CORDLESS TELEPHONE DESIGN USING SURFACE MOUNTED PRODUCTION ASSEMBLIES

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and
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Declaration

I declare that this dissertation has not been, nor is currently being submitted for the award of any other degree or similar qualification

Signed: MJ Butcher ....

M.J.Butcher

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The author would like to express his gratitude to all involved in the collaboration between the Polytechnic of Wales (POW) and Autophon (UK) Ltd. which enabled the study, on which this dissertation is based, to take place.

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Contents

Page

1 Introduction

2 Radio Frequency Techniques Applicable to Low Band Cordless Telephones

3 Surface Mount Technology

4 Surface Mounting Design Guidelines and Justification of the Test Vehicle

5 Test Vehicle Development Study

6 Conclusion

Appendices

List of Figures

page

page

page

ABSTRACT

Cordless Telephone Design using Surface Mounted Production Assemblies

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The incentive to employ surface mounted devices (SMDs) in place of leaded components in high volume assemblies can be attributed to their improved manufacturing and performance properties. They are particularly suited to automatic placement and have an inherently greater reliability. Their small size and short lead lengths make their use especially attractive in miniaturised radio frequency circuits. However, to fully exploit the advantages offered by the technology, new design procedures must be developed and evaluated.

A review of relevant radio frequency design techniques and an analysis of surface mounted production processes were performed. These were used to compile a set of design rules for developing a miniaturised cordless telephone (transmitting at 1.7 MHz and 47 MHz). Its overall specification and features were based on an existing product manufactured with leaded components. This provided a benchmark against which to improve on performance efficiency, production costs and manufacturing repeatability.

In order to prove the validity of the new design it was necessary to subject the product to various approvals tests. These were conducted within the project and the telephone gained full approval for operation and sale in the United Kingdom. Through the experience gained during the course of the project an update to the initial set of design rules was made.

From the study it was concluded that, the higher self resonant frequency of SMDs over leaded components offers significant decoupling advantages in medium frequency circuits. SMDs also offer improved in-circuit tolerance because of the removal of insertion accuracy uncertainty. The use of SMDs at cordless telephone frequencies did not compel a change to the circuit design but further study is necessary to access the situation at ultra high frequencies. Single-sided, mixed technology was identified as an ideal surface mount assembly (SMA) entry technique because it maintains the familiar wave soldering process. In addition, it allows the optimum choice between SMD and leaded components to be made, in order to take advantage of cost/performance trade-offs and minimise acquisition difficulties.

NOMENCLATURE

0805 1206 1210 1812 2220	Surface mount chip component dimensions. (See figure 3-2)
a	Area
AGC	Automatic Gain Control
AM	Amplitude Modulation
AMIE	Advanced Manufacturing In Electronics
BW	Bandwidth
BW_m	Bandwidth of modulated signal
CFC	ChloroFluoroCarbon
dBm	dB relative to 1 mW
dBmP	dB relative to 1 mW, measured through a psophometric filter
COG	Dielectric type. (Low dielectric constant, high stability)
DIL	Dual-In-Line
DSBSC	Double Sideband Suppressed Carrier
DTI	Department of Trade and Industry
EMI	ElectroMagnetic Interference
EMC	ElectroMagnetic Compatibility
ESR	Effective Series Resistance
FET	Field Effect Transistor
FM	Frequency Modulation
f_o	Channel centre frequency
f_s	Channel spacing
FR2 FR3 FR4	Printed circuit board base material grades
IF	Intermediate Frequency

IR	Infra Red
JEDEC	Joint Electronic Device Engineering Council
l	Length
LC	Inductor/Capacitor combination
LCC	Leadless Chip Carrier
MELF	Metal Electrode Face Bonded
MF	Medium Frequency
m	Modulation Depth of amplitude modulated signal
M	Modulation Index of frequency modulated signal
PCB	Printed Circuit Board
PM	Phase Modulation
PCC	Plasic Chip Carrier
PLL	Phase Lock Loop
P_{out}	Power out
Q	Quality factor
PRE	Product Responsible Engineer
PSTN	Public Switched Telephone Network
RF	Radio Frequency
R_L	Load Resistance
R_s	Radiation Resistance of Short Antenna
R_{loop}	Radiation Resistance of Loop Antenna
SINAD	SIgnal to Noise And Distortion ratio
SMA	Surface Mount Assembly
SMD	Surface Mount Device
SMT	Surface Mount Technology
SRF	Self Resonant Frequency
SSBSC	Single Sideband Suppressed Carrier
UHF	Ultra High Frequency

