array (ULA).[67] This was an integrated circuit which could be modified by the customer to perform a specific function. The earlier decision to develop the CDI process became a significant factor in the success of this logic circuit, by enabling an increase to be made in component packing density. Ferranti sold its first ULA's in 1972, and sales roughly doubled every year until at least 1981.[68] Manufacturing the ULA provided a springboard enabling the Company to produce the first European designed microprocessor, the F100-L.[69] This device used fast reliable bipolar logic, and was aimed at military markets. Apart from the usual shortage of funding, the microprocessor project was also hampered by a shortage of high-level engineering expertise within the area of process development, and also CAD software.[70] Nevertheless, these developments demonstrated that the strategy of developing suitable "niche" markets could be successful.

Public support through the Ministry of Technology and the NRDC had been vital in maintaining the Company's position in the forefront of semiconductor technology during the late sixties.[71] However, the position was to change during the early seventies, with the election of the Heath government, committed to "free market" principles. Initially, this event had an adverse effect upon the fortunes of the company, due to the abolition of the Ministry of Technology and a reduction in the amount of research and development support available through public funding. However, a further change in policy under the same Government took place in 1972, resulting in a substantial increase in assistance to private industry.[72] Consequently, an improvement in the financial situation occurred following the decision in 1973 by the DTI to set up the Microelectronics Support Scheme, which provided 50% of the costs of approved development projects over a period of six years, the repayments to be based on a levy on profits rather than sales.[73] Under this scheme, Ferranti received £4 million, and were able to continue to develop their component technology.[74] In 1973 the Company achieved their peak output for semiconductor devices.

However Ferranti continued to experience financial difficulties, although perhaps largely unconnected with the Components Division. These difficulties led to the financial collapse in 1974/5, followed by the Company's rescue under the Labour Government,then in power, through the National Enterprise Board. A consequence of this event was a fundamental change in the management structure, with the Ferranti brothers now reduced to non-executive status. A part of the rescue consisted in additional Government funding amounting to £15 million. Consequently, the Electronics Division (renamed Ferranti Electronics Ltd. in 1978) were then able to carry out further development work, and also market ULA's. As part of the rescue package, the NEB held 50% of voting equity in the Company, and an additional 12.5% of non-voting shares.[75]

In November 1977, the Company borrowed a further £8 million from the Chase Manhatten Ltd. and £7 million from the Chase Manhatten Bank. This was used to repay money to the NEB, and also pay off overdrafts, and expand its activities. In order to improve its position in the American market, Ferranti acquired a subsidiary, Interdesign, in Dec. 1977. This firm manufactured custom designed logic arrays, and was based in California. This strategy appears to have been successful, since by 1980 integrated circuit sales in America alone were over $14 million, this figure being about half Ferranti's total sales.[76] By 1979. Ferranti were the only profitable British integrated circuit manufacturer.[77] Sales of integrated circuits grew from £1.6 million (1976) to £35 million (1983) and by the early eighties the market share of World ULA production amounted to 25%.[78] The Company remained extremely innovative, introducing its technically advanced FAB-2 bipolar Uncommitted Logic Arrays (ULA's) in 1981.[79] In spite of

Ferranti's policy of diversification, by 1982 more than 60% of Company turnover was going to military markets, two thirds of this amount to the MOD.[80]

The 1980 Industry Act, passed by the incoming Conservative Government, prevented the NEB from extending public ownership into profitable areas of manufacture. It had already been instructed by the new administration to sell its 50% Ferranti holding.[81] In 1982, the Company returned to full independence. However, profits stagnated by the mid-eighties, and a mounting financial crisis towards the latter end of that decade led to the Company's decision to sell off its assets in an attempt to remain financially viable. The Ferranti Semiconductor Division was consequently sold to Plessey in 1987 for the sum of £30 million.[82]

Briefly reviewing the above events, it appears that although Ferranti were manufacturing silicon devices at an early stage, and moved into integrated circuit technology fairly quickly, they were unable to use their existing military market as a springboard to achieve wider sales. It is highly significant that Ferranti, who were extremely innovative and who had a good record of production development (in spite of a shortage of qualified semiconductor engineers), found themselves forced away from their chosen technology (DTL) by the strength of overseas market pressure, and into adopting TTL7400 logic. Nevertheless, the Company was able to adapt quickly and successfully to this technological challenge. This switch to TTL production was not, however, economically successful because of the technical lag then existing, enabling the most advanced American companies (and Texas in particular) to enter high-volume production at an earlier stage. Furthermore, the introduction of their rival TTL54/74 technology threatened Ferranti's existing sales within the British computer industry.

At this critical stage, the only possibility of success in the TTL logic field lay in large financial investment, coupled with some degree of economic protection, such as a guaranteed computer market, or a significant surcharge upon imported devices. Even measures of this nature might not have succeeded, in view of the then existing ability of foreign companies sited in Britain to manufacture TTL logic on a high volume production basis. At all events, even with existing Government support, Ferranti was unable to succeed in the highly competitive TTL sector, and wisely decided to fall back on their existing CDI expertise to manufacture semi-custom logic. The price to be paid for this decision was that only a limited (and diminishing) market was available for these devices, and there remained no prospect of the Company substantially increasing its share of the British semiconductor market, which had by 1977 fallen to only 1.1% of total sales.[83]

Ferranti's integrated circuit marketing strategy had therefore by this stage resulted in heavy dependence upon one particular overseas outlet (namely the American semi-custom market, which by the early eighties accounted for about 50% of total sales).[84] However, this left the Company without a home base of any significance, a particularly vulnerable situation. Marketing weaknesses, particularly in the civil sector, had unfortunately been a long-term problem and generally speaking, the Company might well be described as a technology-led rather than a market-led organisation. An almost constant cash flow problem had limited activities within the Semiconductor Division, although much of the difficulty stemmed from losses within other sectors of activity.

The Plessey Company

The Plessey Company was founded in 1917, and initially carried out contract engineering work. Between the Wars, it expanded into the electronics field, manufacturing radios for both civilian and military use, and also components and telephone headsets. During the Second World War, the Company expanded considerably, with increasing emphasis on military requirements. Plessey had always been a production oriented concern, and until the Second World War carried out virtually no research. During this time, however, close relationships were built up between the Ministry of Supply and the firm's research facility at Caswell, Northants.

By the early fifties, Plessey had become the major supplier of passive components within Britain. During this time a shift took place from the production of components for the entertainment industry towards high quality products designed for military and industrial use. This change offered a better return on capital, and a less volatile market. Plessey did not enter into valve manufacture, involving as it did high capital cost.[85] Already therefore, a policy of supplying specialised devices for a secure market at minimal cost had emerged.

Prior to 1960, the Company's interests lay mainly in component and equipment production for the radio industry and telecommunications, but it was also extremely active in the fields of defence electronics and engineering. During the sixties these activities were diversified and considerably extended to include solid-state technology and the production of complete radar and telecommunication systems. From about this time onwards, exports were to become an important feature of the Company's activities. From the middle to the late seventies, the firm's strategy was aimed at becoming an integrated organisation, concentrating upon telecommunications, defence communications and electronic components.[86] Plessey's semiconductor strategy and manufacturing programme must therefore be seen in this wider context.

Interest in semiconductor technology began in 1952, when Plessey research staff attended the initial Bell technology symposium. Research within the field then immediately commenced, and a licence agreement was negotiated with RCA to manufacture germanium transistors. (However, this association soon ended with the termination of the agreement in 1955).[87] Military (CVD) contracts for work on silicon were obtained in 1953, and the first silicon crystals were grown within that year. By the following year, silicon-alloy rectifiers were being produced. Research also commenced at that time on lll-V compounds, including indium-antimonide,[88] emphasising the firm's military work. The laboratory at Caswell grew substantially throughout the fifties and by 1959 the research effort in silicon and compound semiconductors had become substantial. Work at Caswell then consisted not only of market-oriented research, but also that of a long-term speculative nature.[89]

In 1957, research programmes on silicon solar cells and silicon diffused power rectifiers were instituted at Caswell. The power rectifiers were manufactured at Plessey's Towcester plant under licence, using a batch process developed by the General Instrument Corporation. These devices were of the alloy-junction type, and were developed over the next few years until capable of reverse breakdown voltages of about 1000 volts, and rated at one amp.[90] However, in spite of this undoubted technical achievement, it has been stated that this product was consistently unprofitable.[91] It has been suggested that Plessey suffered from marketing weaknesses at that time, and failure to exploit the silicon power rectifier may lend some support to this view.

Meanwhile, in 1957, a joint venture had been established with Philco, in order to fabricate a high-frequency Micro-alloy Diffused Transistor (MADT). This resulted in a production unit for these devices being established at Swindon, Semiconductors Ltd., with Plessey holding 51% of the equity. This project had been opposed by the scientific staff at Caswell, on the grounds that silicon double diffused mesa technology, because of its greater flexibility, would become dominant.[92] They felt that maximum effort should be made in developing silicon mesa technology, but were overruled by management. In 1961 Plessey purchased Philco's share of the joint venture. From that year onwards, the MADT process at Swindon was used to manufacture silicon transistors. However, production yields remained consistently lower than those being obtained by Philco, and the operation remained unprofitable.[93]

There can be little doubt that the decision to manufacture Philco MADT devices was a technical error. To persist in attempting to develop what had become an obsolete process, in spite of objections from Caswell, calls into question the efficiency of decision making at the highest level. This event illustrates a problem faced within vertically integrated companies where technical decisions can be overridden by senior personnel, unfamiliar with the technology. In a rapidly changing and complex process such as semiconductor manufacture, this danger is much more likely to arise.

Plessey were the first British company to become engaged in the manufacture of integrated circuits, having obtained a contract from the Ministry of Aviation in April 1957 for the development of a linear amplifier within a single silicon chip. This development, amounting to only £10,000 per annum, was transferred to CVD in 1960.[94] This work, based at Caswell, involved only a small team. During the earlier part of the contract, only pre-planar processes were available, but in 1961 Plessey took the decision to develop and move into production of both discrete silicon planar devices and integrated circuits, setting up a pilot plant during 1962.[95] Work proceeded extremely slowly due to lack of effort, this being largely due to lack of funding. Consequently, integrated circuits only entered limited production at Caswell in 1965.[96] CVD support until the late sixties was confined exclusively to linear circuits for use in intermediate frequency (IF) amplifiers. These were:[97]

(a) Linear amplifiers operating up to 100 Mhz.

(b) Logarithmic amplifiers operating up to 100 Mhz.

(c) Low noise input stage amplifiers.

(d) Detector and video amplifiers.

(e) A "true" logarithmic amplifier.

In 1967/8, a research contract was issued for the development of digital counters for use in frequency synthesisers. Also at this time, both digital and linear circuitry for CLANSMAN were developed under Ministry of Technology contracts.

There can be no question that Plessey was substantially assisted during the sixties in developing integrated circuitry through Government contracts. It has been estimated that the CVD contribution in this respect between 1961 and 1968 amounted to approximately £0.5 million.[98]

By 1967, discrete planar production had been phased out at Swindon, and a silicon integrated circuit product design group established there. It has been suggested that discrete planar production was abandoned since rapidly falling market prices had convinced the firm that it could not hope to compete because satisfactory economies of scale could not be achieved.[99] However, the Company maintains that the decision to manufacture discrete devices was primarily a technical decision, made in order to obtain experience in silicon planar technology, this to be used as a stepping-stone to entering integrated circuit manufacture.[100] Certainly Plessey went into production of discrete silicon devices when competitors unit costs had fallen to a very low level, and entry into the market at this stage was hardly an economic proposition. Nevertheless, the decision to manufacture discretes on a production basis before committing the firm to integrated circuit manufacture was undoubtedly a logical path to take.

In 1968, the Swindon factory was extended to include manufacturing plant for MOS P-channel device manufacture. This was the first ever commercial MOS process to go into production,[101] and providing clear evidence of Plessey's innovative capability. By 1970 a research programme involving silicon gate N-MOS and C-MOS began at Caswell. However, in 1974, a serious fire occurred at the Swindon plant, totally destroying the MOS facility. Consequently, it was decided to re-establish MOS production on a new site near Plymouth, and under independent management. This factory became operational in 1975, and the high-speed bi-polar Process lll production facility was then transferred to Swindon. Capable of handling an input frequency of 1.2 GHz., devices made by this process were claimed to be the fastest in the World, and in advance of their Motorola equivalent.[102]

In 1971, like other European semiconductor manufacturers, Plessey had been forced out of the standard bipolar mass-market by the TTL "war". Consequently, during the first half of the seventies, the Company concentrated on producing a limited number of types for a more restricted sales area. From this time onwards, the firm's strategy was defensive, with emphasis upon the production of custom and semi-custom devices. The Company's policy, following the TTL "war" was expressed by the Manager of the Microsystems Division, writing in 1978, who stated "I do not think that any of the purely European oriented companies have the strength and credibility to set new international standards in these mainstream areas".[103] Furthermore, he saw no financial advantage in second-sourcing logic systems such as DTL and TTL, since their originators were "much further down the manufacturing curve".

From 1974 until 1979 Plessey received financial help from the Government through the Microelectronics Support Scheme, under which the manufacturer was required to provide an equal amount of funding. Further Government assistance was given at this time through the Electronics Component Scheme. The yearly cost of Government contracts grew substantially during the seventies, the Company being the major contractor in the field from 1975 until 1978.[104] Financial losses sustained in integrated circuit manufacture were consistantly high. Sciberras, writing in 1977, stated that in MOS technology alone losses amounted to £10 million over a 10 year period.[105]

1975-76 has been described as "the toughest year ever" for the Plessey Group, the firm's profits falling from £39 million to £34 million in spite of a 14% sales rise.[106] In 1977, in order to reduce losses, Plessey attempted unsuccessfully to sell its semiconductor plants, discussions taking place between the NEB, GEC and General Instruments. From 1980 onwards, under new management, an increased committment was made to large scale integration. From then on, however, an increasing share of production was being used for in-house assembly, this proportion rising from slightly over 10% in 1980 to about 40% in 1984.[107] At Caswell, research of an advanced nature continued, one example being the growth of device quality gallium arsenide on silicon substrates.[108]

In November 1987, Plessey purchased the Ferranti Company's semiconductor manufacturing facility for £30 million, and it appeared at the time that Plessey would become the major semiconductor device manufacturer in the United Kingdom. However, following Plessey's previous eight years of profitability and growth in this sector, a successful bid by GEC and Siemens was made in September 1989. Previously, in 1985/6, GEC had been prevented from taking over the Company by the Mergers and Monopolies Commission and restricted to a 15% share holding, but in January 1988 the Commission changed its policy, opening the way to GEC's takeover.

At the time of the takeover, Plessey was the largest manufacturer of integrated circuits in Britain, exporting half its production. It possessed research facilities at Caswell specialising in solid-state research and also at Roke Manor (Hants.), the base for research in electronic systems and telecommunications. In addition to the semiconductor manufacturing facilities at Towcester, a new integrated circuit production plant had recently been completed at Roborough, Plymouth, at an estimated cost of £50 million, to be commissioned in 1986. At the end of 1985 the total number of employees within Britain amounted to 26,900, the World-wide figure being 33,700. Of these, 5,120 were engineers, scientists and technologists and a further 5100 technicians.[109] Together with GEC, Plessey had been involved in integrated circuit development under both the Alvey and ESPRIT programmes, Plessey's share in 1986 amounting to 1.5% of the ESPRIT budget.[110]

General Electric Company (GEC)

This is the largest UK firm engaged in the field of electrical engineering and electronics.It took an early interest in semiconductor manufacture, although this activity has always constituted only a small part of the firms operations.[111] It was originally founded in the 1880's as the General Electric Apparatus Company, manufacturing electrical fittings and telephones. It was renamed GEC when it became incorporated as a private company in 1889. By the turn of the century, it employed about 3000 people, and had wide overseas interests. The Company rapidly expanded during the First World War, and continued to do so during the inter-war period. The advent of the Second World War led to an increased diversification of the Company's activities, including extensive R&D in the Radar field. GEC then became involved in the production of microwave valves and also of silicon and germanium polycrystalline diodes. Silicon crystals manufactured at that time were made from highly purified powder to which impurities were subsequently added, thus anticipating later material preparation techniques.[112] Research, development and also the manufacture of these devices was carried out at the Hirst Research Laboratories, Wembley, which had been formally established in 1919.[113] By 1939, total staff employed at these Laboratories amounted to about 550.

Following the Second World War, diode production continued at GEC's Coventry works. In 1949, under pressure from the Ministry of Supply, GEC accepted an extensive committment to R&D in both radar and guided missile systems. Consequently, new laboratories were built at Stanmore, Middlesex, to carry out this work. By 1956, the total staff employed at both Wembley and Stanmore had risen to about 3000, including 650 graduates. About half of the total effort in R&D carried out within the GEC Laboratories at this time was on Government work.[114] During the early 50's, the fabrication of germanium point-contact transistors was also carried out at this site, and these devices were soon followed into production by a range of alloy-junction transistors.

In 1953, an agreement had been made with Western Electric, to obtain information on the process of growing single germanium crystals.Following the successful completion of this project, Hirst Laboratories attempted the more difficult production of single crystal silicon, this being achieved in 1955. From about this time onwards, research in solid state technology became the principal focus of effort at Wembley. By 1957, large high quality crystals weighing 5Kg were being grown there on a routine basis, and it has been claimed that crystal growing technology at Wembley led the world at this time.[115] The abovementioned point contact types were used in the construction of portable radio receivers and also high- speed detectors at the Atomic Research Establishment, Aldermaston. Their reliability was however poor, and work on point contact devices soon ceased. These early transistors and germanium power diodes were also produced on a factory basis at GEC Radio Works , Coventry, although later in that decade transistor production was transferred to the Hazel Grove factory at Stockport (Cheshire). By the latter end of the decade, research on large-signal germanium power transistors at the Hirst Laboratories resulted in world leading performances being achieved. The EW 53 alloyed germanium power device, for example, operated with a cut-off frequency of 20Mhz. It was used for RF applications in guided missiles, and switching versions were employed in computing and other digital fields.[116] Work on large-signal power diodes and transistors by this time was receiving CVD support.

It was during the late 50s that the process of post-alloy diffusion was invented at GEC by Dr. J.S.Lamming.[117] This method of manufacture was used to produce the EW 69 germanium drift transistor with a base width of only 2 microns and a cut-off frequency in excess of 200 MHz.[118] The post-alloy diffusion technique was later to become of great importance when used by Philips in the manufacture of their Germanium Post-Alloy Diffused Transistor. Also at Hazel Grove, mesa transistors with a diffused base and alloyed emitter were being produced with a cut-off frequency of 1GHz. In line with its emphasis on power applications, work began at Hirst Research Laboratories in about 1958 on the development of silicon controlled rectifiers (thyristors). Access to previous work carried out in this field by General Electric (an American firm having no connection with GEC) led to the rapid development of these devices and their production at Hazel Grove. A weakness which existed prior to the formation of the Semiconductor Division in 1959 was that device development and pilot production was carried out at Wembley rather than at the factory site, leading to difficulties in translating this stage of the process into full-scale manufacture. Furthermore, Head Office staff, with little appreciation of semiconductor technology, were responsible for marketing operations.[119]

In 1961, management changes resulting from the acquisition of Radio and Allied Industries resulted in a re-assessment of policy towards semiconductor manufacture within the Company. An important reorganisation of the GEC Research Laboratories took place at this time, involving decentralisation of all operating units excepting long-range activities. The new reorganised structure now became the GEC Hirst Research Centre. R&D spending at the Centre in 1962 amounted to £250,000, in addition to a Government contribution for that year of almost the same amount. It was realised that considerable investment would be needed in order to continue to compete effectively in the semiconductor area, and it was decided that GEC could not afford to raise the required capital in order to do so.[120] Consequently,a merger was negotiated with Mullard Ltd in 1962 to form Associated Semiconductor Manufacturers (ASM). By the terms of this agreement, GEC held a one third share and Mullard the remaining two thirds. GEC were to cease device fabrication, and the Hazel Grove (Stockport) factory came under the control of Mullard. The Hirst Research Laboratories remained with GEC,a section of which was to assist in carrying out development work for ASM. However, emphasis on integrated circuit development was now shifted to Philips laboratories elsewhere, and Wembley was hardly involved in this work during the remainder of the sixties.[121]

The above arrangement led to problems however, due to the major semiconductor production site at Millbrook being physically remote from the Hirst location. Because of this, Mullard management formed the view that advanced development would be best carried out in close proximity to the production area.[122] Consequently, in 1969 when GEC effectively rescinded the agreement, the Hirst Research Centre withdrew from its association with ASM. The formation of Associated Semiconductor Manufacturers had brought into question the role of the Wembley Laboratories, since Mullards main interests then lay in the mass production of germanium transistors for commercial markets.[123] Opinion within GEC at this time was that of growing concern at the potential of silicon integrated circuitry which was now being produced within the US.[124] Although research and development at Wembley in the area of silicon technology was reduced, it was not altogether abandoned. This continuing research in silicon was subsequently to prove of great value during the period following the introduction of the silicon planar transistor, and played a leading role in assisting both Mullard (Southampton) and Philips to set up production facilities to develop this new technology.

In 1967, GEC had acquired Associated Electrical Industries Ltd. (AEI), thereby obtaining a semiconductor facility at Lincoln. Since under the terms of the ASM contract, the Company had agreed not to engage in independent semiconductor production, they reduced their shareholding to a nominal percentage. GEC's stake in semiconductor manufacture was however strengthened the following year by the merger with English Electric, thus acquiring the Westinghouse Brake/English Electric plant, then producing power silicon and germanium rectifiers.

These mergers and acquisitions were strongly supported by the Wilson Government through the Ministry of Technology and the Industrial Reorganisition Corporation.[125] The Corporation encouraged these activities on the grounds that it would lead to a necessary rationalisation of the heavy electrical engineering sector and also add to the effectiveness of the UK electronics industry. [Government support was given to the GEC-English Electric merger in preference to a rival bid by Plessey for that company.] Other acquisitions obtained through this purchase included Marconi Microelectronics, operating at Witham, and Elliott Automation at Glenrothes. Elliott Automation at this time produced 930 DTL and 990TTL by licencing agreement with Fairchild,[126] although production was being adversely affected by the TTL logic war with Texas Instruments. The decision by GEC to leave ASM in 1969 resulted from unsuccessful negotiations with Philips to incorporate these new acquisitions within a reconstituted partnership.

Nevertheless, having made these major acquisitions, the Group Managing Director, Lord Weinstock, took the decision virtually to cease production of semiconductors, concentrating exclusively on tailor-made chips.[127] In 1971 GEC closed down both the Elliott Automation and Marconi-Elliott fabrication plants. The reason for this decision was that, because of the TTL "logic war", a major re-appraisal affecting the future strategy of semiconductor manufacture within the Company was felt to be necessary.

Apart from the production of bipolar DTL, which was based upon licenced information from Fairchild, Marconi Elliott had also been manufacturing MOS (Metal Oxide Silicon) devices, and these were considered to be on a par with those being produced by Intel.[128] Nevertheless, it appears that a technical lag existed at this time in bipolar logic, and Marconi-Elliott were finding difficulty in obtaining TTL know-how from Fairchild. Also, GEC claimed that, contrary to reports before the takeover, substantially no work on I.C.'s had been carried out at AEI Lincoln.[129] The decision by GEC to close down these production facilities resulted in the UK being without any facility for standard chip fabrication. These closures formed part of a major restructuring of the Company, which was then taking place. During this period,and up to 1972/3, the pre-merger workforce of GEC, AEI and EE was reduced from 241,000 to 170,000. Although only low-level production of devices was being maintained following the re-organisation, GEC participated in the Government funded Microelectronics Support Scheme which ran between 1974 and 1979, and in addition received funding under the Electronics Component Scheme.

For well beyond the first half of the decade, GEC remained only marginally involved in device manufacture. For example, in 1977, although estimated turnover in UK semi-conductor manufacture amounted to $255 million, no more than 6.6% of this value was accounted for by GEC's activities.[130] During the following year, the Company's turnover in IC's in 1978 amounted to only $5 million. However in that year a substantial attempt was again made to enter the field through an agreement with Fairchild in order to produce 16k Dynamic Random Access Memories (DRAM's) and 64k Charge-coupled Devices (CCD's). A factory was to be built at Neston in Cheshire and it was planned to begin production in 1980. Both GEC and Fairchild were each to contribute $20 million initially and the UK Government about $14 million. However,in that year the project was abandoned, following the takeover of Fairchild by Schlumberger. This was because Schlumberger's management were less enthusiastic about the agreement, and commissioned a consultants' report which indicated that the joint venture would not be viable.[131] GEC subsequently decided to give up any large-scale attempt to manufacture digital IC's.

In 1980, GEC established Marconi Electronic Devices Ltd. (MEDL) from AEI Semiconductors in order to make power semiconductors and microwave components. GEC Semiconductors (Wembley) were then producing custom integrated circuits, MSDS Hybrid Division (Portsmouth) making hybrid circuits and Circuit Technology Inc. of New York, also manufacturing hybrid circuits. Subsequent expansion of MEDL has been the acquisition of Tektronics at Swindon, who make telecom hybrids, and Marconi Specialised Components at Billericay, manufacturing passive microwave components. In 1985, Marconi Microsystems was established at Swindon to incorporate all hybrid circuit interests.[132] By 1984/5, turnover in IC's amounted by value to about 1% of the British semiconductor market.[133]

The position of the Company by 1985/6 was that the total number of personnel employed amounted to 165,700, this figure including 127,800 in the UK Research within the fields of electrical and electronic engineering was carried out by GEC Research Ltd. This Division was organised into three centres, namely the Hirst Research Centre, Wembley, the Marconi Research Centre at Great Baddow, and the Engineering Research Centre Laboratories at Stafford and Whetstone. The staff employed at these three centres amounted to about 2,400, and this organisation was the largest of its type within the UK.[134] By 1986, GEC had become the sixth largest semiconductor manufacturer in Europe. Total R&D expenditure during 1984/5 amounted to £619 million, 37% of this sum being funded by the company. Operating profits for the Electronic Systems and Components Division from 1980/81 to 1984/5 increased fairly linearly from £107.2 million to £234.6 million, this figure constituting the largest Divisional contribution. Total company profits before interest and tax between 1981 and 1985 increased from £381 Million to £529 Million.[135]

From 1969 onwards, both Plessey and GEC had collaborated with the British Post Office in the development of System X, a major digital telephone exchange project, and since 1983 had held discussions on an occasional basis to consider the possibility of combining the switching businesses of both companies.[136] The object of this move, made under pressure from the DoI, was to be able to compete more effectively with the larger American and Japanese telecommunications firms within Europe.[137] The need for this strategy became more pressing, following the announcement in May 1982 by British Telecomm. that it would be offering around 30% of its switching business to international tender.[138] The main obstacle to agreement, however, lay in the fact that this activity comprised more than half of Plessey's activities. Furthermore, the amalgamation was viewed with disfavour by the MOD.[139] As talks progressed, GEC formed the view that in order to complete a successful merger it would be necessary to include, in addition, Plessey's semiconductor components activities supporting the System X development. A further round of discussions between GEC and Plessey began in June 1985, this time also involving British Telecom. However, no positive result emerged, and on 3rd Dec.1985, GEC informed Plessey of its intention to bid for the Company.[140]

Subsequently, during the period 1985/6, GEC attempted to take over Plessey. However, they were prevented at the time from doing so by the Mergers and Monopolies Commission, which ruled that the GEC should not purchase a share holding in excess of 15%. GEC's principal argument in favour of the merger was that it would provide the economies of scale necessary to fight off all foreign competitors both at home and abroad.[141] Plessey had argued against the merger on the grounds that it would create a situation of market dominance by one company within the United Kingdom. This view was supported by the MOD, which had recently been moving towards more competitive procurement policies. Such a merger would have created an organisation holding almost 25% of the MOD's £7.8 billion equipment budget.[142]

However, following the lifting of the imposed restrictions in September 1989, a successful bid for Plessey was made jointly by GEC and Siemens and in May of the following year GEC plc. took full control of what had been Plessey's device manufacturing facility. As a result, virtually all semiconductor manufacture within the UK was now in the hands of the General Electric Company. In July 1990 GEC Plessey Semiconductors (GPS) was formed by grouping together Marconi Electric Devices Ltd. (MEDL) and Plessey Semiconductor Ltd. (PSL). At that time, MEDL's primary product areas included hybrid devices, various microwave products,radiation hard silicon on sapphire (SOS) devices, and power semiconductors. Plessey semiconductors included CMOS, (which had been produced since the mid 70's) and high speed bipolar devices. Following the merger, G.E.C. semiconductors consisted of a Division 4000 strong, with main locations at Swindon, Plymouth, Oldham and Lincoln, together with a somewhat smaller design centre and chip fabrication facility at Scotts Valley, US.[143]

The history of semiconductor research, development and production within GEC reveals that the Company has a long record in all of these fields dating back to the industry's earliest days. Research of a considerably high standard, involving a wide range of materials and devices, and often in the forefront of technology, was carried out over many decades, principally at the Hirst Research Laboratories, Wembley. The Company received substantial Government support in its research activities, obtaining the highest percentage of CDV research contracts allocated to the various semiconductor firms from at least the late 60's up to and including 1974, when the number allocated still remained only second to Plessey until the end of the decade.[144] In view of the Company's lack of commitment to device manufacture, this level of involvement appears unduly high.

GEC is atypical of the semiconductor industry within the UK in respect of the number of takeovers and mergers in which it has been involved. This has necessitated considerable restructuring, which cannot have failed to have imposed a penalty upon both progress and efficiency and this is of particular importance within a rapidly evolving technology such as semiconductor manufacture. Although a large concern, GEC has found it difficult to support financially the continually rising costs which must be met in order to remain competitive within this field, and this in spite of Government assistance over a considerable period. It should be remembered however that this financial support was directed exclusively towards R&D, rather than into production technology, an area particularly subject to escalating costs.

The Company's general approach towards the leading edge of solid state device manufacture appears to have been one of caution. For example, GEC rejected participation in the Government proposed UK consortium to back INMOS, and in 1979 refused to buy that concern when it was offered for sale by the newly elected Conservative Government.[145] In retrospect, it appears that a critical watershed in the company's policy occurred during the period 1970/71 when the decision was taken to withdraw from manufacture of TTL bipolar circuitry. Like both Plessey and Ferranti, GEC were unable to meet the aggressive challange posed by the price war initiated by the high volume production of TI 54/74 logic.

It was particularly unfortunate that at this critical time Government support was not forthcoming, and the company subsequently forced, in common with the remaining European IC manufacturers, to adopt a defensive stance, withdrawing from mass-market bipolar logic production. In this respect GEC, like other British semiconductor manufacturers, suffered from an absence of a National long-term planning strategy designed to support the industry, or even a consistently defined role. GEC's participation in European collaborative research programmes during the period uder review was somewhat less than wholehearted. Although the company initially contributed to both the Alvey and ESPRIT activities, they subsequently pulled out of many of the Alvey programme's mainstream chip R&D projects before completion.[146]

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Chapter 7

Factors involving Industrial Performance - a Comparison between Britain and the United States

Introduction

The American semiconductor industry has been by far the major external influence upon the development of the industry in Britain. A significant contribution to this influence has been the disparity in the technical, industrial and financial resources available to both countries. The following review of these various resources is intended to assist in achieving an understanding of the environment in which the British semiconductor industry developed, and also help to define the limits governing both British industrial and governmental policy decisions.

With the exception of the United Kingdom, the European thermionic valve industry was in fairly poor shape in the immediate post-war years. In Britain, although both efficiency and output were greatly above pre-war standards, success in this field gave no indication of the ability of the industry to respond to technical changes which might ultimately undermine this very success. Technical expertise in thermionic valve production was to be of little use in the new solid-state technology, and within the latter area an undoubted advantage lay in the sheer volume of effort available within the United States. Considerable solid-state "know-how" had already been transferred by Britain to America from 1941 onwards, as part of wartime technology transfer agreements, so that any initial advantage possessed by the United Kingdom within this area had been lost. The American effort from this time onwards, both in the production of solid-state devices and fundamental research, was much greater than the British and, at the end of the Second World War, the size of this enterprise far exceeded that in Britain or indeed anywhere else.

Research and Development

R&D Resources within America and Britain

A comparison within this field shows a considerable imbalance between numbers of scientists and engineers employed in the respective countries. Furthermore, due to the larger size of American firms, research effort tended to be more highly concentrated. As well as being much larger, it was estimated in 1962 that the American electronics industry received nearly 2.5 times the relative research support.[1] Concentration of scientific effort within the field of solid-state research has been important, particularly in view of its multidisciplinary nature. It has enabled research teams to be formed which comprised first-rate individuals from a variety of disciplines. The recruitment of such teams from a smaller scientific community, such as in Britain, presented a greater problem.

In this context, it is important to mention the special role of Bell Laboratories, the research division of the American Telephone and Telegraph Company (AT & T). Based in New Jersey, Bell was far largest research organisation engaged in semiconductor research. This company was responsible for the majority of innovations during the formative years of the industry, and held a virtual monopoly of expertise in the field until about the mid-fifties. During these early years, it assisted greatly the diffusion of semiconductor technology, by supplying technical information to the industry through symposia and licensing activities. It also played the principal role in training the first generation American semiconductor engineers.

At the time of the invention of the transistor, Bell Laboratories employed 5700 personnel. Of this number, 2000 were described as professional staff of the highest quality.[2] By

1959, the total number of personnel had risen to 10,800, a third of whom were professional scientists and engineers.[3] In contrast, a survey held in 1963 gave the total figures of those engaged in research within the field of electronics and radio within the whole of the United Kingdom as only 2460. Of these, about 1000 were employed by industrial firms, and another 700 by the universities.[4] The largest British Government Research Establishment employed probably less than 2000 staff at this time, and of these, only a few hundred would have been qualified scientists. The number of professionally qualified scientists in both countries was probably somewhere in the ratio of between 8:1 and 10:1 in favour of America. Of those working within the solid state field, the ratio was most likely even greater.

Equally important, was the difference in the number of production engineers engaged in such activities as "on the line" device development and yield improvement. The number of production engineers trained to degree standard within the United States was estimated in 1966 as being around 10,000, compared with 300 in Britain.[5] After making due allowance for differences in respective degree levels, an overwhelming advantage in trained manpower could hardly fail to lie with American industry. Apart from these numerical differences, there existed a large discrepancy between the ratio of research workers within the electronics manufacturing industry and the total number of workers employed. It was estimated in 1963 that within the United States, every thousand workers were backed by 13 research scientists and engineers, whilst in the Britain. the figure was 5 per thousand.[6] Apart from American manufacturing industry's possessing a stronger scientific base, these figures suggest that a larger reservoir of scientifically trained personnel was available for recruitment into the rapidly growing semiconductor industry than was the case in Britain.

British and American Public Funding - A Comparison

Government research activities within the United Kingdom have been generally less productive in terms of commercial spin-off than similar work within the United States. One important reason for this is that at least until the late 60s most funding within Britain was directed into government research institutions and the universities. This activity was not intended to produce a commercial spin-off, although some of the work had undoubtedly an indirect, marginal effect on sales.[7] Nevertheless, much of this research was of a technically advanced nature, and therefore mainly of use to organisations working at the leading edge of the field. Unlike the situation within commercial laboratories, published findings were available on a World-wide basis. It is likely therefore that a fairly high proportion of this work would have been of greater use to more technically advanced rivals overseas than to indigenous firms.

In the United States, in contrast, public funding tended to be directed towards establishing industrial production lines, in order to produce devices designed to satisfy the needs of the Department of Defense. Other funds were made available by the Department of Defense for commercal R&D to selected firms. It is unlikely that a high proportion of this money would have been spent on work of a fundamental nature, but rather upon projects with prospective market potential.[8]

Apart from R&D contracts, American Government money was assigned to semiconductor firms through the Army and Signal Corps in the form of "Production Engineering Measures". From 1951 onwards, annual sums were distributed for specific semiconductor R&D work. However, additional sums were also spent, mostly in the form of cost reduction and yield improvement contracts, and to improve product reliability.[9] From about 1958 onwards, research efforts were considerably increased, funded by all branches of the United States armed forces. This strategy was given particular urgency by the Soviet

Union's successful 1957 Sputnik programme. The development of microminiaturised components was as a result given considerable priority, with the object of producing reliable devices with minimum payload for applications in rocketry.

There can be little doubt that this form of directed funding played a highly important role in stimulating the early development of efficient production processes within the rapidly emerging American semiconductor industry. The U.S. Department of Commerce has published the following data regarding direct Government funding for semiconductor R&D and Production Engineering Measures.[10]

Year	**1955**	**1956**	**1957**	**1958**	**1959**	**1960**	**1961**
R&D ($M)	3.2	4.1	3.8	4.0	6.3	6.8	11.0
Product refinement (Trans.)	2.7	14.0	-	1.9	1.0	-	1.7
Diodes & rectifiers	2.2	0.8	0.5	0.2	-	1.1	0.8

Apart from the sheer scale of effort, American Government support formed an extremely high percentage of Research and Development. One estimate puts the total Government contribution to R&D between 1958 and 1974 as $930 million, compared with $1200 million supplied from private funds.[11] The same author estimates total technical effort between 1955 and 1975, including production assistance and marketing, as at least $3 billion.

When comparing the procurement strategies of both governments, it is important to realise that the same objectives lay behind their different approaches. Acting through their respective military authorities, their objective was to obtain adequate and reliable supplies of solid-state devices with approved characteristics as rapidly as possible. This was particularly the case with the integrated circuit. Within America it was done by generously stimulating industry through direct Government R&D funding, and also, perhaps more importantly, through the medium of production contracts aimed at increasing production efficiency. Furthermore, a guaranteed market was assured, since the Government was prepared to buy very large quantities of these devices during the early high-cost phase of production.

In the United Kingdom, the approach adopted was to obtain, from whatever source, the components needed to meet requirements. Consequently, until the late sixties, no attempt was made within the United Kingdom to assist local industry in developing the field of production technology, state funding being restricted instead to assisting the production of a limited number of specialised devices for military applications. During this early period, Government Research Establishments within Britain were also engaged in research activities in the field of microelectronics, although on a limited scale. Some measure of contact existed between these establishments and their counterparts in America, but it seems unlikely that any exchange of information at this time contributed significantly to the development of the industry. This was because of lack of British effort in silicon technology within the establishments, and also the non-commercial nature of these organisations.

Early Government Involvement in Transistor Manufacture

The American Government's interest in semiconductor technology had been present from the time of the invention of the transistor. However, there was some initial hesitation in procuring large quantities of units while it was an untested device. Reliability was a major consideration to be taken into account when operating complex electronic systems in a military environment, and a period of life-testing was therefore essential before acceptance. Nevertheless, substantial support was given from the outset to American semiconductor manufacturers, as can be seen from the following table:[12]

Year	% of total sales to US government
1950	24%
1951	36
1952	59.5
1953	57.7
1954	55.2
1955	54.6
1956	53.4

The US Military were quick to realise the importance of the *silicon grown junction* transistor, first manufactured by Texas Instruments (TI) in 1954. For the first three years or so all supplies were bought up for Government use. As in the case of germanium devices, large scale production resulted in rapidly falling unit costs, enabling these devices to become increasingly attractive to commercial markets[13]:-

Year	Sales of silicon devices (M's)	Average device value ($)
1954	n/a*	23.95
1957	1.0	17.81
1961	13.0	7.48
1964	118.0	1.46
1965	256.0	0.86

**Certainly well below one million units.*

In contrast to the American approach, the policy pursued by the British Government, as discussed in Chapters 4 and 5, was to procure devices for military requirements from any reliable source, in order to meet current needs. Government research establishments, although carrying out some work in the microelectronics field, at least during the early years, largely concentrated upon work of a more specialised and fundamental nature, avoiding areas leading to commercial spin-off.[14] In view of the relatively weak state of the local industry, the practical result of this policy was that the Ministry of Defence itself soon became a substantial market for overseas competitors devices.

University Research

A major problem facing university research during the early years of semiconductor development within the United Kingdom was the shortage of money to finance research projects. At least in the early 60s, practically no money was available from university sources, and departments involved in the area of solid-state physics were dependent almost entirely upon grants and contracts from outside organisations.[15] Evidence exists that although there was not a shortage of potentially qualified research material, there were restrictions on what could be done, due to funds from the Department of Scientific and Industrial Research (DSIR) being limited. A further difficulty was that this Department did not seem to have a committee dealing specifically with electronics research, and applications had to be channelled through other committees, with consequent lack of co-ordination. As a result, almost all research students had to be maintained with money from American sources.[16] However, these sources usually wanted their help to be matched by contributions from the countries receiving this assistance.