VCO	Voltage Controlled Oscillator
VHF	Very High Frequency
VP	Vapour Phase
Y5U	Dielectric type. (High dielectric constant, low stability)
θ	Phase Angle
λ	Wavelength

Preface

The Teaching Company scheme operates through Teaching Company Programmes in which a University or Polytechnic participates in a company project to achieve a substantial and comprehensive change in product technology and skills base.

The scheme was devised by the Science and Engineering Research Council (SERC) and the Department of Industry (DOI) and aims to develop active partnerships between academic institutions and manufacturing companies in order to:

a - raise manufacturing performance by effective use of academic knowledge and capacity.

b - improve manufacturing methods and the effective implementation of advanced technology.

c - train able graduates for careers in manufacturing.

d - develop and re-train existing company and academic staff.

e - give academic staff broad and direct associations with industry for research and as a background for teaching.

The Teaching Company programme which enabled the work described in this thesis to be undertaken was a partnership between the Polytechnic of Wales (POW) and Autophon (UK) Limited. The author was an associate of that programme.

Chapter 1

Introduction

1-0 The Dilemma in Electronics

To be competitive in the consumer electronics market place a product must incorporate the most up to date features and be packaged in an appropriately appealing style. The majority of modern households contain examples of such products. Each equipment manufacturer attempts to surpass the competition with extra operational features contained within smaller, lighter and better ergonomically engineered housings. At the same time as product features are increasing, the customer is not expected to pay heavy premiums for the added complexity. Video recorders and compact disc players are appropriate examples of how the competition in, and development of, new technology brings with it the benefits of more powerful, yet cheaper equipment. Customer expectations are high, fuelled by the speed of recent amelioration.

The equipment designer and manufacturer is faced not only with catering for the increased complexity but doing so against shorter product life times. Figure 1-1 shows graphically how the relationship between product life and development times have been influenced since the 1960s. With the reductions in marketable life span, the possibility of a product becoming obsolete even before it enters the market place becomes apparent. The simple conclusion is that for a company to survive in the consumer electronic market place it must meet the market demands; innovation must be linked with appropriate advancements in product design and manufacturing efficiency. Investment in new design and manufacturing