In view of the large American financial contribution to university research, access to this work would be immediately available to both parties involved. Because of the technical lag already existing between the British and American semiconductor industries, the results of research findings would be more likely to be of immediate value to American companies. Furthermore, the close links established between research workers in British universities, and the various institutions within the United States engaged in similar work, facilitated movement of personnel from Britain to America, where research funds were more readily available, and salaries more attractive. Indeed, recruitment by various American organisations was not confined to British universities, but extended to Government research departments. A report by a committee appointed by the Royal Society on "Emigration of Scientists from the U.K." published in 1963, and confined to scientists who were normally resident, and had obtained a Ph.D in the United Kingdom, concluded that the number of permanent emigrants had increased by a factor of 3 between 1952 and 1961. Also, the annual rate of emigration of recent Ph.D's was currently 12%, more than half this number (about 7% of the total) going to the United States.[17]

Unlike the situation within Britain, where no specific programme existed aimed at encouraging work within the solid-state field, the United States Department of Defence supported training within this area from the early 50s onwards, in addition to encouraging faculty research. Defence funds amounting to between $1 to $2 Million, supported over 100 doctoral candidates during this time.[18] Furthermore, the number of doctoral degrees in physics generally grew fourfold between 1950 and 1970.[19] Following the launching of Sputnik, a crash programme was initiated, student support being greatly increased at all levels. The programme, initiated in 1959, resulted in a marked increase in Government support which did not decrease until after 1966[20] Although full details for electronics and solid-state physics student support are not available, the data published below, covering grants for students of all scientific disciplines, is believed to be representitive of the prevailing pattern.[21] The figures are published by the American National Science Foundation, the body responsible for student financial support.[22]

Estimated National Science Foundation Obligations for Student Support

Year	Funding ($M)	Year	Funding ($M)
1954	1.8	1959	14.71
1955	1.85	1960	15.94
1956	2.36	1961	15.23
1957	3.00	1962	20.01
1958	4.22	1963	26.6

Industrial and Economic Factors

Availability of Venture Capital

In the early days of semiconductor manufacture, the relatively small amount of venture capital needed to enter the industry did not constitute a barrier, at least in the United States, where funds were at that time readily available. Furthermore, the rapid success of semiconductor firms then starting up attracted additional capital to the industry, in direct contrast to the situation in Britain and the rest of Europe, where start-up companies were almost non-existent. The successful companies entering the industry at that time tended to adopt "creaming" tactics, selling new types of devices under monopoly or near-monopoly conditions to an expanding and assured market. Subsidiaries of start-up companies operating overseas, such as Texas Instruments within the United Kingdom, did not suffer from the same disadvantage as their European counterparts in raising capital, operating as they did under the financial umbrella of their parent companies.

Number of Employees within the Domestic Sector of the Semiconductor Industry

No. within the US [23]		*No. within the UK* [24]	
Year	*Number*	*Year*	*Number*
1954	4,300	1954	n/a
1956	11,200	1956	"
1958	23,400	1958	"
1960	52,600	1960	"
1965	67,400	1965	"
1970	88,500	1970	"
1973	120,000	1973	15,200
1978	131,200 (+ 89,300 outside the US)	1978	12,200

The above figures show that following the inception of semiconductor manufacture within the United States, the number of employees within the industry rose rapidly, although by 1974 it reached a plateau. An important feature contributing to the latter development was the decision taken by American semiconductor manufacturers to move the labour intensive assembly process, involving wafer and thermocompression bonding, to countries overseas in which wage rates were considerably lower than in the parent country. Published figures for the British semiconductor industry are meagre, although they are sufficient to show that the total numbers employed are no more than a small proportion of those within America.[25] Furthermore, the discrepancy is even greater when it is realised that the British figure includes labour employed by overseas manufacturers operating within the host country.

Wage Rates

From the early 60s onwards, an increasing proportion of American semiconductor chip final assembly work took place overseas. Since this part of the production process was the most labour intensive, the result was a considerable cost reduction. The initial capital cost of setting up assembly plant would of course be more likely to inhibit smaller manufacturers, including the majority of British firms. Although British firms would gain in wage differentials by overseas activities, the gain would not be as great as for American firms. Hourly wage rates for assembly workers both in America and in countries where assembly plants were set up are included below for reference.[26]

Hourly Wages

Country	*Year* 1966/7	1973/4
United States	$2.50	$3.50
United Kingdom	$0.6-0.8	$0.8-1.0
Hong Kong	$0.25	n/a
Korea	$0.10	$0.15
	(Adjusted for fringe benefits)	
Malaysia		$0.15 (1973) $0.30 (1974)
	(Adjusted for fringe benefits)	
Mexico	-	$1.25
Singapore	$0.11	$0.30
Taiwan	$0.19	n/a

Cost of Entry into the Industry

During the early period, entry into semiconductor manufacture involved a relatively small capital investment. Due to readily available venture capital during the early years of the industry, the barrier to entry was low in this respect and within the United States a rapidly growing number of firms began production. With increasing complexity of the production process, the initial capital investment needed became progressively greater, and during the 70s the number of start-up companies declined. This increasing cost of entry also coincided with a decrease in availability of investment capital, and higher interest rates. The average or "typical" capital investment needed to set up a production facility over the first thirty years of device production was approximately as follows.[27]

Year	Average or Typical Investment
1950-55	$100,000
1965-70	$500,000
1972	$2,000,000
1979	$10,000,000
mid. 80s	$30-40,000,000
1992	> $500,000,000 (to set up a VLSI plant)
1993	$500,000,000-$1bn.

For a firm lacking any semiconductor expertise, the barrier to entry would be considerably higher than the above figures suggest. (At present therefore, there is little question of any British firm setting up VLSI fabrication plant. Such work can now only be undertaken on a European scale, possibly as a joint venture with substantial government backing.)

Cost of entry into manufacture includes buildings, plant and equipment, in addition to expenditure upon R&D. By far the most expensive item, and therefore the principal financial barrier to entering semiconductor manufacture,is production equipment. Furthermore, this item is an increasing proportion, amounting by the mid-eighties to typically 40-50% of total cost. Once the plant had been established, principal running costs would be wafers and masks, which might amount to at least 50%. Labour costs tend to diminish as a proportion of running costs, and by the mid-eighties amounted to about 5-8%.[28]

Although it may be possible to specialise, and to enter the industry on a low volume production basis, subsequent growth may be more difficult. Entry at a point well down the production cycle may substantially reduce initial capital cost, as equipment costs fall, but the price to be paid for this policy is high, since competitors will by then be producing devices in quantity, more cheaply, and breaking into the market under these conditions may be costly. Furthermore, the cost of R&D increases markedly as the product becomes more sophisticated, and consequently this facility must be maintained on an increasing scale.
As an example of increasing manufacturing cost, Golding mentions a six-fold increase in annual capital expenditure per production worker between 1958 and 1966.[29] He quotes a

figure for entry into integrated circuit manufacture within the United Kingdom as $2 million per year in 1968.[30]

The increasing cost and sophistication of production equipment during the seventies, restricted its manufacture to a small number of specialised companies, mainly located within the United States. (For example, Perkin Elmer, Electromask, Kulicke & Soffe and GCA.) Consequently, from then onwards, British semiconductor manufacturers had no choice but to rely on these firms for essential items of production plant. This situation was new to the device manufacturing industry, which had been to a large extent nationally self-sufficient since the beginning of thermionic valve manufacture. Being centred far outside the major skill clusters, this development introduced further disadvantages to prospective equipment buyers in Britain. For example, extended delivery dates, higher installation costs, less efficient after-sales assistance and perhaps less of an opportunity to evaluate alternative equipments.

The rapid escalation of equipment costs may be gauged from the following figures, published in 1980.[31]

Ion Implantation Equipment: Cost: $500,000-$600,000.
Two of the above machines are needed for each chemical to be implanted.

Wafer Steppers: Cost: $500,000 each. (INMOS ordered between 15 and 30 of these).

Plasma Etching Equipment: Cost: about $100,000 per unit. Two each are needed for the substances which have to be etched. (For example, Aluminum, polysilicate, silicon dioxide and silicon nitrite.)

Projection printer: Cost: $150,000 each. A large company such as Intel would possibly have 100 of these units.

Electron beam lithography equipment: Cost: about $1.5 million each. A replacement for photolithographic equipment. Slower, but a means of obtaining the higher resolution needed for very large scale integration.

As the cost of production equipment increases, it becomes increasingly important to choose the right technology. For example, a decision whether to go for ion implantation or electron beam lithography would be a major policy commitment, and if the wrong decision were reached it would have considerable repercussions. Not only does this situation mitigate against the financially weaker firm, but it also disadvantages smaller national industries, such as the British. In a country with only one or two major producers, a wrong decision at this level by one manufacturer would seriously weaken the whole industry. In Japan or America, where larger numbers of firms exist operating at the leading edge of technology, a wrong decision by one or two firms would not be such a serious matter at a national level.

A further barrier to entry into the industry which may arise due to increasing technical sophistication, is shortage of qualified personnel. This problem has considerably more significance in a country such as Britain, where a pool of highly skilled semiconductor engineers does not exist. The situation becomes worse as a technical lag develops, and then it may become necessary, as in the case of INMOS, to import key personnel from more technically advanced countries. It has been suggested that Ferranti had difficulty in recruiting engineering personnel of a suitable calibre, specifically affecting the manufacture of Uncommitted Logic Arrays,[32] and it is likely that this problem may also have prevented other firms from expanding production.

Technical Spin-Off under Conditions of an Assured Market

Several early American semiconductor spin-off companies started with two considerable advantages: they had the technical expertise to satisfy an assured (military) market; and they operated under conditions of limited or non-existent competition. For example, Texas Instruments held a monopoly on silicon grown junction transistors from 1954 for about three years, supplying these under US military contract. Transitron produced gold-bonded diodes from 1953 onwards, supplying the great majority under military contract, whilst Fairchild, set up in 1954, was also almost entirely dependent upon military contracts during its first years. All these firms made extremely high profits, and grew rapidly. Texas Instruments, for example, saw its share values increase from $5 in 1952 to $191 in 1959.[33] Transitron sales rose from $1 million in 1954 to $42 million in 1959, and Fairchild's sales rose from $0.5 million in 1958 to $27 million in 1961.

All the companies mentioned above had obtained their technology by the transfer of technical personnel from Bell Laboratories. Although these Laboratories were very liberal with regard to licensing policies towards foreign firms,[34] this is quite a different situation to the actual transfer of technical personnel. This because such individuals bring with them expertise in production technology, and are able to implement it in minimum time, having experience already well down the learning curve. A number of these spin-off companies, armed with state-of-the-art expertise from Bell Laboratories, rapidly became dominant within the American semiconductor industry, and having established that dominance, tended to retain their pre-eminent position.

Skill Clusters

An important characteristic of the American semiconductor industry has been the presence of "skill clusters". Semiconductor firms have, with a few exceptions, tended to set up business in close proximity. Factors responsible for this development include the need for close contact between semiconductor firms and suppliers of materials such as highly pure metals, gases, and manufacture of equipment specific to the industry. Furthermore, the cost of these sophisticated materials and services has been higher in Europe than within the United States.[35]

As a skill cluster developed in size, other specialised technical and financial services necessary to support and maintain the industry would tend to be attracted to the area, increasing in turn the desirability of the given location. The most important example of this development is the "Silicon Valley" complex in California. Within the United Kingdom, because of the relatively small size of the industry, no comparable skill clusters developed. Services and equipment had therefore to be obtained from specialised sources, often distant from the user. For example, high quality diffusion furnaces, wafer bonding equipment and thermocompression bonders were usually imported from the United States. The alternative was to manufacture this equipment on site, with consequent delay and perhaps no real insight into what was really required. In a rapidly developing industry, such as semiconductors, this situation puts the manufacture at a grave disadvantage, and even in America it is notable that the only firms which have survived outside skill clusters, for example Texas Instruments in Dallas and Motorola in Arizona, are very large and well established.

In an industry where the swift transfer of technology is at a premium, firms operating within skill clusters rapidly obtain technical knowledge through a wide variety of sources, particularly within a culture of high labour mobility, such as the United States. The important factor in this situation is current technical know-how, particularly in the field of process technology, and its speed of transfer. Geographically isolated firms situated far from skill clusters, for example within Europe, are denied any immediate spin-off, and under these conditions up to date technical know-how is much more difficult to obtain. It is therefore significant that a survey of forty-two American semiconductor firms demonstrated that only four regularly transmitted information on process technology to foreign companies.[36]

Labour Mobility

A further advantage held by American microelectronics industry over that of Britain has been that because of its large-scale industrial development, there were many more sophisticated firms operating within the electronic industry, with a much larger potential pool of skilled personnel. Unlike the situation in Britain, skilled labour mobility within the United States has tended to be high.[37] Because of this culture of high labour mobility, a sizable reservoir of highly skilled scientists, engineers and technicians has constantly been available for recruitment into any new rapidly developing technical field. This factor is of particular importance within such an industry as semiconductor manufacture, which, because of its multidisciplinary nature, involves bringing together numbers of chemists, physicists, metallalurgists and engineers in order to form balanced teams. The relative strength of these teams, whether operating at the research or development-production level, must largely determine the rate of technical progress and production efficiency.

A specific case where labour mobility greatly assisted the early growth of semiconductor manufacture in America, is the well-known example of the diffusion of technical expertise from Bell Laboratories to an extremely large number of firms. In this respect, Bell was unique in providing a technical stimulus. This situation has been analysed in detail by Golding.[38] In general, movement between academia and industry has been much more frequent within the United States, and a higher proportion of goal-oriented work carried out within the universities.

Communications

In spite of its size, the United States possesses an excellent communications network, and one advantage of this asset is that it generates an environment which assists the exchange of technical expertise, and enables knowledge to be diffused extremely rapidly. However in Europe, communications between firms operating across nation states are hampered by both language difficulties and cultural factors, and little movement of personnel between companies has occurred. A good communications network can hardly fail to assist the rapid solution of technical problems· With its considerably larger number of semiconductor companies, enjoying a high degree of technical interaction, the American semiconductor industry has been certainly better placed than either its British or Continental counterparts in this respect.

Conditions Governing Market Entry

Since the major stimulus for technical progress in device manufacture during the 50s and 60s, lay in the field of US military procurement, entry into this market was highly important to semiconductor manufacturers. Undoubtedly this military market was far larger than any within Western Europe, and because of its size the only effective one large enough to be able to stimulate a "pump-priming" effect. Because of this, one would expect foreign firms also to attempt to gain access to this lucrative market. This was however effectively prevented by the "Buy America" policy. Under this arrangement, foreign firms seeking contracts have been required to bid 6% below the lowest bid made by any competing US company, and 12% under the lowest bid made by those US companies located in a "labour surplus" area, or qualifying as a small business concern.[39] Furthermore, for balance of payments reasons, foreign bids involving military procurement have since 1962 been subject to adjustment by having imposed upon them an increase of 50%, this figure including transportation costs, but excluding duty. This method of adjustment, or alternatively the 6-12% rule, may be applied on the basis of whichever most favours competing US companies.[40]

European observers have regarded the Buy America Act as being of importance in restricting access to the large American semiconductor market.[41] Not only has it restricted market size for non-American producers, but done so within the most sophisticated and technically advanced sector. In view of the relatively small size of the European defence industries, the economic advantages of producing technically advanced products have been considerably diminished, by effectively being denied access in this manner. There can be little doubt that this situation has also significantly contributed to technical lag within the industry, since small-scale production of such devices involves considerable costs, and it may not be economically worthwhile to enter production. Restricted to potentially small markets for advanced devices, there is then no opportunity to develop the techniques of mass production, so essential in reducing unit costs.

Apart from the abovementioned trade barriers, many military contracts are arranged on an exclusive basis, and foreign firms would not of course be a party to this type of arrangement. Also, all semiconductor imports into the United States are subject to an ad valorem duty which in 1968 stood at 11%. As well as security and tariff restrictions, other considerations mitigate against semiconductor firms attempting to export overseas. For example, equipment manufacturers usually prefer to buy within their own country, since this makes liaison between supplier and user easier to maintain. Licensing agreements with American companies may also prevent the export of semiconductors from competing countries.[42]

It appears therefore, that the most technically advanced portion of the American semiconductor market was, from its earliest days, effectively protected against overseas competition. Within the United Kingdom, the situation was in complete contrast. From 1957 onwards, the most technically advanced devices were being manufactured by a major overseas competitor, who, with Government encouragement, established a bridgehead, unaffected by import restrictions of any kind, and with an assured indigenous military market. Heavy penetration of the home market by large overseas firms, already mass-producing extremely advanced devices within the United Kingdom, constituted a formidable barrier to entry for any potential British manufacturer. The problem was compounded by the constantly high rate of technical progress within the industry, and a shortage of adequately trained personnel at all technical levels.

Marketing

An OECD survey published in 1968 stated that the relatively stronger performance of American firms (including subsidiaries) in the European market was to a large extent explained by the rapid commercial exploitation of the more up-to-date technology and to some extent by superior marketing attitudes and techniques.[43] A major impact upon semiconductor sales within Britain was made at an early stage by Texas Instruments, operating from production plant situated within the United Kingdom, and employing British sales staff. Sciberras points out that "it has been claimed by competitors that TI had the most efficient planning and decision making procedure of any company in the World".[44] Certainly the organisation placed great emphasis upon its marketing activities and was highly efficient in this respect, employing only sales engineers with degrees, who were relatively well paid and enjoyed a high status within the company.

Significantly, Texas, as market leader, were selling, right from the start, more advanced products than its British competitors. It was particularly unfortunate for British semiconductor manufacturers that the home market was targeted at an early stage by such a formidable rival. This company was of course most suited to supplying the needs of the Ministry of Defence during the early years of transistor production.

Apart from emphasising Texas Instrument's activities, research has shown that volume of sales per sales engineer in Europe is roughly 3 to 5 times lower than within the United States, and this ratio also applies to overseas subsidiaries of American companies.[45] It has been suggested that this significant difference is not due to the volume of sales per sales engineer, but to the environment in which they operate, since for an equivalent volume of sales, the number of contacts that must be made is greater. Although it is difficult to see how overseas subsidiaries could be so advantaged, it is certainly the case that the number of large firms engaged in equipment manufacture within the United States considerably exceeds that in Britain, or indeed any other European country. Consequently, orders for components would tend to be correspondingly larger.

Although no specific data appears to exist regarding the sales performance of British semiconductor manufacturers, comparative figures published for the electronics industry show sales per employee to be lower than in any other major electronic producing country. Since British semiconductor manufacturers are invariably vertically integrated electronic equipment manufacturers, it seems reasonable to conclude that the following figures, published by Larson Sweeney Associates Ltd. in 1981, give a reliable indication of semiconductor sales performance.[46]

Electronic Industry Sales per Employee

Country	*Sales per Employee*
West Germany	£20-£40,000
France	£20-£50,000
Sweden	£20-£30,000
Italy	£12-£20,000
America	£15-£50,000
Britain	£10-£13,000

These figures appear to give some support to the frequent assertion that sales and marketing personnel are accorded a relatively low status in British manufacturing industry.

The above report also stated that capital utilised by employees within the United Kingdom electronics industry then stood at between £3,000 and £6,000 per employee - the lowest in any major electronic producing country.

The Integrated Circuit

The US Integrated Circuit Procurement Programme

The US Integrated Circuit Procurement Programme played a major part in increasing the disparity of resources which exist between the British and American semiconductor industries. This programme was inaugurated under conditions of urgency in response to a perceived military threat. For example, a report, published in 1966 for the National Commission on Technology, stated "Technological gaps, like that highlighted by Sputnik in 1957, must be avoided if we are to remain ahead".[47] The United States Government's procurement strategy, designed to stimulate integrated circuit production, proceeded on similar lines to the successful policy used to initiate the large-scale production of transistors, but within a reduced time scale. Total funding for R&D of integrated circuits alone amounted to more than $100 million between 1959 and 1965.[48] In the case of integrated circuits, however, the effort was much more highly concentrated than in the discrete device programme, both in the number of firms involved and in terms of time scale.

Also, unlike the case of the transistor, in which substantial Government support was given only a few years after its announcement, (i.e. from about 1952 onwards) support for the Integrated Circuit was immediate. This support came soon after the beginning of the Soviet space programme, at a time when missile systems were rapidly replacing aircraft.

For example, within the United States defence budget in 1955, aircraft accounted for 36.3% of total procurement, and missile systems only 5.4%. By 1960 the picture had changed substantially, with aircraft accounting for 22.5% and missile systems substantially increased to 23.4%.[49] It is significant in this context that 42% of the cost of a missile at that time was accounted for by electronics equipment, and in addition to a reduced payload, the integrated circuit was able to offer increased reliability at decreased cost.

The first patent for an integrated circuit was filed in February 1959 by J. Kilby of Texas Instruments. This involved a germanium device which would have been extremely difficult to manufacture on a production-line basis. This was followed about six months later by the invention of a silicon planar diffused integrated circuit by R. Noyce at Fairchild. This device was to establish the future pattern for the successful production of integrated circuitry. Already by March 1961, Fairchild had produced its first range of these new microelectronic components.

Highly aware of the significance of this invention, Texas Instruments initiated a six-month crash programme, which resulted in the production of a range of integrated circuits by August of that year. As early as 1959, the first U.S. Air Force contract to produce integrated circuits had been given to a number of firms, including Westinghouse, followed by further contracts late in 1960. In 1962, the first major contract for integrated circuits was awarded to Texas Instruments. This involved manufacturing 300,000 devices for the Minuteman 1l missile programme. The value of contracts assigned to Texas and Westinghouse at that time amounted to a little over $5 million.[50] It was estimated in October 1962 that 60% of the value of all orders for integrated circuits up to that time were accounted for by the Minuteman 2 missile programme. However, in 1963 the NASA Apollo contract overtook Minuteman 2 with regard to the number of units supplied, although not in terms of Dollar value. The majority of the units supplied under the Apollo contract were made by Fairchild. In 1964, these contracts absorbed over 90% of the industry's output in dollar terms.[51]

Not only therefore was the diffusion of integrated circuit technology between the leading U.S. semiconductor companies extremely rapid, but immediate Government support on a lavish scale was made available to rush these devices into production. At the same time, considerable funds were also made available to key firms for continuing R.&D. For example, between 1967 and 1969, Texas Instruments received $229 million in Government support, amounting to 60% of its total R.& D effort.[52] The major recipients of these large production contracts, were, with this assistance, able to advance substantially down the learning curve, enabling them not only to establish themselves as market leaders, but also helping them to continue to maintain this position. As in the case of the transistor, the pump-priming action initiated by Military funding resulted in a rapid fall in price, as shown in the following table.[53]

Year	Average price per device ($M)	% consumed by military
1962	50	100
1963	31.6	94
1964	18.5	85
1965	8.33	72
1966	5.05	53
1967	3.32	43
1968	2.33	37
1969	1.67	

Note that the average selling price = (1971) current dollars.

Some idea of the rapidity of integrated circuit development due to the pump-priming process, may be obtained from a consideration of the magnitude of production within the United States destined for the commercial market during the period in question, and reproduced below.[54]

Year	Unit Volume (Millions)	Dollar Volume (Millions)
1963	0.5	15.8
1964	2.2	40.7
1965	9.5	79.1
1966	29.4	148.4
1967	168.1	220.4
1968	133.2	303.2
1969	252.9	413.4
1970	298.8	433.1

The effect of these large US Government government contracts was to establish the principal recipients as the leading World seniconductor manufacturers for at least two decades. These few companies were consistently to dominate the American semiconductor industry, and should therefore be considered as a special case. Furthermore, it was these companies, and Texas Instruments in particular, which were also to dominate the British semiconductor market fron the early 60s onwards.

In contrast to the situation in America, the semiconductor industry in Britain was fragmented, with overseas companies producing the principal number of components. This state of affairs existed right from the start, with Mullard Ltd. being the main producer. The dominance of foreign-based manufacturers is illustrated by the following data.[55]

Year	No. of firms operating in UK	% of market share held by top 3 companies	Top 3 companies
1958	15	89	Philips, AEI, GEC.
1962	19	72	ASM, TI, Ferranti.
1967	16	55	ASM, TI, SGS-Fairchild.
1968	17	61	TI, ASM, SGS-Fairchild.

By 1967 at the latest, all the three top companies were foreign multinationals, operating with the advantage of technical and financial resources provided by their parent organisations, and also engaged in the mass production of devices within their home base. The problem facing indigenous companies almost right from the start was how to break into the home market. The leading British semiconductor manufacturers, for example, Plessey, Ferranti and GEC proved unable to do so on a substantial scale, and it is therefore doubtful whether any start-up company, even if provided with similar financial backing, could have succeeded in this environment. Attempts at establishing start-up companies were rare, and invaribly ended in failure. Not only was there significant market penetration of the home base by foreign producers from the earliest days of the industry, but this penetration was most pronounced in the field of United Kingdom Government procurement. This was because, right from the start, the most technically advanced devices were needed by the military authorities, and British companies were unable to meet their requirements, due to technical lag.

Patents and Licencing

Unlike the situation existing within the thermionic valve industry, American firms have held a dominant position in respect to the possession of patents. The generic (Shockley) patents were held by Western Electric, (Bell Labs.) and contained details of the bipolar transistor effect. They covered all transistors of this type, regardless of their method of construction. In addition, Bell held patents covering the circuitry necessary to obtain the transistor effect. Bell also held the extremely important patents covering diffusion and the epitaxial process. Fairchild held the patents covering the planar process, and Texas Instruments held the bipolar integrated circuit patents. In view of much earlier work, no master patents exist covering the important Metal Oxide Silicon (MOS) process, either at the discrete or integrated circuit level.

Previous to 1968, patent rights within the United States were granted for sixteen, and thereafter for twenty, years from the date of registration. Possession of semiconductor patents covering the key processes of manufacture, therefore allowed Bell laboratories, together with a number of leading manufacturers, to obtain substantial royalties through licencing activities over a considerable period. From the very beginning, Bell adopted an open policy towards the granting of licences, thus assisting in the rapid diffusion of transistor technology. This policy resulted from an anti-trust suite, negotiated with the Department of Justice in 1956, under which AT&T was prevented from selling semiconductors to commercial customers. Furthermore, the Company was required to licence all existing patents royalty-free to any domestic firm and guarantee licencing at reasonable royalty rates.[56]

Between 1952 and 1964, Bell transistor patents were licenced to about 100 firms, of which the majority were outside the United States.[57] By 1974, 179 licences had been issued by Bell, of which about 65 were foreign. All firms attending the Bell first technology symposium held in April 1952 had to obtain a licence costing $25,000, to be credited against future royalties should the firm concerned decide to begin manufacture.[58] Evidence does exist that this sum constituted a barrier to smaller companies at this stage.[59] Royalty fees under the basic Bell patents were set relatively low, amounting to 5% until 1953, thereafter being set at a maximum of 2% of transistor sales.[60] However, Fairchild has asked for royalties as high as 5-6% in addition to lump-sum payments, which has restricted the number of licences which have been taken up by European firms. Texas Instruments has been more reluctant to grant patent rights, generally preferring to award these to its subsidiaries. An indication of the sums involved through licencing activities may be obtained from the fact that Fairchild royalties in 1971 amounted to $9 million, and

$6 million in the following year. In 1970, Japanese firms paid over $25 million to American semiconductor licensees.[61]

The importance within the transistor industry of holding key patents cannot be too strongly emphasised. Both Siegel and Kuhn argue that mere patent counting is an inadequate measure of a country's eminence in invention. In this context, Siegel states "a much more relevant factor is the wide variation in the quality and significance of discoveries and inventions".[62] Judged in terms of the economic potential of certain patents, there is strong evidence to support this view. The key integrated circuit patents held by Texas Instruments have actually formed that company's principal source of income in recent years.

The amount of income obtained by Texas Instruments from royalty payments based on the possession of such patents may be illustrated by the following data.[63]

Texas Instruments Royalty Income and Semiconductor Operating Income ($million)

	YEAR			
	1989	*1990*	*1991*	*1992 (Forecast)*
Income from royalties	165	172	415	500
Semiconductor operations	190	-198	-203	212

Unlike semiconductor operations income, which may go into loss for any given year, income from royalty payments is a constant asset, financially cushioning the firm concerned against trade fluctuations. Most of the above royalty income derives from Japan. Although the key integrated circuit patents date back to the late fifties and early sixties, and would normally lapse after 20 years, the Japanese patent authorities dealt with them extremely slowly, and firms within that country are therefore still liable for payments.[64]

Possession of key patents by firms such as Fairchild and Texas has enabled them to obtain further patents by trading them for those held by competitors, and passing on the consequent savings to their subsidiaries operating within host countries. This situation cannot fail to act in favour of large companies, such as Philips, holding desirable patents to trade in exchange. The Fairchild and Texas patents have, like those of Bell, been made widely available. It has been suggested that the coincident claims of these two companies has ensured this situation, since an agreement between them to refrain from licencing to other parties would have been challenged under the US Anti-trust Laws.[65]

The fact that patents are held by parent companies ensures a more rapid diffusion of information to their subsidiaries than to other competitors wishing to obtain licences under these patents. In the case of a subsidiary, corresponding technical "know how" would be transmitted in its entirety rather than being open to negotiation. In an industry subject to rapid technological change, the time factor involved in obtaining information is of vital importance, and in this respect foreign subsidiaries possess a considerable advantage over indigenous firms, operating under conditions of technical lag.

It is common among equipment manufacturers using semiconductor devices to insist upon more than one source of supply in order to safeguard themselves against shortages arising due to a particular semiconductor manufacturer being unable to meet demand. This practice is known as "second sourcing". Most American Federal Government Agencies, and also most computer manufacturers demand at least two sources before they will design any transistor or integrated circuit into an equipment.[66] Consequently, second sourcing (or copying) is widespread within the semiconductor industry, and may or may not be authorised. Copying circuitry by competitors has always been widespread, and within the United States this activity has been assisted by the high level of personal mobility of scientists and engineers.[67]

Sciberras cites instances where the refusal to second source by American firms has been used to preserve their market position. (For example, the refusal by Fairchild to supply its licencees GEC (Marconi-Elliott) and ITT in order to ensure "responsible pricing" and to prevent ITT from obtaining lucrative contracts.)[68] A further instance quoted was the joint decision by Fairchild and Texas to refuse to second source facilities for the Ferranti CDI process.[69] In view of the widespread customer demand for more than one source for a particular product, this form of action undermines the prospects of smaller companies such as Ferranti to operate successfully within the market, irrespective of the quality of their product.

In view of widespread copying of solid state circuitry, most patents do not confer strong property rights on the holder. What is more important is technical know how, and this is much less likely to be divulged. Although patents are traded fairly freely, this is not the case with production expertise. In an industry where technical change is constant, and production cycles are short, with rapidly falling unit costs, trade secrets may be of more importance than the possession of patents. The exception are key patents held by a few firms on basic processes. Since these are of a generic nature, they are not subject to technological obsolesence, and have been extremely lucrative.

Although infringement of patent rights is fairly widespread within the industry, it would be impossible to ignore the situation if the volume of a competitor's sales became of sufficient importance to affect the patent owner.[70] It might then be possible by legal action to delay entry into production by a competitor, thus gaining an advantage on the learning curve, although this could not be guaranteed. The main advantage of litigation in such cases is that a patent action could impose a significant delay, during which time unit costs would have fallen considerably, to the disadvantage of competitors. With increasingly high levels of circuit complexity per slice, patent actions have increasingly tended to centre around the design of this type of circuitry. Consequently these actions have become technically complex, and usually involve prolonged and expensive litigation. Within the present state of the art, it seems unlikely that possession of a patent covering a particular circuit layout would confer more than a transitory advantage.

Fees charged for licences will depend to a great extent upon the degree of information included in the licence. In the semiconductor industry (unlike valve manufacture), because of its nature, many patents rapidly become obsolete. As a consequence of this, the main object of patenting has been to increase revenue by licencing on an extensive scale. Although processes such as diffusion, oxide masking and epitaxy are clearly patentable, difficulties arise when an attempt is made to patent, for example, the physical layout of a specific integrated circuit. As circuit complexity increases, this problem becomes progressively more difficult. Consequently, in this area patent protection is of doubtful value, and the possibility of patenting offers little or no incentive to innovation.

This situation was revealed when in May 1979 the American Electronics Association attempted to draft an amendment to the US Federal Copyright Law , extending copyright protection to chip circuit layout. This move was opposed by some companies who were members of the Association on the grounds that they might have more to lose than gain. As expressed in an article in "Business Week", "Stripping down a competitor's chip to analyse how it works and possibly learn a trick or two that can help to improve performance in future products is such an everyday, universal practice that producers are loath to give it up".[71] Not surprisingly, supporters of copyright protection tend to be the major companies, producing integrated circuitry at the leading edge of technology, such as Intel and Mostek.

Although the actual number of patents held by an individual firm gives no indication of that company's patenting strength, it does give some indication of the amount of R&D

activity, and it may also reflect that company's attitude towards filing patents. There can be little doubt that possession of key patents by American firms has been a significant long-term disadvantage for British companies. This principally because of the burden of royalty payments, but also by acting as an additional financial barrier to any firm contemplating entering the industry. Extensive data has been published by Tilton,[72] also Wilson, Ashton and Egan[73] detailing patents granted to American semiconductor firms and Government agencies. No attempt has been made however to identify patents in terms of their relative importance. This data shows that device manufacturers have been overwhelmingly responsible for filing semiconductor patents in the United States. The United States Government's share of patents between 1968 and 1980 amounted to only 2.1% of the total, and included no major innovations, and the universities, although researching extensively, were also responsible for only a small number of semiconductor patents during that period.[74]

An obvious advantage conferred by technical lead, and the consequent possession of key patents, has been the strong position of American firms when negotiating licencing agreements. It has been reported that some of these firms have tried to restrict competition by prohibiting foreign companies from entering American markets, by making this restriction part of a licencing agreement.[75] However, according to an OECD survey, there appears to have been no attempt to prevent the entry of new firms into semiconductor manufacture by the restrictive use of patents.[76] Such a policy could only be successful with the co-operation of the major American semiconductor manufacturers, and therefore could not be used by British semiconductor manufacturers to block entry to prospective producers.

Attempts to protect or regulate market prices of microelectronic components through a patent pool, or control entry into the industry, on the lines practised successfully by the

British thermionic valve industry during the inter-war years, could not succeed for the reasons given above. Any move by British manufacturers to combine in this way would not be possible without the co-operation of the key patent holders, and in particular Western Electric, Fairchild and Texas Instruments. Such an agreement would directly conflict with their interests, and has been therefore out of the question. The weak position of European semiconductor manufacturers with regard to patents reinforces the view that any attempt to protect the semiconductor market within Britain or Europe, in order to enable it to become strongly established, would only be possible through means other than patent ownership.

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Chapter 8

Technical Innovation and Economic Factors: Their Part in the Cycle of Industrial Growth and Decline

Introduction

The electronic components industry does not operate in isolation, but exists to supply devices to a market. The relationship between device manufacturers and equipment users is therefore a vital aspect of the industry. This relationship is not a passive one, in which devices are merely supplied to meet a demand, but a complex interaction in which both industries influence the development of each other. The way in which this occurs is itself subject to change, sometimes favouring one type of industrial structure, sometimes another. Perhaps the most important ingredient in bringing about these changes is the development of the technology itself, which in recent years has acted to blur the distinction between device and equipment manufacturers. With these remarks in mind, this chapter considers the effect of technical and economic factors contributing to the development of the industry. It argues that the semiconductor industry has remained in a constant and rapid state of technical development, which has occurred through the industry's being involved in synergistic relationships with markets which themselves constantly made increasing technical demands. The chapter analyses a number of factors likely to contribute to industrial success, and concludes that the conditions for this success were never in place within the United Kingdom.

The Concept of Industrial Synergy and its Importance in Semiconductor Manufacture

A comparison between the semiconductor industry and its thermionic valve predecessor reveals the important difference that solid state technology has continued to develop rapidly since the invention of the transistor, rather than reaching a stable plateau. It is significant that no precedent for this state of affairs appears to have existed in the field of electrical or electronic engineering. This unique lack of technical stability has imposed an environment upon the components industry quite unlike that of previous developments, and its understanding may require a form of economic analysis dealing with dynamic systems, unlike the static classical theories now fashionable.

Although silicon planar technology established a basic process which has not been fundamentally supplanted since its inception in the early sixties, it has steadily evolved with increasing sophistication since that time, bringing rapidly increasing economic returns in its train. The industry therefore stands in direct contrast to the classic Ricardian economic model where it was assumed that economic activity eventually results in diminishing returns. In this respect, microelectronics component manufacture typifies the "locked in to success" situation described by Prof. W.B. Arthur.[1] In this alternative economic model for high technology industries, a technical lead is particularly important, provided that a market exists for the continually developing product. Prof. Arthur cites the pharmaceutical industry in Switzerland, the consumer electronics industry in Japan, and the computer software industry in America as examples of this development.[2] It is argued in this chapter that certain branches of the electronics industry also exhibit similar characteristics, and that the principal factor assisting economic success in semiconductor manufacture has been industrial synergy.

A consequence of market leadership in semiconductors being established through a significant technical lead is that it becomes increasingly difficult for competitors to catch up. This is because (a) the capital cost of entry into the industry rapidly increases with increasing technical complexity.(see Chap.7); (b) It becomes progressively more difficult for potential entrants to obtain "state of the art" techical experience, particularly at the production-development stage; (c) Since the product leader is further down the "learning curve" production yields are significantly higher, resulting in lower unit costs. Because of this factor, aggressive price cutting is possible, raising further barriers to possible competitors. (d) After a period of time, an increasingly close relationship builds up between specialist equipment suppliers and device manufacturers, allowing more efficient interaction of ideas, thus aiding diffusion of expertise. Technical leadership is also reinforced by economies of scale (itself a product of success) and the presence of skill clusters, which are only likely to develop as a product of economic success.

If the initial conditions can be met successfully then, once the production process gets under way, the factors listed above tend mutually to reinforce each other, setting up what has been described as a positive feedback loop. Once this stage is reached, entry into the new technology then becomes increasingly prohibitive, assisting the dominance of a few major Companies.[3] At this stage in the process, possession of superior technology alone may be of little value in the competitive process, and increasing technical returns on inferior technology may well give a "selective advantage", thus shutting out its rival.[4] A possible example of this situation was the failure of Ferranti in 1973 to develop the advanced CDI process in the face of Texas Instrument's 54/74 TTL, in spite of better performance of the former process at the time. Only industrial investment on a massive scale, combined with a long-term industrial strategy, as for example with the Japanese VLSI programme, seems likely to enable competitors to break into the market, and effectively challenge the technical leaders.

Technical innovation within the semiconductor industry has been stimulated by the growth and development of computer manufacture. The rapidly growing computer industry has been extremely dependent upon semiconductor integrated circuits since their development in the early sixties. However, the development of integrated circuits themselves has in turn been largely due to the continuing demands of the computer industry. Interdependent situations of this kind have been described as "industrial synergism".[5] This phenomenon has greatly contributed to the "locked in to success" situation described by Prof. Arthur.

I.M. Mackintosh, writing in 1978, and therefore before the full impact of the Japanese VLSI programme, argued that the continuing success of the American semiconductor industry was largely due to the establishment of a condition of industrial synergy, through its relationship with computer manufacture.[6] He attributed the corresponding lack of success of the Japanese and European semiconductor industries to their inability to develop this type of association. However, he was writing precisely at the time when Japanese semiconductor manufacturers were in the process of developing a synergistic relationship with equipment producers supplying the commercial electronics mass market, although the consequences of this development were not yet fully appreciated.

The major Japanese firms followed the pattern set by the American "multinational" IBM, in the sense that such a link between device and equipment producers took place within each single company through vertical integration, rather than following what was then the more typical American model of horizontally integrated device manufacturers supplying the electronic equipment industry. Although this synergistic linkage took a different form to that in America, it also proved to be extremely effective. When accounting for the relative lack of success in European microelectronics, it is notable that no national semiconductor industry has yet succeeded in establishing such a relationship .

The significance of technological advances in integrated circuit production upon the relationship between device and equipment manufacturers was not immediately realised. For example, an influential OECD report published in 1968,[7] failed to appreciate how important the adoption of MOS technology was to become in conferring an advantage upon vertically integrated companies, particularly in Japan. This advantage came about because with increasing microminiaturisation, more and more complicted circuit functions could be built onto the silicon slice, thus eroding the previous distinction between the device and equipment manufacturer. Opinion however was soon to change, as evidenced by an article written in 1975, stating that "it is now generally recognised that components, sub-assemblies and system design cannot be viewed independently, they are inter-related and equally important".[8]

Prior to the advent of MOS circuitry and the microprocessor, a strong case could certainly be made out for the advantages of horizontal integration in the semiconductor industry, in view of the success of new entrants such as Texas Instruments and Fairchild, when compared with the traditional thermionic valve companies such as RCA, General Electric and Westinghouse. For example, by 1957 these new horizontally integrated circuit semiconductor producers had captured 64% of the total semiconductor market, compared with 31% held by the the receiving valve firms. (Western Electric held the remaining 5%).[9]

This situation was to change during the seventies. The invention of the microprocessor made it possible to extend computer techniques to a wide range of equipments, and, according to Webbick, this development played a significant part in the move by a number of major American integrated circuit manufacturers in the direction of vertical integration.[10] This was because these companies held the belief that it would be more profitable to sell the completed product than to supply components to equipment manufacturers.[11] Webbick quotes an example where the production costs for a $20 or $30 digital watch might be $4 for a watch chip, digital display, battery, and plastic case.[12] (These costs exclude all overhead expenses). Also at this time, backward integration by a number of the larger companies, including Texas Instruments, Fairchild and Motorola took place, involving, for example, crystal growing and purification. Such a move suggests that additional reasons for changes in company structure were then present.