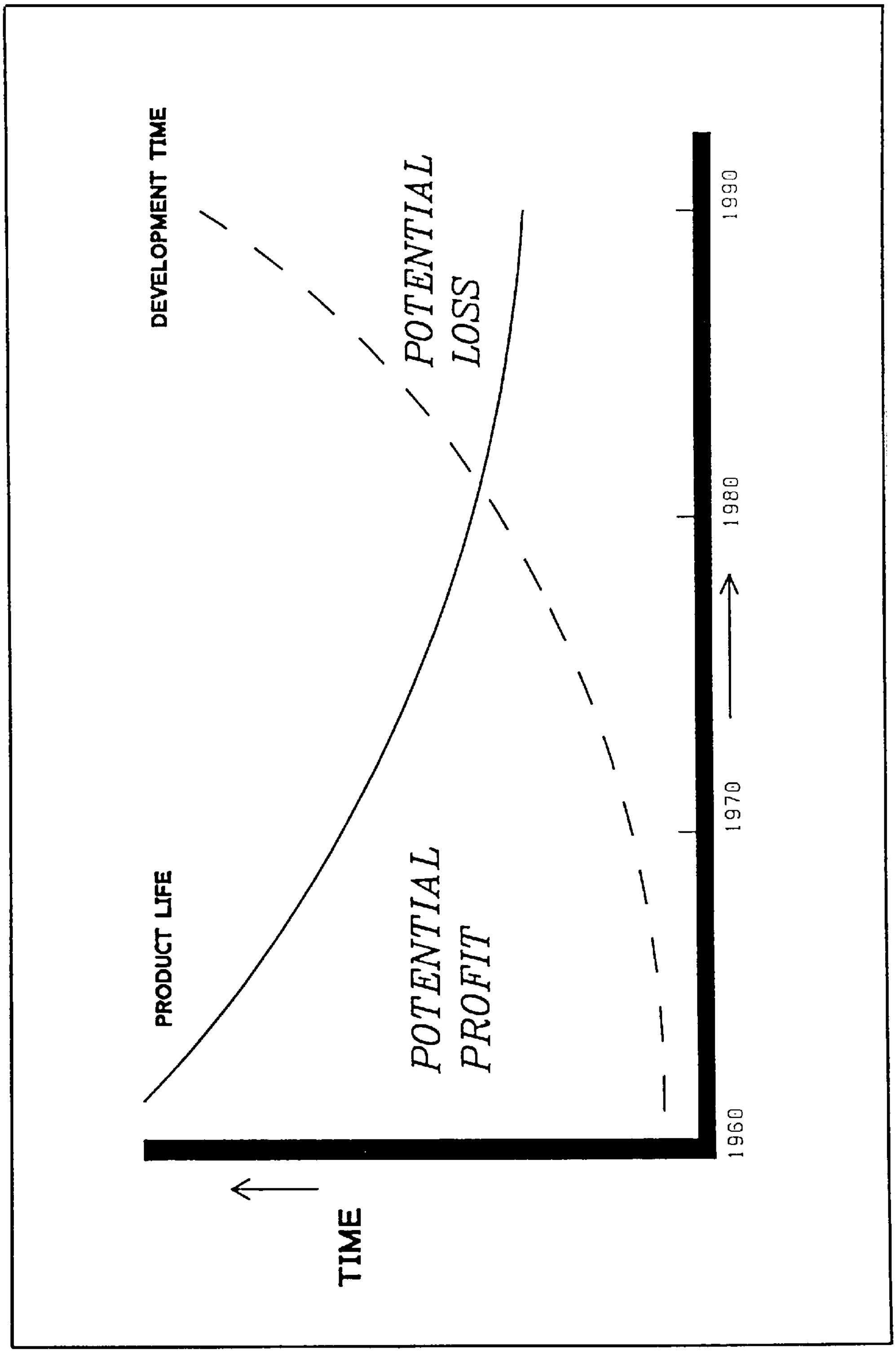


Figure 1-1 The relationship between product life and development times

technologies is fundamental to maintaining the necessary competitiveness.

1-1 Surface Mount Technology

Surface mount assembly (SMA) techniques represent one possible method by which manufacturers can increase competitiveness. The surface mount technology (SMT) offers the potential to produce high volumes of compact and reliable electronic equipments. Having no legs or leads for connection through holes in a printed circuit substrate, surface mounted devices (SMDs) are fixed directly onto connection pads (footprints) by soldering to component terminations.

SMDs are commonly smaller than their conventional counterparts resulting from their disparate packaging requirements and are suitable for automatic placement within automated assembly lines. The adoption of SMT offers possibilities to reduce manufacturing costs and product size, whilst increasing performance, throughput and reliability. The adoption of SMT does, however, involve capital investment in the machines to place components and solder them to the substrate. It also involves investment in the training of personnel to adapt to the new techniques and a change in approach by designers of circuits, printed circuit boards and assemblies.

Figure 1-2 shows a comparison between a typical conventional resistor and a surface mount resistor, known as a chip device due to its construction. The chip format is typical of passive components such as resistors and capacitors, while common active device packages are compared in figure 1-3. A printed circuit board employing various surface mounted devices is shown in figure 1-4, illustrating the small circuit size that may be achieved using the technology. This technology is not new since it has been used successfully for over twenty years in the realm of hybrid circuits[1] but these were typically employed in only specialist applications and not until recent years have commercial manufacturing companies exploited the methods for large volume production.

In 1980, SMDs accounted for only a small percentage of assembled devices. By the early 1990s it was predicted that they would account for over 50% of all components assembled worldwide. The trends are shown in figure 1-5. The price of a component in surface mount form has tended to be higher than its conventional counterpart but, due to the demand for the new technology, the price gap continues to close. Various forecasts suggested that by mid. 1988, general component prices would be comparable.