The obvious success of horizontally integrated companies during the early years of semiconductor manufacture, strongly justified belief in an economic model which well fitted the ideology of the free market entrepreneur. This appears to have made the subsequent success of the Japanese semiconductor industry harder to understand, and to accept. It is hardly surprising that the Japanese were widely criticised for not adhering to the "rules". For example, Braun and Macdonald quote Lester Hogan, Vice Chairman of Fairchild, complaining that "the Japanese, with their protected markets and heavily supported technology, have just not been playing the game".[13] A strong belief that economic success would only be obtained by playing to the existing rules, could hardly fail to lull American semiconductor manufacturers into a false sense of security during the early stages of the Japanese VLSI programme, and thus delay an effective response. This failure in perception lay not only in the lack of realisation that alternative financial systems might be equally successful, but also that it might be possible to establish synergistic relationships of a different nature to that operating successfully between semiconductor manufacturers and the computer industry.

The Manner of Industrial Growth

Within the United States, from the fifties onwards, computers formed a considerable proportion of military equipment. Large quantities of discrete devices and integrated circuitry were supplied to the military for their construction during the industry's initial period, resulting in a substantial fall in unit costs. The consequent availability of cheap solid-state devices greatly assisted the growth of the commercial computer market. It thereby enabled the initial stimulus to silicon integrated circuit manufacture through military "pump priming", to be maintained. (This earlier development is discussed in more detail in Chapter 3).

The major demand by computer equipment manufacturers was for digital circuitry, and this resulted in a concentration of technical effort within that field. Progressive reduction in the size of digital integrated circuits led to a corresponding reduction in cost per bit, with the additional bonus of increased switching speed and higher reliability. The reduction in cost per bit took place linearly from about 1970 to the present, enabling equipment manufacturers confidently to plan ahead on the assumption that a chip with a given packing density would be available at a given time. This fact gave an enormous impetus to the development of digital circuitry generally, and played an important part in shifting the centre of gravity of the electronic industry away from analogue circuitry. The key to this achievement was the development of MOS technology, which has now become the dominant fabrication technique within the industry.

The most significant technical advances occurring within the computer industry since the early sixties centred around the demands and responses of computer equipment manufacturers and the leading semiconductor firms. Consequently, semiconductor device development did not take place uniformly, but was technically skewed in favour of the needs of computer manufacturers. Although analogue and discrete device production was to some extent able to take advantage of the technical spin-off generated by this development, there was no question of competing in terms of cost reduction.

The mass market for digital circuitry, stimulated by computer manufacture, resulted in substantial economies of scale, enabling unit costs to fall rapidly. This is illustrated by the following data, comparing the rate of reduction in prices for silicon discrete power devices, together with DTL and TTL digital integrated circuits over the same period.[14]

Wholesale Price Index for the Period 1968-1974

(December 1968 = 100)

	Discrete Devices	**Digital Integrated Circuits**	
Year	*Silicon power transistors, 60 watts & above*	*TTL high-speed J-K binary*	*DTL J-K binary*
1968	100.0	100.0	100.0
1969	101.0	91.8	89.7
1970	111.4	68.8	79.9
1971	98.4	37.3	63.9
1972	79.6	37.3	63.5
1973	85.8	29.6	64.0
1974	84.0	27.3	68.3

Not only do these figures show the extremely rapid rate of price reduction in digital integrated circuitry, when compared with discrete devices, but also the more rapid rate of price decline in the case of the more advanced TTL circuit compared with the earlier DTL circuit, which performed the same function. Under such conditions, older technologies become rapidly obsolete, severely penalising technical lag. Entry into the industrial mainstream, in order to be successful, must therefore be at the leading edge of the most advanced technology, in order to avoid the disadvantages of technical lag. This situation appears to have been well understood in Japan by MITI, at the time of launching their VLSI programme.

The timing of the Japanese VLSI programme was of particular importance. Firstly, although financial barriers to entry were increasing rapidly during the mid-seventies, they had not reached the high levels of the mid eighties. Secondly, due to the successful development of synergism between the American computer industry and device manufacturers, unit costs per device had by the mid-seventies fallen to such a level that a large potential now existed within the consumer goods market for new a synergistic relationship to be established. The strength of the Japanese electronics industry lay precisely within this area, and the result of major efforts, backed by MITI, to take advantage of this situation and establish such a relationship, are well known.[15]

Factors Governing Synergistic Industrial Growth in the Components Industry

The basic aim of component production is to mass-produce devices at a consistent quality to satisfy present, and possibly future, needs. However, in the process of achieving this aim, future possibilities may become apparent, and these may ultimately even lead to a transformation of the user industry, which in turn makes fresh demands upon the component manufacturers. Under these conditions, a synergistic relationship holds between producer and consumer, forming an excellent environment for rapid technical progress. Indeed, this situation appears to be an optimum condition for rapid technical growth.

The main stimulus for thermionic valve production, following the First World War, lay in the domestic radio receiver market, but in spite of the industry's extensive expansion during the inter-war years, a synergistic relationship did not really exist, since the technical demands of the domestic radio industry were relatively limited. However, World War Two requirements, particularly in the field of radar, pressed valve technology towards its limits. In the years immediately following, these limitations prevented the thermionic valve from playing a synergistic role in the rapid development of the computer industry.

The above situation directly contrasts with the development of the transistor, which, together with its successor, the integrated circuit, rapidly achieved a synergistic role with its partner, the computer. The catalyst in this development, enabling the process really to take off, was the invention of planar technology. From that point onwards, technical progress has remained rapid and continuous. It is this technology-driven aspect which sets semiconductor manufacture apart from earlier industries, and therefore demanding a distinctive analysis.

It appears from past developments, that the prerequisites for a synergistic relationship between the semiconductor industry and computer manufacture have been a more or less constant demand pull in the direction of greater circuit complexity, together with the need for increased reliability and lower power dissipation, to be achieved if possible with minimum packing density per component. This demand was initiated by the urgent need to develop a computer industry, originally in connection with weapons systems, but with falling unit costs soon spreading into industrial and commercial fields.[16]

Not only was this demand consistently met by major semiconductor manufacturers, but the production of advanced devices in turn stimulated designers to invent applications circuitry in order to use them to full effect, and so opened up a wide new range of uses. The net result since the inception of the transistor has been decades of technical progress without precedent in any other area of engineering endeavour. The importance of this relationship between device manufacture and computing was stressed by Lester Hogan

(Vice-Chairman of the Fairchild Corporation). Speaking in 1979, he said "Up until now, the whole history of industrial development in this World has not yet produced a story of synergistic growth as significant as that of the computer and the semiconductor industry."[17]

Some idea of the rate and magnitude of this process of industrial synergism may be gained from the following data.[18]

US Markets for IC's		**Changing Market Distribution of IC's**			
	1962	*1965*	*1969*	*1974*	*1978*
Government.	100%	55%	36%	20%	10%
Computers.	0%	35%	44%	36%	37.5%
Industrial.	0%	9%	16%	30%	37.5%
Consumer.	0%	1%	4%	15%	15%
Transistor Unit Costs ($).	4.39	0.86	0.37	N/A	0.21 (1977)
IC Unit Costs ($).	31.6	8.33	1.63	N/A	0.05 (bipolar,1977)
Total US Domestic Shipments ($ million).	4	39	413	1,204	2,080

The Failure of Semiconductor Manufacture in Britain to Establish a Condition of Synergy

By the beginning of the 70s, Britain's position was that, although strong in a number of areas vital to building a synergistic relationship between device manufacture and computers, the overall situation was extremely weak. A characteristic of successful synergism is that the industry in question depends upon a strong industrial partner, able to support a developing market at a high technological level. In both America and Japan, the computer industry has played such a role. Within Britain, in contrast, this relationship never really became established, in spite of efforts made by government to assist the industry under the Wilson Government's National Plan. These efforts were however primarily aimed at supporting the computer industry through a programme of rationalisation and financial assistance, semiconductor development being seen as of secondary importance.[19]

Nevertheless, certain areas have shown some strength. For example, the United Kingdom is generally recognised as being fairly strong in the development of software, although according to Oakley,[20] the rate of increase in production within this field has nowhere near matched the increase in performance of the hardware. Professional recruitment within the information technology (IT) industry in Britain grew at about 8% for some years prior to 1990.[21] Until recently, Britain remained a World leader in the marketplace for parallel computers, although with the sale of INMOS, this lead has now been lost.[22]

Any attempt to achieve a synergistic relationship between European device manufacturers and the computer industry, was effectively prevented by the activities of the American owned multinational, IBM. During the early stages of computer development, the only European country with a relatively strong industry was the United Kingdom. This was mainly due to the presence of ICL and its precursor ICT, whose activities were however largely confined to Britain alone. ICL was formed in 1968 by the merger of International Computers and Tabulators (ICT) and the English Electric Company.

The merger was encouraged by the DoI, then under Tony Benn, and was in line with the Wilson Government's policy of rationalisation within the computer industry. The government took a 10.8% share in the new company, which was increased to 24.4% in 1976.

ICL also received government funding, amounting to £17 million between 1968 and 1973, in addition a loans of £40 million in order to develop new computers.[23] Previous mergers had resulted in ICT acquiring Ferranti Computers in 1963, whilst the English Electric Company acquired Leo Computers(1963), Marconi Computers (1964) and Elliott Automation(1967). The result of these mergers and acquisitions was that from 1968 on-wards, only one British company, namely ICL, was engaged in computer manufacture.

The resources of ICL/ICT were dwarfed by those of IBM, which also had the advantage of operating within a considerably larger home market. Some idea of the relative strengths of both companies may be obtained from the fact that the research and development budget for the IBM System 360 amounted to about $500 million, and the total cost of development and manufacture was approximately $5 billion over a four-year period.[24] Launched in April 1964, System 360 was a third generation computer system, therefore stimulating demand for large quantities of integrated circuits. In contrast, ICT's annual research and development budget during this four year period amounted to only about $56 million. By 1985, IBM's yearly research and development budget had risen to $3457 million. The total MOD budget for that year was $4106.8 million.[25]

Some further idea of the relative strengths of both companies may be gauged from the following data.[26]

Number of Computers Installed

	IBM		ICL/ICT	
DATE:	1962	1967	1962	1967
USA	4,806	19,773	N/A	N/A
UK	56	649	159	953
Europe (Exc. UK)	582	3,194	13	115

The above figures illustrate the large extent of European market penetration achieved by IBM compared with ICL/ICT, and the significant increase achieved following the introduction of System 360. What is also evident is the far larger size of the American computer market, together with its rapid growth. Although the actual growth rate of the European market actually exceeds the American, what matters in establishing a condition of synergy is market size, in order to enable mass production techniques to be operated efficiently. To achieve a synergistic relationship between European device manufacturers and the computer industry during the sixties would have been extremely difficult, even if ICL, as the major European producer, had managed to obtain a much larger share of the local market. Consequently, any attempt within Britain alone to establish such a relationship, through a policy of co-ordination between the principal device manufacturers and ICL/ICT, would have been most unlikely to succeed.

ICL does not appear to have ever pursued a policy of co-operating with specifically British firms in order to establish a mutually supportive relationship, which might have resulted in some degree of industrial synergy. Instead, the purchasing policy of ICL up to at least the early eighties was dictated by cost and delivery dates. This involved obtaining supplies from various sources. The policy began to change during the early eighties, with the development of the 39 Series, which heavily used advanced silicon integrated circuits (ASIC's). This development resulted in ICL's being essentially "locked in" to one supplier, Fujitsu.[27]

The inability of British semiconductor firms to compete in the VLSI mass market was a major factor in the collapse of ICL, which was the last remaining British computer manufacturer. By at least the beginning of the eighties it was realised that "chip technology was at the heart of ICL's problems"[28] and that "the Company lacked the semiconductor technology to manufacture systems price-competitive with IBM". Consequently, ICL obtained an agreement with Fujitsu in October 1981 in order to gain access to their technology.[29] This relationship with Fujitsu was eventually to lead to the takeover of ICL by Fujitsu, depriving the United Kingdom of its indigenous computer manufacturing facility. Any subsequent attempt to use the computer industry as a vehicle for the synergistic development of components within Britain can therefore be virtually ruled out.

It is significant that IBM, which has dominated European computer markets for decades, is an extremely large manufacturer of semiconductor devices, most having being used for "in house" applications. Successful synergism therefore appears to be possible within one particular company, if it is sufficiently large for economies of scale to operate. This suggests that it might be possible to create such an organisation, perhaps on a European scale, either through amalgamations between existing companies, or by selecting one of the larger existing European electronics companies as a nucleus for subsequent expansion. Such a project would obviously require considerable co-operation between Community members, as well as the agreement of the major electronics companies.

The Rise of Computer Manufacture and its Consequences for the Development of the British Semiconductor Industry

In the field of computing where advantages in size, high reliability and low power dissipation made the transistor particularly attractive, replacement of valves was not immediate, although semiconductor diodes were used in large quantities. This was because of doubts regarding their long term reliability. For example, in America, Whirlwind 1 was constructed by the Massachusetts Institute of Technology, becoming operational in 1951. This machine contained some 5000 valves and 11000 semiconductor diodes.[30] In 1955 the I.B.M. Corp. produced a computer for the commercial market by modifying an existing machine, replacing 1250 valves by 2200 transistors. Apart from the reduction in size, this modification reduced power consumption by 95%, illustrating an important advantage in using solid-state amplifiers in this application.[31]

Significant production of transistorised computers began about 1960,[32] and from this time onwards the valve was superceded very rapidly in this application. For example, the UNIVAC solid state 80/90, first marketed by IBM in Europe in 1957, contained 215 valves, 900 transistors and 36,500 diodes. The CD 1064, manufactured by the Control Data Corporation, and containing 25,000 transistors, was installed during 1960, and the Bendix G20 installed in April of the following year, contained approximately 240 valves, 38,000 diodes and 8900 transistors.[33]

During the fifties, the British computer industry was also in a leading position, but like its semiconductor counterpart was unable to capitalise on its early achievements. The Lyons Leo Mark 1, built between 1949 and 1953, used Mullard germanium diodes and hard valve amplifiers. The first in the series to use transistors was the Leo Mark 111, developed during the late fifties, where they were used for its core storage.[34]

The Ferranti Sirius, first delivered in 1961, used transformer-coupled threshold logic, which involved the use of OC44 and OC45 germanium transistors, sourced mainly from Mullard. The Ferranti Orion,constructed between 1958-1964, also used transformer-coupled logic, with transistors upgraded to Mullard OC 41 and OC42 type. Also during this period, the Elliott 803 was being produced using a similar transformer coupled logic, using OC42, OC44 and OC45 devices.[35]

The Ferranti Atlas, built between 1958 and 1962, was a high-speed scientific computer using diode-transistor logic. This involved the use of OA91 and OA47 diodes and OC170 and OC171 germanium type transistors. These were sourced principally from Mullard.[36]

Until the mid- sixties, therefore, the manufacture of commercial computers in Britain had been based upon the use of germanium transistors, which were principally supplied by Mullard Ltd. From this time onwards, however, a shift took place from germanium discrete devices to silicon integrated circuitry. American suppliers now began increasingly to dominate the industry, as can be seen from the data supplied within the following paragraphs. This situation was to continue until the ICL-Fujitsu agreement in 1981, which ushered in the third phase of component procurement, which tied ICL exclusively to Fujitsu component technology.

The Ferranti Orion Mark II occupied a transitional position in this development. It used diode-transistor logic, derived from a medium-sized computer produced by Ferranti's Canadian subsidiary, Ferranti-Packard. This was the the Ferranti-Packard FP6000, which later formed the basis of the ICT 1900 series. However, within the anglicised version, the logic was changed from germanium to silicon transistors, based on the Fairchild 2N2894. These were supplied from various sources. Many other transistor types were also used, including the Motorola MM2614. This computer also used germanium diodes, probably based on the OA47, as well as a few silicon diodes.[37]

From the mid-sixties onwards, English Electric manufactured their System 4, which was based on the RCA Spectra 70 series. The large machines in this series used a form of Motorola MECL1, (Emitter Coupled logic). The major effect of the introduction of System 4, was to force ICT into rapidly introducing integrated circuits within their 1900 series computers.[38] It has been suggested that this move may have been due to competition between English Electric and ICT, rather than as a response to any American challenge.[39]

The early ICT 1900 series, manufactured from 1964 until about 1970, used diode-transistor logic, based on proprietary or custom-made transistors. Later computers in the series (1901A-1904A), constructed from about 1966 onwards, used early Texas Instruments TTL circuits. These were re-specified in order that other manufacturers, in particular Mullard Ltd., could also supply. By the mid-seventies, the ICT 1906A was introduced, using Motorola Emitter Coupled Logic, with some second-sourcing by other companies, including RCA and Marconi, and probably including Mullard Ltd.[40]

From the mid-seventies until about the end of that decade, the ICL 2900 series were manufactured, the large machines within the series using standard Motorola Emitter Coupled Logic, but generically specified in order that other manufacturers could second source. Semiconductor storage was based on progressively larger chips, initially 4 kilo-bits, 16 kilo-bit chips being introduced when they became economic. Mid-range machines used TTL and Schottky TTL integrated circuits, which were always generically specified. Sources for Schottky TTL included both Philips and Texas Instruments.[41] Memory chips were supplied by Mostek, Intel, AMI, Mullard, NEC and others.[42]

By the late seventies, it became obvious to ICL that increases in circuit complexity beyond medium-scale integration would require the design of chips with application specific content. The Company therefore responded by building up an in-house semiconductor design and prototype fabrication capability. However, by the early eighties it became evident that, with ICL's market size and limited development resources, this approach could not provide ICL with the world class technology it needed[40]. Consequently, in 1981 an agreement was concluded with Fujitsu by ICL's Managing Director Robb Wilmot, who had joined the Company from Texas Instruments six months previously.

The agreement in October 1981 between ICL and Fujitsu ensured that all architecture and design control would remain with ICL, whilst Fujitsu was to be responsible for the semiconductor technology. From this time onwards, ICL's policy of buying components from alternative sources of supply was effectively ended, Fujitsu manufacturing and supplying the requisite components. The supply of microelectronic components to the last remaining British computer company was therefore now in the hands of a single foreign manufacturer.

The American Technical Lead in Components: its Consequences for European Equipment Markets

A technical lead in components makes its major impact in the most sophisticated areas of equipment design. This is well illustrated by the impact of the integrated circuit upon the development of the computer industry. The United States Department of Defense not only assisted device manufacture through the medium of lucrative contracts, but, as in the case of integrated circuitry, initiated military programmes which acted to "pump prime" the computer industry. For example, between 1950 and 1959, IBM alone received military contracts worth $396 million, accounting for sixty percent of its research and development spending.[43] By 1964, more than 30% of the estimated national total of 22,000 computers were financed by the US Federal government.[44] In Britain, by contrast, the only form of government support through the fifties was from the NRDC, which had funds amounting to £5 million, and furthermore was required to be self-financing. By the beginning of the sixties, the American market was estimated to be at least three years ahead of Europe in its per capita consumption of computers.[45] American military funding therefore acted as a springboard enabling its computer industry to enter the European market, and quickly achieve domination.

Mass production of computers in America was well under way by the late fifties, unlike the situation elsewhere. By 1959 there were 3810 computers in existence within the United States, but only 550 in the whole of Europe.[46] The British Government were slow in installing computers, only 150 being in use within the public sector in 1964, compared with 1700 in the United States.[47] Computer installation within Continental Europe was even less advanced than in Britain at this time. The importance of the computer market for the semiconductor industry was that it demanded large quantities of the most advanced digital integrated circuits. Any British or other Continental supplier was therefore faced, unlike the American semiconductor companies, with only a small internal market for advanced components, unless they could be sold within the United States. To attempt to do so was a somewhat daunting prospect, in view of that country's two to three year technical lead in device manufacture, reinforced by the existence of the Buy America Act. It is significant in this respect that in 1962, a mere 0.2% of computers installed within the U.S. were manufactured by European firms.[48]

The overwhelming extent of American market penetration of the European computer industry during the sixties may be gauged from the following data.[49]

Percentage of European computers manufactured within the US

Country:	Britain		France		Germany	
Year:	1962	1967	1962	1967	1962	1967
%:	20.5	55.4	50.9	65.5	75.5	78.3

These figures not only illustrate the weakness of the relatively small and fragmented European computer manufacturing industry, but also highlight a major dilemma faced by European device manufacturers, namely, the problem of mass-producing components for a relatively small market, yet having to reduce unit costs to a competitive level. Under these conditions, the strategy of establishing a synergistic relationship between the principal computer manufacturer (ICL) and, for example, INMOS, could not possibly succeed. Components account for approximately 10% of the value of a computer, and an inability to compete in terms of device cost would effectively prevent such a relationship. This is borne out by the fact that in 1965, ICL rejected the newly developed Ferranti

Micronor II DTL process, in favour of Texas Instruments 54/74 TTL on economic grounds.[50]

The constant and rapid development of microcircuit technology during the sixties and seventies assisted American device manufacturers, as market leaders, to establish and determine technological trends. Any attempt by others to "buck the trend" by establishing a rival logic system, was out of the question, given the relative strengths of the European and British industries. Furthermore, costs of entry into device manufacture were rising steeply during the entire period, making it progressively more expensive for European firms to compete with the market leaders. These factors placed an additional penalty upon European semiconductor manufacturers attempting to enter the digital equipment market.

For example, during the mid-sixties, opinion within the industry supported the development of custom and semi-custom devices, in view of prospective markets for an increasing number of consumer products, including calculators and wristwatches.[51] However, the development of MOS technology and also microprocessors enabled these applications to be fabricated at substantially lower cost. Mass-production of MOS devices at ever decreasing cost by such companies as Mostek, Intel and Texas effectively prevented firms such as Plessey and Ferranti, which specialised in linear circuitry, from entering these markets, and restricted their activities to smaller, more specialised areas.

With increasing emphasis upon computer manufacture outside the military field, digital integrated circuits assumed greater and greater significance, and as their volume of production increased, unit costs fell. In a situation where a demand for integrated circuitry was becoming dominant, the growing domestic market provided American semiconductor manufacturers, with their significant technical lead, the opportunity to take advantage of economies of scale, and advance more quickly down the learning curve than their European rivals. This development faced British and Continental device manufacturers with the choice of either attempting to compete in a costly and unequal contest, by entering the digital mass-market at a later stage, or retreat into niche markets, such as specialised analogue devices, where competition was less intense. In the event, the latter course of action was usually followed.

Research Programmes and Commercial Spin-Offs

A further problem facing would-be competitors is that research programmes tend preferentially to feed the most technically advanced companies, adding a further competitive advantage. Successful commercial exploitation within the field of semiconductor manufacture depends not only on the ability to produce devices in the quantity needed, of acceptable quality, and in the required time, but also on at least a technological parity with competitors. Although observers may differ when assessing the efficiency of research capability within the UK when compared with America,[52] there can be no question that in sheer scale of resources and effort, that country has considerably outweighed Britain for many decades. Due to this scale of involvement, more lines of research have been followed up within the US at any given time. Should a breakthrough in any particular field occur, more resources are available to bring extra research effort to bear within the chosen area. Because of the wide range of effort, it is more likely that a significant breakthrough will occur in some line of research not being pursued within the UK. When this occurs, it is then easier for the breakthrough to be exploited technologically due to the extra resources available, both in manpower and capital.

An early illustration of a situation where absence of an applied research organisation resulted in the failure in Britain to follow up important theoretical work, was that of A.H. Wilson, when working at Cambridge, who made important contributions in the field of solid-state theory during the early 30s, by applying quantum theory to the motion of electrons in crystalline solids.[53] However, Wilson's work was available to Shockley and others working in solid state at Bell Laboratories during the latter part of that decade. It was certainly an important contribution to a theoretical understanding of energy levels in semiconductor material, and consequently recognised as a significant stepping-stone towards transistor fabrication. Viewed purely as a scientific investigation, Wilson's work was an undoubted success. Viewed as a contribution to a successful applied research programme, instituted with the object of producing a potential product (which was never of course intended) it benefited only the organisation capable of instituting such a programme.

Isolated research in some particular area will benefit only those organisations able to mount such a successful research programme, and the country possessing the resources able to sustain such programmes has the considerable advantage of being able to feed upon research carried out in other countries unable to do so. Furthermore, it is much more likely that the products of these programmes can be successfully developed commercially, at least initially, by the organisations which have successfully produced them, resulting in an initial technical lead and possession of patent rights.

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Chapter 9

The Influence of Multinational Companies

Introduction

A review of the history of the British semiconductor industry reveals its inability not only to compete effectively in World markets, but its incapacity, even at an early stage, to resist massive economic penetration by overseas competitors. It is therefore important, when considering the manner of development of the industry, to examine in some detail the way in which multinational companies have operated, to the disadvantage of local manufacturers. Except for the early germanium phase of the industry, a major problem affecting the development of local manufacture has been the influence of multinational companies. Their dominance, beginning with the introduction of silicon technology, has undoubtedly been the principal reason for the failure of a strong national industry to become established. The operation of these organisations not only caused fundamental difficulties threatening the very existence of the indigenous industry, but also raised the question to what extent Government, as a result of their activities, could assert its sovereignity, in order substantially to assist local industrial resurgence. It is for these reasons that this chapter places particular emphasis upon the policies pursued by Government towards the multinationals, and the consequences of these policies.

Multinationals - The Advantages

Foreign multinationals have been consistently encouraged, under successive governments, to establish themselves within the United Kingdom. Generous development grants were made available, and during the sixties, several of these firms began the manufacture of microcircuits, principally within the central belt of Scotland. The main objective of this policy was stated by the Multinationals Sub-committee of the Electronic Computers SWP in 1979[1] as being "the provision of new jobs, particularly in assisted areas". Apart from the case of Texas Instruments (invited into Britain in order to manufacture silicon alloy devices to meet urgent MOD requirements) evidence supports this statement, since almost without exception the semiconductor multinationals entering Britain from the sixties onwards were all sited in such areas.

Further advantages claimed by the above report for the importation of multinational companies were the acquisition of high level management skills, and stimulation of the local economy through local purchasing. Also, by introducing new products and processes, the general level of productivity in the host country would be raised, and competition stimulated. Another possible benefit, which had become more important in recent years, was the potential improvement in the balance of trade, by reducing imports through manufacture within the host country. Such a prospect would weigh heavily with the Treasury, which, as the most powerful Government Department, would be in a strong position to override the DoI should a conflict of policy arise regarding the activities of multinationals.

From the early sixties onwards, strong emphasis was placed by Government on encouraging overseas investment in microelectronics technology. An example of this approach to industry was voiced by C.Freeman, writing in 1965,[2] who argued that Government intervention to promote research and development should not discriminate against American-owned firms in this respect, "otherwise there would be a danger of xenophobic technical backwardness disguising itself as patriotism". It would therefore be "sensible to give both development and manufacturing contracts to American subsidiaries operating in Britain, especially if they had a good export record".

Despite frequent changes in government, this aspect of public investment policy remained constant over the next two decades. The situation at the beginning the Thatcher administration was that Regional Development Grants towards the cost of new buildings, plant and machinery were being made available in the form of project grants, related to the fixed and working capital costs of a project. Regional Training Grants were also available, covering a fixed 40% of training costs, for projects providing more than 25 employees. Furthermore, these grants could trigger a matching contribution of 40% from the European Social Fund. Guarantees against exchange losses were also offered on fixed-rate medium-term loans from the European Investment Bank, for up to 50% of project costs[3]

The provision of generous development grants by successive Governments was undoubtedly a major incentive for multinationals to base their activities within the designated areas. A "Financial Times" correspondent, writing in 1981, cited the main reason for the location of multinational corporations within the central belt of Scotland as substantial Government grants, which could cover up to 40% of initial investment costs.[4] As a further example of this generous assistance, during the three year period 1977-80, Government aid to the microelectronics companies in Scotland totalled about £40 million, roughly half that commited to INMOS[5] A specific example of this assistance was £3.4 million given to General Instrument Microelectronics in 1978 towards the expansion of its microchip facility in Glenrothes.[6] Without these grants, it is doubtful if the semiconductor multinationals would have located their activities in Britain to anywhere near the same extent. It is notable that Siliconex cancelled its plans to build a wafer fabrication plant at Swansea in 1980, in view of the area no longer qualifying for a Regional Development Grant[7]

An additional incentive to direct investment by American companies during the sixties was the external tariff of 17% ad. valorem, imposed upon semiconductor imports by the United Kingdom. However, although this tariff was well below the cost differences between Japanese and American industry, compared with that of British and European manufacturers, it did offer some degree of economic protection.[8] The continuing importance of import tariffs was emphasised in a statement by Dataquest in 1992 that "Europe's semiconductor industry could not survive without the protection of import tariffs".[9] In the same statement, it was pointed out that even with this tariff, Europe was still the cheapest market in the World for many integrated circuits. Apart from direct tariffs, some measure of protection was exercised through the application of National technical standards for telecommunications and military equipment.

With increasing growth of the American semiconductor industry, the move towards overseas expansion gained momentum, both in device exports and the establishment of foreign-based subsidiaries. Intense competition at home between rival companies, rapidly falling prices and overproduction problems were an obvious incentive to moving abroad. Due to technical obsolescence, manufacturers were often left with large stocks of unsaleable devices which then had to be written down in value. The opportunity to offload these products onto a more slowly developing European market at premium prices, was an attractive prospect, in spite of the tariff wall. Furthermore, locating production plant within the host country assisted in this respect. This was because, due to the activities of the parent company, the new subsidiaries would already start a long way down the learning curve on such products, and could continue to manufacture them economically within the new environment. Surprisingly, W.Finan, writing from New York in 1975,[10] fails specifically to mention the above advantages in his list of five factors influencing the decision of American firms to enter the European market. These factors are nevertheless highly relevant, and are as follows:-

(1) European market size.

(2) Relatively high EEC tariffs.

(3) Competitive advantage over other American firms already in European market.

(4) British and French pressure on American firms, particularly those serving the military market.

(5) As integrated circuits began to include entire systems in a single chip, greater co-ordination in chip design between buyer and seller became a crucial factor in influencing sales.

Certainly such advantages, buttressed by extremely generous development grants, had the required effect in attracting major American semiconductor producers into Europe, and particularly to Britain. Details regarding these companies, including their date of arrival, are included in Chapter 4 of this thesis.

Multinationals - The Costs

Although multinationals progressively improved their share of the British domestic semiconductor market, the balance of payments position continued to deteriorate. In computing, which like component production was becoming increasingly dominated by overseas manufacturers, Britain had a large and deteriorating balance of payments deficit, amounting to £110 million in 1977 and £150 million in 1978. In semiconductors, the trade gap, although already present, began to widen considerably from 1962 onwards, and the deficit grew from £18 million in 1971 to £60 million by 1977.[11] In both these areas therefore, the growth in activity of multinational companies hardly contributed positively to an improvement in the balance of payments. Published Government statistics do not differentiate between the activities of indigenous firms and foreign multinationals in this respect, although by the middle sixties the component industry was heavily dominated by overseas interests, and the computer industry also substantially infiltrated.

From the late 1960s onwards, increasing concern began to be expressed about the activities of semiconductor multinationals, particularly following the TTL "war" of 1970/71. For example, in a speech to the Electronic Engineering Association in March 1967,[12] the Minister of Technology, Tony Benn, referring to the "American challenge", stated that Britain could not afford to rely on American circuits. This was because as the technology moved towards large-scale integration, the need would increase for closer relationships between producers and users of integrated circuits. Economic success would follow from large-scale efficient production, and this would be achieved by concentrating the manufacture of integrated circuits in a very few industrial groupings. A report, commissioned by the Labour Party in 1975,[13] squarely addressed some of the problems raised. It noted that the United States was the most important investor, accounting for 85% of foreign assets in 1968, and averaging about 65% of all direct investment since then, this stake being about 15 times higher than in 1939. The report also listed possible disadvantages which could result from the operation of foreign multinationals. These were as follows:

(a) A potential threat to job security, it being in the interests of a multinational to switch production to countries with a weak or docile labour force.

(b) Concentration of industrial decision making in fewer hands, with consequences for public accountability.

(c) Loss of sovereignity. Any decision by the host government running counter to the interests of the foreign multinational would be opposed.

(d) The host governments ability to plan the economy is rendered more difficult, particularly by the threat of relocation.

(e) Problems could arise between the parent and host country regarding such matters as transfer of capital, export restrictions or tariff measures, which might disadvantage the host government. (The magnitude of the problem is illustrated by the fact that in the case of American subsidiaries, Board of Trade figures showed that in August 1969, 56% of exports were intra-company transactions).[14]

(f) Loss of revenue, due to internal cost accounting by the multinational aimed at realising profits within an area where taxes are low. This activity also creates a balance of payments defecit for the host country. The defecit may be further increased by importing from other subsidiaries, rather than by buying locally.

(g) The considerable funds held by multinationals may be used to undermine currency stability, through shifting assets from one country to another. Such a possibility amounts to a potential threat to sovereignity.

The 1979 SWP Multinationals Sub-committee Report[15] also expressed concern regarding the operations of the multinationals. It referred to the acute shortage in specialist skills in the field of computing, and also semiconductor manufacture, and it was feared that further expansion by these companies would worsen the situation. It recommended that future applications to site these companies in Britain should be reviewed with this problem in mind. Concern was also expressed regarding the erosion of soverignity, and this conclusion was strengthened by the apparent reluctance of many multinationals to provide Government committees with information regarding their operations within the United Kingdom.

A further problem, arising from undue reliance upon foreign multinationals, and which was not mentioned in either report, was that this policy enables foreign equipment manufacturers to dictate the rate at which "state of the art" microelectronics equipment is taken up within the host country. Technical delay could be then brought about by restricting access to the most advanced components, placing British equipment manufacturers at a disadvantage, should their competition be perceived as a threat.[16] In any case, should a shortage of components occur at any time, it is unlikely that indigenous companies would receive preferential treatment. This problem is of particular importance in the case of vertically integrated semiconductor companies, such as in Japan, which also manufacture electronic equipments. A team of engineers, when visiting Japan, under a joint IEE/DTI Overseas Technical Scheme, reported that easy access to advanced Japanese components at the equipment or systems level would be difficult, particularly for the smaller British equipment manufacturers, who would have little with which to bargain in inter-company trading.[17]

Adverse effects upon the local economy are not likely to weigh heavily in decisions taken by multinational companies. In the event of an economic recession, foreign-owned multinationals are more inclined than indigenous firms to make preferential cuts in both capital investment and labour within their offshore operations. This fact is particularly important in the case of the semiconductor industry, which regularly suffers from the effects of trade cycles. For example, in February 1985, during a period of recession, National Semiconductor announced that it was delaying its £100 million expansion programme at Greenock due to a fall in demand.[18] The sackings of 500 staff by Texas Instruments at their Plymouth factory during the mid-seventies, due to international reorganisation, is a further illustration of the dangers of external control. In the event of a worldwide recession, such activities tend relatively to deepen its effects within the host country.

The ability of the host country to maintain fiscal control has been weakened by the growth of in-company trading, offering the opportunity for multinationals to maximise their profits on a global scale through the mechanism of transfer pricing. In this context, Steuer has argued that "It is well known that the International company can, by a process of internal costing and accounting, attempt to realise its profits in a country where the tax burden is light".[19] According to a US Commerce Department estimate, made previously to 1971, over $400 million had been accumulated by American multinational firms through tax referrals in income tax havens.[20] This practice was not confined to American companies, since Sciberras quotes evidence that these strategies were adopted by Texas, Philips/Mullard, Motorola, Fairchild, ITT, Plessey and Ferranti.[21]

In Britain, where the semiconductor industry is effectively dominated by foreign multinationals, opinion has been expressed that there appears to be a lack of effective fiscal control over their activities. For example, as early as 1969 it was stated that "The multinationals can now manipulate the underlying flows of trade which determine the degree to which a nations balance of payments are in deficit".[22]

Multinationals - The Response

Although the policy of Government had been consistently to encourage the semiconductor multinational companies as part of a more general policy, the inability of the local industry to compete effectively, particularly following the TTL "war", led to a belated awareness of its importance, and a consequent concern for its future. One result of this newly-found awareness by Government was the decision by the Prime Minister, James Callaghan, to employ the Central Policy Review Staff in co-ordinating studies of the social and employment effects of microelectronics. A government report, published in 1978, stated that the microelectronics industry was "the key to all other industries requiring high technology electronics. Should the United States and Japan restrict the availability of new I.C. technology to other countries, they could achieve unassailable leads in equipment industries".[23] A further report,[24] published in November, 1978, stated that the Government did not accept a situation where Britain had to import all its microelectronic components, since in a fast-moving technology, total reliance on overseas suppliers would put equipment users at a disadvantage. Also, since it would be necessary to import not only devices but also equipments into which these components would be built, this would result in a balance of payments deficit. The report also stated that technical competence would be greatly enhanced by technology transfer, which an indigenous company could then provide. The NEB INMOS project was supported by Government with this aim in view.

By this time, the weakness of the indigenous industry had been generally realised by Government, and the reasons for this state of affairs became the subject of public debate. An important policy statement was made by the Minister of State for Industry, Alan Williams, in March 1979.[25] He expressed disapproval of the way British industry had so far failed to respond to the microelectronics challenge. Previous perceptions regarding the extent of the State's function in influencing industrial policy were now moderated, with the emphasis on enablement. The Minister saw the Government's role as limited in the sense that technological decisions had to be taken by industry itself. The Government was however prepared to assist in making funds available by launching an awareness campaign. He saw "a depressing lack of awareness on the part of businessmen of the immediency of the threat hanging over them and their companies. It was the Government's wish that efforts should be made to develop a comprehensive production capability within the UK", in view of the fact that Plessey, Ferranti and GEC "tend to be in rather specialist sectors". We should also be "tying ourselves into the technology of the major multinationals; Texas Instruments, Motorola and Rockwell". In this context, he was encouraged by "the favourable way in which these highly competitive companies view the UK as a base".

The tone of this speech, coming at the end of a Labour administration, appears one of urgency, and extreme concern. It contrasts strongly with the indifference and lack of interest shown towards the local industry during the vital years of the early sixties, when considerable inducements were already being made by Government to encourage inward investment. Although about £250 million had been made available in 1978 under the MISP and MAP programmes, a considerable portion of these funds had gone to the multinationals themselves. Furthermore, "tying ourselves into the technology of the major multinationals" with the object of somehow developing the production capability of British companies, appears to be wishful thinking of a highly improbable nature.

The attitude of British manufacturers towards Government investment at that time was typically expressed by the Managing Director of Plessey Microsystems, who felt that although the investment programme to date had been "an immensely valuable contribution to maintaining and improving the UK's capabilities in the IC business, funds had not been of sufficient magnitude to actually break out of the limitations of a small market place, and put in the really massive investment that is necessary for the UK to become a significant operation by World standards".[26] Since a considerable proportion of available government funds had been used to encourage multinationals to locate in Britain or expand their existing plant, the residual money available to British producers was not sufficient to enable them to divert manufacture from linear integrated circuits into setting up mass production facilities for mainstream production. Consequently, government money invested in multinational companies assisted those organisations to compete more effectively in mass markets, whilst the money invested in British companies was spent in more restricted areas such as gate arrays, with considerably less market potential.

The importance of the abovementioned situation can hardly be overemphasised, particularly since it does not show up in published figures for British industrial investment within the industry, and is therefore easy to overlook. The consequences of Government policy over a considerable period, irrespective of whichever party was in power, had therefore been to consolidate and strengthen the multinationals, assisting their expansion into European markets. The money allocated to local industry had been used less effectively, merely serving to maintain a basic production capacity, amounting to perhaps five or six percent of the home market. The decision to set up INMOS was a belated attempt to remedy this situation, since the money invested in this venture was aimed at setting up a "state of the art" production facility to compete within mass markets. The imposition of somewhat moderate import controls had done little to help British firms, and by encouraging inward investment, actually placed them at a further disadvantage.

With the election of a Conservative Government in May 1979, What opposition existed to the activities of the multinationals lost much of its force. Sweeping changes in policy soon took place, and public funding of British semiconductor manufacturers began to dry up, with the result that "niche" markets within the industry became even more attractive. Little or no distinction was now made by Government between British and foreign firms, and the interests of the indigenous industry were subordinated to the policy of attracting foreign investment. It has been suggested that one reason for this development was that *"in the Government's view the corporatist policies of the past had made little impression on state dependent firms like GEC and Plessey, largely because they placed too few demands on firms. This reinforced the Government's inclination to substitute market forces for political pressure because, of the two, the former appeared to carry a more credible threat to state dependent firms".*[27]

Regardless of the Government's intention, the consequent reduction in public funding at this time for British semiconductor manufacturers led to the result that they became even more strongly locked into manufacture for the Defence industry. "Breaking out of the limitations of a small market place" was now out of the question, whatever the threat.

The result of this policy was predictably to weaken, rather than to stimulate the already hard-pressed local industry. An early casualty was INMOS. Disagreement about where the first of two proposed factories within the United Kingdom should be located resulted in a seven month delay in funding on the part of the Minister, Sir. Keith Joseph. Speculation regarding the sale of INMOS was widespread. Such delay could hardly fail to create a highly disadvantageous situation within such a fast-moving industry. The "Electronic Times " commented: "if any moral is to be drawn from this sad and unnecessary saga it is that delay and uncertainty in Government decision making breeds further delay and uncertainty".[28]

In 1979, the Government, against the advice of the DoI and NEB, sold their 50% shareholding in Ferranti, which was then in profit, the condition being that institutions could not sell their shares for two years after the original purchase date. Also against the advice of the DoI, which wished to take ICL into public ownership, the Government guaranteed a loan of £2 million, obtained from private sector banks. This guarantee was given only because failure of the Company might lead to disruption within Government departments, due to difficulties in computer maintenance.[29] Although INMOS did eventually receive the second £25 million tranche of funding in 1980, the Government's disapproval of State funded enterprises led to its eventual sale to Thomsom-EMI in July 1984.

The attitude of the Electronic Components Sector of the EDC at this time was clearly and forcibly expressed by its Secretary in November 1981, when addressing the Technology Policy Unit, University of Aston.[30] He stated that "unlike major competitors, we do not have a single policy for the UK's electronics industry. In fact, I rather suspect that we have no policies at all, or at a minimum, we have a number of ad hoc actions from Government with little apparent reason or principle behind them to make them coherent and mutually supporting". Importantly, he went on to point out that "This is not because of the colour and complexion of the government of the day. It is part of a long-standing inability in the UK to develop the apparatus and institutions which assure that policies for industry transcend the political cycle to take into account the industrial one". Certainly no attempt to develop such policies has taken place, and although the presence of the multinationals strengthened during the eighties, British microelectronics production continued to dwindle.

The "sink or swim" policy of reducing assistance to semiconductor manufacturers, in an effort to encourage them to compete more effectively could hardly succeed, faced as they were with technical lag, lack of alternative funding, and market dominance by the multinationals. By 1988, GEC remained as the only British manufacturer of semiconductors for the open market. With the virtual collapse of an already beleagured industry, manufacture of semiconductor devices then passed almost completely into the hands of the multinationals, who consequently now hold effective control over British electronic equipment manufacturers. The State has therefore lost strategic control over the manufacture of microelectronic devices, and consequently over the whole of the electronics industry, since essential supplies of devices can be witheld from British manufacturing equipment producers with impunity. Such a situation severely limits the power of government and industry in any state, should it ever wish to pursue policies contrary to the interests of the multinational component suppliers, or the national governments standing behind them.

Like Britain, both France and Germany pursued separate national policies, with little co-ordination, until launch in 1983 of the European Strategic Programme for R&D in Information Technology (ESPRIT). Instead, these countries aimed at satisfying the local need for components. This proved difficult in a situation of technical lag, together with an "open door" policy in the face of large scale overseas investment. Measures to render the European semiconductor industry strong enough to capture a significant share of its internal market were unsuccessful, and have remained so up to the present. Any possibility of the existing strategies succeeding has became increasingly remote, particularly since Japanese manufacturers began inward investment. The deteriorating market position of European semiconductor manufacturers can be seen from the following data.[31]

% Shares of the European Semiconductor Market

Countries	*1977*	*1983*	*1986*
European	48	40	35
American	50	50	50
Japanese	2	10	15

What had become significant by the mid-eighties was the rate of increase in Japanese economic penetration, compounding the difficulties already being experienced by the American presence. It was a matter of further concern that although the American market share remained unaffected by this development, the increase in Japanese market share had been entirely at the expense of European manufacturers. Conversely, the European share of the Japanese market averaged less than 1%.[32]

This situation had developed during a period of inward investment by Japanese manufacturers within the United Kingdom, encouraged by a government strongly committed to free market policies, including free movement of capital. The unfortunate result of these policies was renewed economic penetration of the European semiconductor market, making the task of establishing a strong and healthy European semiconductor industry an even greater task than before.

The weakness of the European semiconductor manufacturing base, together with its declining share of markets, is illustrated below.[33]

<u>European Semiconductor Firms Market Share (% value)</u>

Market	*1978*	*1984*	*% change*
Europe	44.6	34.9	-11.6 %
Worldwide	13.9	8.6	-38.1%

Such a degree of economic penetration strongly disadvantages European equipment users, since they now must rely on chips supplied by foreign manufacturers, who might well tend to favour their indigenous industries, in the event of shortages. Furthermore, due to the extent of this penetration, non-European multinationals are also in a position to manipulate the supply of the most technically advanced devices, thereby placing local equipment users at a significant disadvantage.

A consequence of being forced into "niche" markets by the activities of multinational companies, was that British manufacturers were unable to exert any control upon the industry's technological direction. They could therefore only attempt to respond to technical changes directed by their more powerful competitors. Due to their high degree of concentration on linear and bipolar manufacture, the activities of British companies became confined to an ever decreasing proportion of the total market, as world-wide demand for MOS devices increased. This development could hardly fail to act as a barrier to breaking out of the cycle of dependence on MOD contracts, which were mainly for devices of the linear and bipolar type.

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Chapter 10

Summary and Conclusions

Introduction

This chapter seeks to synthesise the preceding information, and to identify the principal reasons why the industry failed to compete successfully in world markets. The epilogue concludes that solutions to the difficulties now facing what remains of the industry can only be addressed on a European scale, and as part of a concerted plan involving user industries, together with the employment of fiscal measures to protect local industry.

Most of the factors determining the performance of the industry may be resolved into three principal categories, namely, those directly involved within the industry itself, those involving the activities of government and, finally, those due to external influences; for example, the activities of multinational companies. Each of these categories will now be considered in turn.

Industrial Factors

It is difficult to understand the development of the British semiconductor industry without an appreciation of the environment in which it originated. What can hardly be too strongly emphasised is that the eventual pattern of this industry was decided during the first decade of manufacture. The review of the British thermionic valve industry in chapter 2 is therefore important not only in setting the scene for subsequent events, but even more importantly because the organisations and attitudes then prevailing determined the behaviour of the new industry, and played a significant part in determining its subsequent history.

The British thermionic valve industry was essentially conservative and inward-looking. Protected by strong tariff barriers and the patent pool during the inter-War years, it had concentrated on supplying the home market, exporting only a small fraction of its production. In spite of considerable efforts made by valve manufacturers during the Second World War, these characteristics remained almost unchanged in the following years, although the conditions of World trade had altered considerably. Virtually no effort was made to move into the European valve market, where little competition existed immediately following the War, and it is significant that the larger and more dynamic Philips organisation, operating through Mullard, rapidly acquired a dominant position in both valve and tube manufacture. It is also significant that as the market share of indigenous valve producers fell, they tended to concentrate their activities within "niche" markets, supplying Government contracts. This pattern was to be repeated at a later date, as these same companies came under market pressure from rival semiconductor manufacturers.

After the invention of the pentode valve in 1928, domestic valve technology reached a fairly stable plateau. Consequently, research and development did not play a significant part within the industry, which was largely centred around the manufacture of radio receivers. Established under totally different economic conditions in the immediate post-war years, the newly emerging British semiconductor industry was faced with the problem of organising adequate research facilities within a fairly short timescale. No centre of excellence comparable to Bell laboratories existed, and work on germanium and silicon took place under conditions of technical lag, which became firmly established with the introduction of silicon planar technology. Attempts to leapfrog silicon technology by research into group III-V compounds were unsuccessful, although this work became important within the military field, particularly in connection with the development of infra-red detectors. Taking into account the disadvantage of being physically remote from Bell

Laboratories, and also the principal skill clusters within the United States, British industrial research in semiconductor technology appears to have a reasonably good record of innovation.

Transistor manufacture in Britain began entirely within the vertically integrated valve companies. Unlike the situation within the United States, where spin-off companies were set up by semiconductor engineers and physicists from Bell Laboratories, the industry in Britain grew up employing personnel recruited almost exclusively from the thermionic valve industry. A major consequence of this was that the management, technicians, sales staff and production personnel could hardly fail to retain outlooks and attitudes developed during the valve era.[1] Technical awareness among senior management and sales staff was much less likely to be found within a company also engaged in valve production, than in a horizontally integrated company of the American type, where the senior management was largely composed of device technologists. Perceptions formed during the valve era were totally inappropriate to the new technically complex, rapidly developing industry, and in this respect, the British laboured under a decided disadvantage compared with the new American spin-off's from Bell Laboratories.

The new industry demanded a particular combination of multidisciplinary skills, which in Britain were in extremely short supply, together with the ability rapidly to establish and maintain unfamiliar production processes. However, in spite of these obstacles, the technology of germanium was fairly quickly mastered, and Mullard Ltd., largely by virtue of its experience in mass-production techniques, soon became the major transistor manufacturer within the United Kingdom, repeating its previous success in valve manufacture. Success in semiconductor manufacture and marketing depended not only upon the ability to master new technologies but also on evolving appropriate management structures in which an awareness of market trends was paramount. In this respect, British firms were generally weak.

Although Mullard Ltd. was the most successful non-American semiconductor manufacturer based in Britain, they nevertheless lacked strength both in technical expertise and marketing experience. The technical demands of silicon planar technology, together with the disastrous decision to delay entry into that field, resulted in the Company's unrecoverable loss of market share. The reason for this event appears to lie within the company structure inherited from the days of thermionic valve manufacture. It has been suggested that the decision to continue to concentrate on germanium production during the early sixties was taken by the Marketing Department on the grounds that there was a full order book for germanium transistors.[2] It appears to have been common knowledge among the senior technical staff at that time that such a course was folly, yet their advice went unheeded. Such an event points not only to a considerable lack of technical awareness on the part of the Marketing Department, but also the inability at that time to devise management structures appropriate to a rapidly developing technology.

Vertically integrated semiconductor companies in Britain appear to have been unable rapidly to organise appropriate management structures involving close and efficient links between research and development, production and marketing. At least in the initial years, they lacked effective chains of communication and command, controlled by individuals with an understanding of the technology and technical potential of the product. To some extent this was unavoidable, in view of the relatively small size of the industry at its inception. However, the urgent necessity for such structures, in order to survive in a rapidly changing technology, does not seem to have been appreciated during the early years of production.

Perhaps this failure is understandable within a vertically integrated industry, where semiconductor production is but part of a much larger operation, and where major decisions tend to be made by technically obsolescent senior management. This factor may also have been responsible for the situation in America, where vertically integrated valve manufacturers entering transistor production performed relatively badly, compared with the newer horizontally oriented spin-off companies. In Britain, during the early germanium phase of the industry, such weaknesses were masked by the absence of strong external competition. With the advent of silicon planar technology, the effects were stark.

Unlike the situation in America, semiconductor spin-off companies in Britain were virtually non-existent, even at an early stage, when the capital investment needed to set up manufacturing facilities was still relatively small. This was not only due to lack of available sources of venture capital, but also to a shortage of trained semiconductor technologists. Furthermore, in view of the size of the British semiconductor industry, there was little to spin off from. In contrast to the spin-offs from Bell Laboratories, armed with the latest technology, any new British company would have been forced to enter the market with a technical lag inherited from its parent company. A combination of all these factors was effective in ensuring that the vertically integrated valve companies continued to dominate the industry.

A major problem confronting the industry following the development of silicon planar technology was lack of suitable European markets of sufficient size to absorb technically advanced products. The situation was one of dilemma. In order to avoid technical lag, these products had to be manufactured, although markets did not exist on a sufficient scale to enable unit costs to be reduced to a level enabling firms to compete directly with foreign rivals. This problem was never satisfactorily resolved, largely due to the early domination of the European computer industry by IBM, and also failure on the part of

European national governments to pursue common objectives in order to safeguard the industry. A specific example, at national level, was ICL's policy of buying devices from whatever source most satisfied their needs, thus preventing a synergistic relationship being established involving Ferranti. The inability to establish such synergistic relationships was certainly a fundamental factor in the subsequent failure of the British semiconductor industry to compete effectively in mass markets.

With the advent of silicon technology, British manufacturers were confronted by a relatively small market, already dominated by foreign producers, who were supplying technically advanced devices at an extremely low cost. The reluctance of industry to invest in solid-state technology, particularly during the early critical period, was largely due to this fact. Some idea of the magnitude of the problem may be obtained from an estimate made in April 1981, that the standard integrated circuit market in Britain was too small to sustain production, and that perhaps 75% of devices produced would have to be exported, principally to the United States computer industry.[3] Given the relatively meagre resources available to British device manufacturers, it is hardly surprising that no attempt was made to enter the mass digital market.

Even at an early stage, a financially advantageous situation had been established in which the principal semiconductor manufacturers concentrated on supplying MoD contracts, thereby being offered a way of avoiding the perils of entering a highly competitive market. The decision to concentrate on Government contracts could hardly fail to be reinforced by the fact that, as vertically integrated companies, British semiconductor manufacturers had a further interest in supplying equipments as well as devices to the MoD, and did not have to rely on the sale of semiconductors alone to survive.

Faced with overwhelming difficulties, it is hard to see how the electronic components industry in Britain could have prospered without a co-ordinated national plan, consistently applied during the period under review. Such a plan would have had to address problems involving disparity of resources, outlined in Chapter 7. Only with investment on a considerable scale, backed up by Government policies involving selective trade restrictions on both imports and inward investment similar to those successfully employed by Japan, might it have been possible, at a fairly early stage in the development of the industry, to resist it being forced, as it was, into small scale, specialised markets. However, in view of the present substantial barriers to entry into manufacture, such a national policy is no longer possible, principally due to lack of available resources, and the strength of multinational companies.

Due to the present relative weakness of the semiconductor industry in both Britain and the rest of Europe,, it became progressively more difficult for governments to adopt efficient fiscal measures to safeguard local manufacture. This was because the industry increasingly had to rely upon imported production equipment, which constituted the major cost in setting up, or updating production plant. It was estimated in 1992 that typically 75% of the necessary semiconductor manufacturing equipment had to be imported, chiefly from America, whereas in the United States the figure was about 25%.[4] It is for this reason that, in the event of any future attempt to establish a competitive semiconductor industry in Europe, tariffs would need to be selective, at least until measures were taken to establish indigenous sources of equipment manufacture. Such a policy would also require simultaneous steps to be implemented, in order to protect local electronic equipment manufacturers against foreign imports.

Governmental Factors

During the period under review, the policy of Government towards the industry may be generally described as being of a short-term, ad-hoc nature, with little co-ordination

Establishment personnel were more aware of the significance of semiconductors than officials at the DTI.

Even during the early sixties, it has been shown that considerable financial assistance was being given by the British Government to foreign multinationals, which were consequently able successfully to dominate and marginalise local manufacturers. The realisation that Governmental policies were unlikely to change substantially in this respect could hardly have failed to play a large part in directing the strategy of firms towards an ever closer relationship with the Ministry of Defence, to the exclusion of other equipment markets.

The most important single event affecting the fortunes of semiconductor manufacture in Britain was the decision by the Ministry of Defence, in 1957, to purchase silicon grown-junction devices from Texas Instruments, and to encourage that firm to set up production facilities in Britain. This decision was taken in order to obtain a reliable supply of these devices for Government equipments. Within a very short time, the unintended result of this move, as explained in chapter 4, was seriously to weaken the indigenous industry. No real attempt seems to have been made to initiate a programme of investment aimed at creating an alternative source of these devices. The principal reason for this omission appears to be that such a decision was outside the terms of reference of the Ministry of Defence, whilst at the same time, a lack of appreciation existed within Government generally regarding the potential importance of semiconductor devices. This situation contrasts strongly with that within the United States, where considerable funds were made available by the Department of Defense to improve the quality of transistors, and set up facilities for their mass production.

The consequent domination of the indigenous industry by overseas multinationals, assisted by Government encouragement of inward investment, resulted in local between the various Government departments involved. Consequently, there was a failure to articulate a consistent public sector policy, which would have allowed industry confidently to plan ahead. This situation contrasted strongly with that in both America and Japan, and to a lesser extent with our European competitors. What was really needed during this period - and what was entirely absent - was some organisational structure, able to ensure continuity of policy towards the industry, and thus attenuating the effects of the continual changes in strategy adopted by various governments. The need for such a structure was of particular importance in the case of the semiconductor industry, in view of the length of manufacturing production cycles, compared with periods of governmental office. There can be little doubt that government by political confrontation, extending to the organisation of industrial policy, has been extremely disruptive, particularly in view of the need for planning long-term strategies. Frequent changes in Government until the end of the seventies, culminating in the radically different free market approach towards industry which was then adopted, have contributed significantly to the present situation.

Government policy towards semiconductor manufacture was of extreme importance almost from the start. This concern is reflected in the detailed treatment given to the topic in chapters 4 and 5. The Ministry of Defence was quick to realise the value of transistors, and soon became involved with the various firms, providing a small amount of financial assistance to enable work to get under way. This help was soon followed by a number of Government contracts, although on a modest scale. However, apart from the Ministry of Defence, little awareness of the importance of the industry appears to have been present in Government until the late sixties, and only during the late seventies was any real effort made, through the MISP and MAP programmes, to assist the by then ailing industry.[5] The most likely reason for this state of affairs is that senior Government Research manufacturers being reluctant to enter mass markets, seeking instead Government contracts for products outside mainstream production. Attempts to assist financially both local industry and the newly arriving multinationals, on the principle that a "level playing field" existed between them, could hardly have inspired confidence. Furthermore, throughout this period under review, it was not the policy of the MOD under successive governments to favour local suppliers when purchasing devices. A consequence of these policies was that indigenous firms were discouraged from gaining experience of mass-production techniques, this itself constituting a further barrier to market entry. Faced with a constant technical lag, together with the increasing cost of setting up production plant in an environment of rapid technical change, it appeared that there was little likelihood that the local industry would be able to expand its activities substantially. Since the Labour Government's policy from the mid seventies onwards was to ensure that, for strategic reasons, Britain should possess a semiconductor facility capable of competing in mass markets, consideration was given to the possibility of setting up a publicly financed manufacturing facility, to produce advanced devices for the mass market.

The Government's decision to set up INMOS, was therefore taken with the specific aim that the United Kingdom should possess a semiconductor facility capable of operating at the leading edge of technology. It would develop, manufacture and market advanced products, to be sold within world markets. This move was made in face of a lack of enthusiasm on the part of existing British semiconductor companies. For example, the NEB was strongly criticised at that time by Plessey's Chairman, Sir J. Clark, and also by its Technical Director G. Gaut, who argued that Plessey offered a more viable alternative for investment than INMOS.[6] However, it was unlikely that Plessey's intention was ever to set up a mass production facility for standard devices. D.H. Roberts, Managing Director of the Microsystems Division, stated that it was more appropriate for his Company to apply its resources to producing products other than standard high-volume circuitry[7] Furthermore, in view of the company's past reluctance to invest appreciable capital within the industry, it is hardly surprising that the NEB decided to invest in a new company more closely dedicated to implementing its policies.

Lack of success on the part of Government in Britain, in its attempts to fund industrial projects through existing firms, appears largely to stem from structural and cultural factors. Specifically, the need to obtain money from the Treasury, in constant competition with other Departments, cannot fail to put Departments of relatively low status, such as the DTI/DoI, at a disadvantage[8] The money which is allocated has then to be spread over a certain number of competing projects. Such a system is unlikely to result in a predictable flow of capital, over the long term, for any particular project. This system of funding is therefore quite unsuited to assisting the requirements of the semiconductor manufacturing industry, where long-term planning is of great importance. The result can hardly fail to be a lack of confidence on the part of industry.

In an industry subject to rapid and continuous technological change, a high degree of technical awareness in government, coupled with the ability to respond rapidly and effectively to current industrial needs, is particularly important. Timing and allocation of funding is therefore critical. Evidence strongly suggests a weakness in this respect, direct Government involvement within semiconductor manufacture only beginning on a substantial scale in 1978, through the Science Research Council and the DoI. Had adequate funding been made available when requested by G.W.A. Dummer (RSRE) and D.H. Roberts (Plessey) at a MOD meeting in February 1959,[9] and subsequently used to initiate a large-scale planar programme, there can be little doubt that its impact would have been considerably more effective.

The relatively low status of the industry, and the Government Department representing it, remains part of a much deeper problem involving the perception of manufacturing industry within British society. This state of affairs is well known, and has been analysed in detail elsewhere.[10] An unconstructive attitude towards science and technology on the part of civil servants and politicians has been described by Trier as a reflection of British society as a whole, including the fields of industry, business and finance.[11] During the period under review, little seems to have changed in this respect.

External Factors

The major external influence upon the development of the semiconductor industry in Britain was the multinational companies, whose activities have been outlined in Chapter 9. These organisations were crucial to the fortunes of local manufacturers, and their presence largely contributed to the industry's inability to develop successfully. Whatever the merits of Government policy regarding industrial development in other fields, there can be little doubt that the decision to allow large-scale multinational investment in semiconductor manufacture within the United Kingdom led to the virtual extinction of an indigenous component manufacturing capability. This result could hardly be unexpected, in view of the wide disparity of resources outlined in Chapter 7 of this thesis.

The British semiconductor industry, like that of the rest of Europe, was dominated from the early days of silicon technology by American multinationals. Largely due to the activities of IBM, the computer industry was also similarly affected, preventing any synergistic relationship developing between local device manufacturers and the former industry. As pointed out in chapter 9, the situation became increasingly complicated, to Europe's disadvantage, by Japanese intervention, including substantial inward investment. Furthermore, this new threat was specifically targeted at the rapidly growing consumer and industrial market, in which indigenous component suppliers hold a relatively small share.

This development highlights a weakness within Europe, which is that the major semiconductor manufacturers, such as Thomson and Siemens have mainly concentrated upon supplying their internal needs, rather than the more general European consumer market. This rapidly growing market has been supplied largely by American producers, and more recently has also been targeted by Japanese inward investment. Apart from loss of market share, the result of this situation is that the rate and extent of applications within the microelectronics field have become effectively controlled by non-European firms, who are now in a position to withold or delay access to the most advanced components. Under these conditions, the rate of European industrial growth is effectively outside the control of its governing bodies.

Epilogue

This thesis concludes that the establishment of a viable semiconductor industry, able to compete successfully in the international mass market, appears now to lie well beyond the financial means of Britain. In view of their somewhat similar resources, this situation can hardly fail to hold in the case of other individual European states. Only on a European scale might it therefore be possible to build such an industry.

Any attempt at building a strong indigenous components industry must depend upon creating an environment in which European manufacturers can produce substantial quantities of devices for mass markets, in order to take advantage of economies of scale. Because the structure of demand for semiconductors in America, Japan and Europe has tended to coincide since the early seventies, European manufacturers have now no alternative but to compete directly with overseas companies within the open market, whilst suffering from the many disadvantages already discussed, including technical lag. Faced with this situation, there is now little possibility of building a strongly based local industry, without a concerted effort to curtail the activities of non-European multinationals.

This conclusion is supported by the fact that the strategy of attempting to catch up with American companies through "forced learning" programmes was tried by Philips, Siemens, and also the French companies, but without success.[12] British semiconductor manufacturers did not even attempt such a policy, limited as they were by a weak techological base, financial constraints and the prevailing attitude of "short termism", typified by GEC under the directorship of Lord Weinstock.

The question may be raised whether, with more resourceful and committed industrial leadership, it might have been possible for British manufacturers to have competed successfully within semiconductor mass markets. This appears unlikely, due to the importance of several key factors. For example, a mechanism for raising sufficient long-term capital at low rates of interest was absent. It is notable that that no spin-off company succeeded in Britain, or indeed in the rest of Europe, at the earliest stage in the development of the industry, when conditions of entry were most favourable. A significant effort to overcome the disparity of resources existing between local industry and the multinationals would have required strong participation from government over a lengthy period, presupposing a continuity in ministerial policy over perhaps several decades. Furthermore, the implementation of a viable industrial support policy would have most likely resulted in considerable trade friction, due to the need to impose selective import controls, or other measures needed to protect the industry during its formative years. Such an approach would have been unacceptable, given the political complexion of successive governments during the period under review.

Only in Japan were the abovementioned basic economic and political conditions established , enabling a successful semiconductor industry to develop, capable of competing successfully with American manufacturers in World markets.

A more dynamic British industrial leadership alone would therefore have had only a fairly marginal effect under existing conditions. However, there can be little doubt that this factor would have become of much greater importance if the necessary prerequisites for industrial success had been met. When considering the effectiveness of industrial management, it must be remembered that its attitudes and outlook are part of the much wider culture of a society, and any failings are likely to be reflected in that society at various levels, including government.

Looking towards the future, the establishment of a strong European components industry, capable of supplying the most advanced devices, appears essential to Europe's economic, and ultimately political independence. Success in this respect can only therefore be achieved by a high degree of inter-state co-operation. Any attempt at assisting the indigenous components industry without a concerted programme, aimed at establishing synergistic relationships with local equipment producers, together with fiscal measures strictly regulating inward investment, is unlikely to succeed. It is significant that Japan, in spite of an appreciable technical lag, was able to succeed on a World scale, after establishing a self-sufficient local industry by following a similar policy.

If such a strategy were to succeed, it would necessarily involve Britain participating strongly in a programme of restructuring the European semiconductor industry, and consequently abandoning its present *laissez faire* industrial policy. Furthermore, a significant change in attitude on part of industry would be needed, in view of the necessity to participate in, for example, a major VLSI programme, which would be required to meet head on the challenge of the multinationals. Anything less than such a programme would only result in continuing technical lag, and consequent economic domination. To be successful, a policy of this nature would require a degree of management and technical skills well beyond what has often been shown in the past.

The prevailing reaction to the problem of poor European performance within the industry, has been for many commentators to argue in favour of continued inward investment, together with inter-governmental co-operation between Europe states, in order to improve the competitive position of indigenous firms. For example, in 1979, the Editor of "Electron" argued that Britain should seek to attract American inward investment, in view of the poor performance of British semiconductor companies.[13] Hobday, as recently as 1989, advocated an "open door" policy, in which European firms should aim to achieve export-led growth.[14] In the case of a powerful local industry, possessing technological parity, this approach might be possible, but as things stand at present, it appears totally unrealistic. In 1984, the underfunded European semiconductor industry held a shrinking 8.6% of World markets,[15] and was technologically backward, with its mass markets heavily penetrated by competitors operating from within its boundaries. It seems, therefore, that no real prospect exists of indigenous manufacturers succeeding in a World economy dominated by the current trade rules. Only when this situation is fully confronted by decision makers within the respective European governments, can any constructive measures be implemented.

Alternative approaches to the problem of foreign economic domination which have been canvassed include the strategy of European manufacturers setting up production plant in America, or alternatively concentrating on a narrow field of device manufacture, in an effort to obtain market leadership in one particular area.[16] Investment within the American semiconductor industry, in order to gain the advantage of local technical expertise has already been tried, although without any great success. For example, the purchase of Signetics by Philips in 1975, and Interdesign by Ferranti in 1977. Unlike American and Japanese penetration within the European market, this type of overseas investment was made with the intention of reducing technical lag, and therefore of an altogether different nature to the aggressive domination of European markets by overseas producers. A concentration of effort within a narrow field of device manufacture, even if successful, would not address the general problem of massive penetration of European markets, and the subsequent problems outlined within this thesis.

It has also been suggested that rather than manufacture semiconductor devices, it might be better to import all or most of the components needed by equipment manufacturers. An OECD report argued as early as 1968 that such a solution for a major European country was out of the question, in view of the size of the equipment industry. Furthermore, an industry with a high technology content, like electronic companies are " most likely to be suited to the capability and structure of the very industrialised countries".[17] Such a policy would also be open to the various objections raised in Chapter 9 [discussed under the heading Multinationals - The Costs].

Ultimately, measures to establish a viable European semiconductor industry can only be taken at a political level, and therefore lie outside the scope of this thesis. Nevertheless, the issue is clear; if Europe, or any nation state within its borders, is to achieve a substantial measure of political and economic independence, it cannot do so in a technological age without control of its technology.

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1. It is the author's conclusion, based on personal experience within the industry and numerous conversations with colleagues, that these attitudes, translated into outdated management structures, were a significant factor in the inability of the British semiconductor industry to achieve the motivation required to compete successfully in world markets.

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3. D.Alun-Jones, "Ferranti: attacking systems markets", Electronic Industry 4, vol.7, (April 1981), p.31.

4. J. Walco, "Europeans on the ropes", Electronics Times (11th June, 1992), p.5.

5. An ACARD report even as late as 1978 (The Applications of Semiconductor Technology (London: HMSO, Sept. 1978), addresses the problem of lack of awareness in semiconductor technology, both within Government and industry.

6. D. Erskine, "How Plessey voice remained unheeded" Electronics Times (27th March, 1980). p.12.

7. D.H. Roberts "R&D pays off" Electronics Industry (April 1978) p.32.

8. In this context, the Rothschild Report stated that each Department should specify its R&D requirement and pay for it. See: "Civil Service Dept.", A Framework for Government Research and Development Cmnd.4814, (London: HMSO, 1971).

9. D.H. Roberts, "Silicon integrated circuits: a personal view of the first 25 years", Electronics and Power (April 1984), p.283. Also conversations with G.W.A. Dummer concerning this topic.

10. For example, see M.J. Wiener, English Culture and the Decline of the Industrial Spirit 1850-1980 (Middlesex: Penguin Books Ltd., 1985), also K. Smith, The British Economic Crisis (Middlesex: Penguin Books Ltd., 1984).

11. P.E. Trier, "Is R&D really relevant to industrial performance?", Physics Bulletin 37, (1986), p.457.

12. The French "Plan Circuits Integers" dating from May 1977 and the German-Dutch VLSI programme (the Volvo project) commencing in 1980.

13. D. Manners, "Future of UK electronics industry: Is it really bleak?", Electron (22nd May, 1979).

14. M. Hobday, The European Semiconductor Industry: Resurgence and Rationalisation (University of Sussex: Science Policy Research Unit, July 1989), p.25.

15. M.G. Borrus, Competing for Control: America's Stake in Microelectronics (Camb. MA: Ballinger Publishing Company, 1988), Table 8.1, p.195.

16. For example, apart from INMOS, Philips purchased Signetics in 1975 and Ferranti purchased Interdesign in 1980. Ferranti's concentration within the restricted market of ULA's is an example of an effort to obtain market leadership within a narrow field of manufacture.

17. Gaps in Technology- Electronic Components (Paris: OECD, 1968), p.122

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Appendix A

Glossary of Commonly Used Terms in Semiconductor Technology

This review is not intended to be comprehensive, but to explain terms commonly used when discussing the technology of semiconductors.

Acceptor

This is an impurity, which, when added to semiconductor material, or, for example, to N-type intrinsic semiconductor material in a sufficient amount, makes that material P-type.

Active component

Active components are those which are capable of the amplification of electrical signals. Thermionic valves and transistors are widely used examples of this type of device.

Alloyed junction

A junction which has been formed by recrystallisation from the molten state in which there is an abrupt change from P-type to N-type material.

Bandwidth

This is defined as the range of frequency response of an amplifier over which the power output remains above half its maximum, or mid-frequency value.

Base

This central region of a bipolar transistor is so called because it comprised the wafer upon which the point contacts of the original transistor were located. It is situated between the emitter and collector regions of the device.

Bipolar transistor

This device consists of a three layer P-N-P or N-P-N sandwich of semiconductor material, its action being initiated by the injection of majority carriers into the base. Here they exist as minority carriers and diffuse towards the collector, the majority then being swept into it by the aiding field provided by the reverse-biased base-collector junction. Applications include its use as an amplifier, oscillator, and as an electronic switch.

Charge carrier

This is a carrier of electrical charge within a semiconductor crystal. It can exist either as an electron (negative charge) or as a hole (positive charge).

Chip

A portion of a semiconductor slice containing either a single device or integrated circuit.

Collector

This is the region of a bipolar transistor which receives the base transit charge

Cut-off frequency

The frequency at which transistor gain falls to a certain defined value. For example, the frequency at which the gain of a bipolar transistor in common emitter configuration is equal to unity. Cut-off frequency is a function of transistor base width, increasing with decrease in base thickness.

Depletion layer (or region)

In this region of a semiconductor junction the charge carriers have been removed by the electric field existing at the junction. The region has therefore been depleted of free charge carriers. The depletion layer acts as a barrier to majority carrier movement, although thermally generated minority carriers are able to cross the barrier because of their opposite charge polarity.

Dopant

An element which, when added to a semiconductor crystal, strongly increases its ability to act as an electrical conductor.

Dynamic memory

This type of memory will not retain information without the application of a periodic read-write cycle. It allows more memory to be fabricated on a given area of chip than in the case of a static memory.

Emitter

This region of a bipolar transistor acts as a source of mobile charge carriers which it injects into the base region.

Gettering

The process of removal of adsorbed gases from vacuum tubes by means of the introduction of a substance capable of readily absorbing the gas. Such a substance is termed a "getter".

Hole

This term describes the absence of an electron in the covalent band of an atom within a semiconductor crystal. The absent electron acts as a positive charge, consequently hole conduction in semiconductors is equivalent to the motion of positive charges.

Integrated circuit

An array of circuit elements, typically diodes, transistors and possibly other circuit parts, formed during the same manufacturing process on a single substrate and interconnected to form an electronic circuit. It may therefore be an assembly of both active and passive components. The silicon planar method of device construction lends itself readily to this type of approach.

Intrinsic conduction

This is the process of electrical conduction which would take place in a pure, or intrinsic, semiconductor material; namely, one that has no impurities present.

Ion implantation

This method of forming P-N junctions has now to some extent supplanted the diffusion process, having the advantage of more accurate definition of the dimensions of P-N junctions. This factor is of great importance in the fabrication of integrated circuitry. High-voltage ionic bombardment is used to introduce selected impurities into the desired regions. A wider range of impurity gradient can be obtained by the use of this process than can be achieved using the alternative method of diffusion.

Junction

This is the boundary between two semiconductor regions usually of P-type and N-type conductivity. A P-type and N-type semiconductor in electrical contact constitutes a junction diode.

Logic gate

An electrical circuit in which an output having constant amplitude is registered if a particular combination of input signals exists. Examples are "OR, AND, NOT and INHIBIT" circuits. These logic functions may be realised by various bipolar families, for example, diode transistor logic (DTL), transistor transistor logic (TTL) and emitter coupled logic (ECL) or by MOS and CMOS logic.

Majority carrier

This is the mobile charge carrier most responsible for electrical conduction (either a hole or an electron) within a semiconductor material. Thus, electrons in N-type are majority carriers in N-type material and holes in P-type material.

Metal Oxide Field Effect Transistor (MOSFET)

This is an Insulated Gate Field Effect Transistor, the insulation between the gate electrode and the conducting channel being a layer of silicon dioxide. MOSFET devices may be manufactured with an extremely high packing density. They are widely used, for example, in the construction of computer memories.

Microelectronics

The technology of manufacturing semiconductor devices and using them to construct equipments.

Minority carrier

This is the mobile charge carrier of opposite electrical polarity to the majority carrier (either a hole or an electron) which exist within a semiconductor material. Thus, holes are minority carriers inN-type material and electrons in P-type material.

N-type material

Semiconductor material in which the majority carriers are electrons.

Ohmic contact

A semiconductor-to-metal contact, or a metal to metal contact which does not behave as a rectifier.

Passivation

The protection of the surface of a semiconductor in order to ensure that its electrical properties remain stable. This is achieved in the planar process by growing a layer of silicon dioxide over the junctions of the device, electrically stabilising its surface and shielding it against moisture and contamination.

Passive component

Passive components are defined as those which are unable to function as amplifiers of electrical signals. Resistors, capacitors and diodes are commonly used examples of this type of component.

Planar Process

A manufacturing technique used in the construction of transistors and integrated circuits, in which a layer of silicon dioxide is grown on a silicon substrate. A series of etching and diffusion steps is then carried out, in order to delineate the P & N type junctions. During each diffusion, a further layer of silicon dioxide is deposited upon the surface, rendering the device electrically stable. This process has now almost universally supplanted previous manufacturing techniques.

Polycrystalline

This term is used to describe a material consisting of many small distinct crystalline regions of different orientation, rather than a single crystal. Polycrystalline semiconductor material is unsuitable for fabricating transistors, owing to the grain boundaries between each crystal acting as recombination centres for charge carriers.

P-type material

Semiconductor material in which the majority carriers are holes.

Radar

A detection system, developed prior to the Second World War, using pulsed radio waves, in which the reflected pulses are used to measure the distance and direction of an object. The efficiency of the system depends largely upon signal strength, hence the importance of the magnetron valve as a generator of powerful electronic pulses.

Random access memory

This is a memory device in which the access time is the same for any address within the memory.

Recombination

The mechanism whereby holes and electrons combine. It is affected both by surface imperfections and volume impurities within the crystal. Recombination in the base of a bipolar transistor reduces the number of minority carriers available for conduction, thus reducing current gain.

Rectifying contact

An electrical contact, permitting the easy flow of current in one direction (called the "forward" direction) whilst restraining the flow of current in the opposite direction (the "reverse" direction).

Semiconductor

This is an element intermediate in electrical conductivity between insulators (nonconductors) and metals (conductors). The most widely used semiconductor in electronic devices at present is silicon.

Slice

A thin slab of semiconductor sawn from an ingot. The ingot is usually in single crystal (monocrystalline) form, and may be currently up to six or eight inches across, although, in the early days of semiconductor manufacture, they were typically half an inch in diameter. The advantage of larger diameter slices is economy of scale in production. In the planar process, discrete devices or integrated circuits are manufactured on the silicon slice. The slice is cut up into individual wafers or dice before final assembly and encapsulation.

Static memory

This type of memory will retain information without the need of a periodic re-write cycle. The data will remain in store as long as power is applied.

Substrate

The underlying layer of material upon which a device, circuit or epitaxial layer is fabricated. In present semiconductor manufacture this layer is usually a silicon slice.

Superheterodyne receiver

A radio receiver in which the frequency of the incoming signal is transformed into an intermediate frequency before conventional detection. The advantages of this system include better signal gain and selectivity, although at the expense of increased circuit complexity and cost.

Surface states

The electrical properties of a semiconductor are strongly influenced by its surface conditions. This is because of the interaction between the environment and the particular electrical conditions present at the semiconductor surface. A problem in device manufacture is that these surface states may cause electrical instability and high surface leakage currents. The planar process overcomes this problem by electrically stabilising or passivating the surface by means of a layer of silicon dioxide.

Unipolar transistor

This is a device such as a field effect transistor whose action depends upon the movement of majority charge carriers only.

Very large scale integration (VLSI)

This is defined as a chip containing one hundred thousand or more components.

Wafer

This word is used interchangably with "dice". During manufacture, the silicon slice upon which devices have been fabricated is separated into individual wafers, each containing either a single device or integrated circuit. This is done during a latter stage in the production process.

Appendix B

Interviews and Private Communications

Name	Organisation	Position
Prof. W.B. Arthur	Stanford Univ., Calif.	Dean and Prof. of Population Studies and Economics.
Dr. B. Avient	Philips Components, Southampton	Plant Director.
Dr. J. Bass	Plessey	Technical Manager.
R.W. Beckham	DRA (Farnborough)	Manager, Intellectual Property Development.
A.W. Benn	HM Government	Ex. Minister for Technology.
J. Bolt	SIHE and RAE, Farnborough.	Physicist.
M. Bond	Texas Instruments	Physicist.
J. Brown	Texas Instruments	Quality Control Manager and Engineer.
T.G. Brown	Mullard Ltd.	Semiconductor Engineer.
C.P. Burton	ICL	Computer Engineer.
E.B. Callick	SERL	Ex. Secretary, CVD.
Dr. M. Campbell-Kelly	Univ. of Warwick	Computer Scientist.
K. Dickson	Brunel Univ.	Senior Lecturer.

Name	Organisation	Position
G.W.A. Dummer	RSRE	Ex. Superintendent, Applied Physics.
Prof. W. Eccleston	Liverpool Univ.	Faculty of Engineering.
Dr. W. Fawcett	RSRE	Head of Physics.
C.A.P. Faxell	Post Office & GEC	Ex. Technical Director, PO, & Man. Dir., GEC.
P. Harris	Mullard (Southport)	Plant Director.
Dr. C. Hilsum	RSRE & GEC	Director of Research, GEC (Wembley).
Dr. W.J. Hossack	Edinburgh Univ.	Dept. of Physics & Astronomy.
Prof. H. Kemhadjian	Southampton Univ.	Prof., Solid-state Physics.
Sir G.G. Macfarlan	RSRE	Ex. Superintendent of Physics.
Dr. J. Pearson	Ferranti	Technical Manager.
Dr. J.M.M. Pinkerton	Eng. Elect. & ICL	Chief Designer, English Electric.
B. Proctor	ICL	Technical Manager.
Prof. D.H. Roberts	Plessey	Technical Manager. Now Provost, Univ. College, London.
J. Salter	GEC-Plessey	Marketing Communications Manager.
Dr. A.A. Shepherd	Ferranti	Ex. Manager, Electronic Components Div.
B. Talbot	ICL	Chief Engineer.

Name	Organisation	Position
Prof. B.K. Tanner	Bradford Univ.	Dept. of Physics.
P.W. Trevett	RSRE	Chief Librarian.
A.D. Weston	Mullard (Southampton)	Research Engineer.
G. Wharam	Texas Instruments & Marconi Insts. Ltd.	Sales Engineer.
Dr. B.L.H. Wilson	Plessey	Technical Manager (Caswell).
Dr. J.F. Wilson	Manchester Univ.	Senior Lecturer.
Dr. G.P. Wright	RSRE	Ex. Director of Services, (Electronics), SERL.