According to Frost and Sullivan[2], the European SMD market totalled $784 million in 1986 with the UK claiming one fifth of this total. The report suggested that the European market would total $2.2 billion by 1991, in constant US dollars. A breakdown of the application of the devices in 1986 is shown in figure 1-6. At the time of the survey, the Japanese market was worth six times the European total.

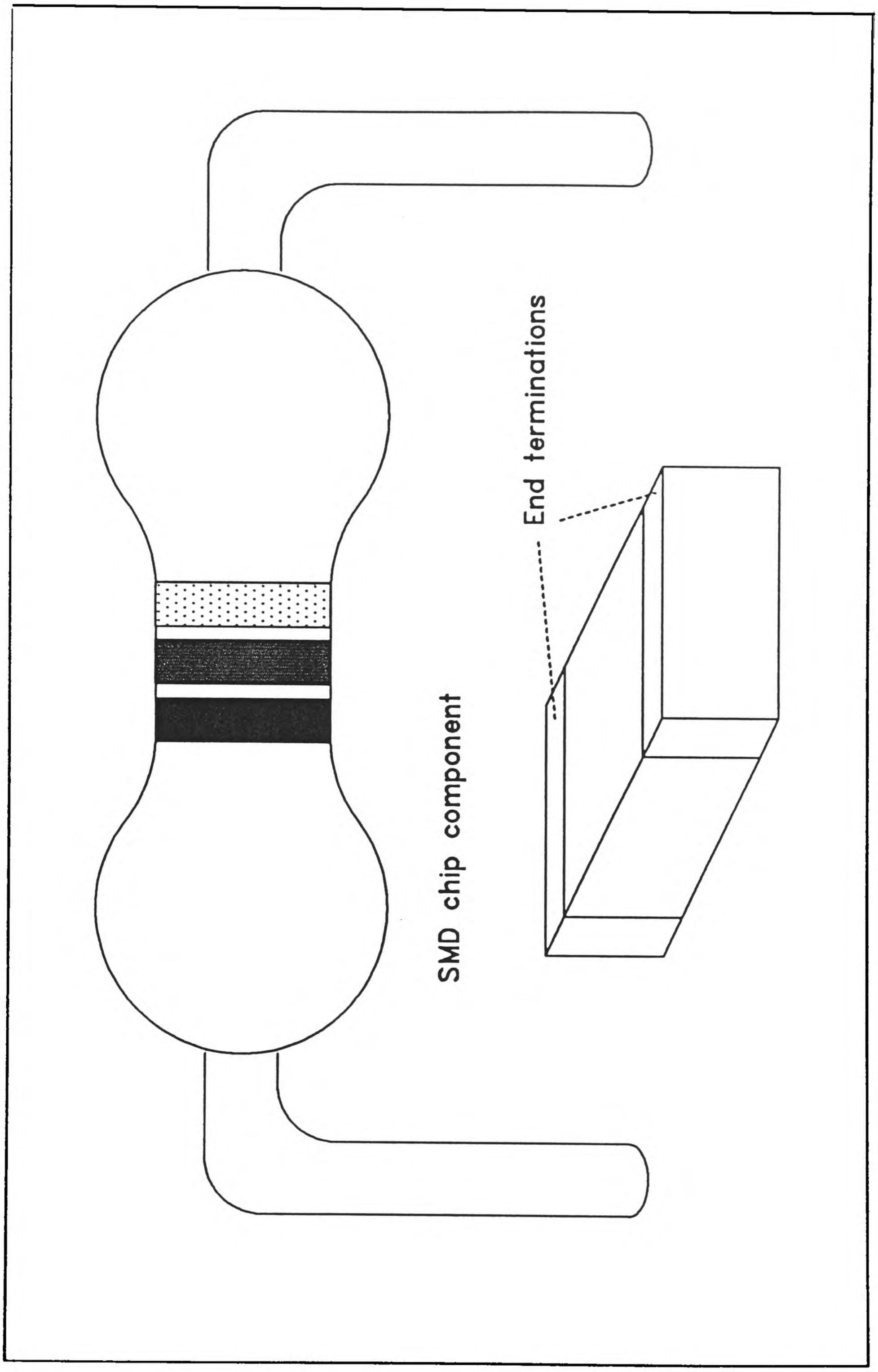


Figure 1-2 Comparison between typical leaded and SMD resistors

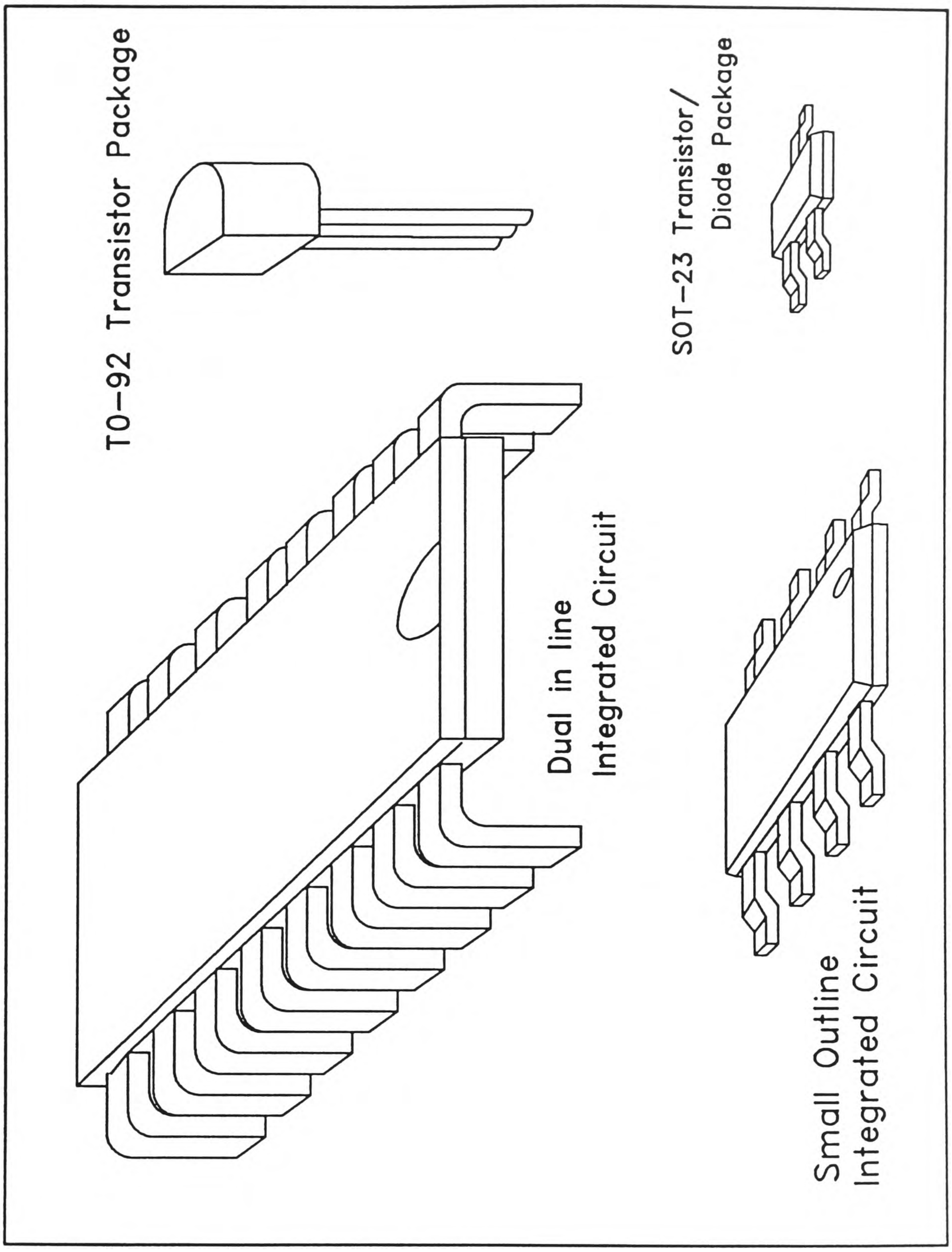


Figure 1-3 Comparison between common active circuit components

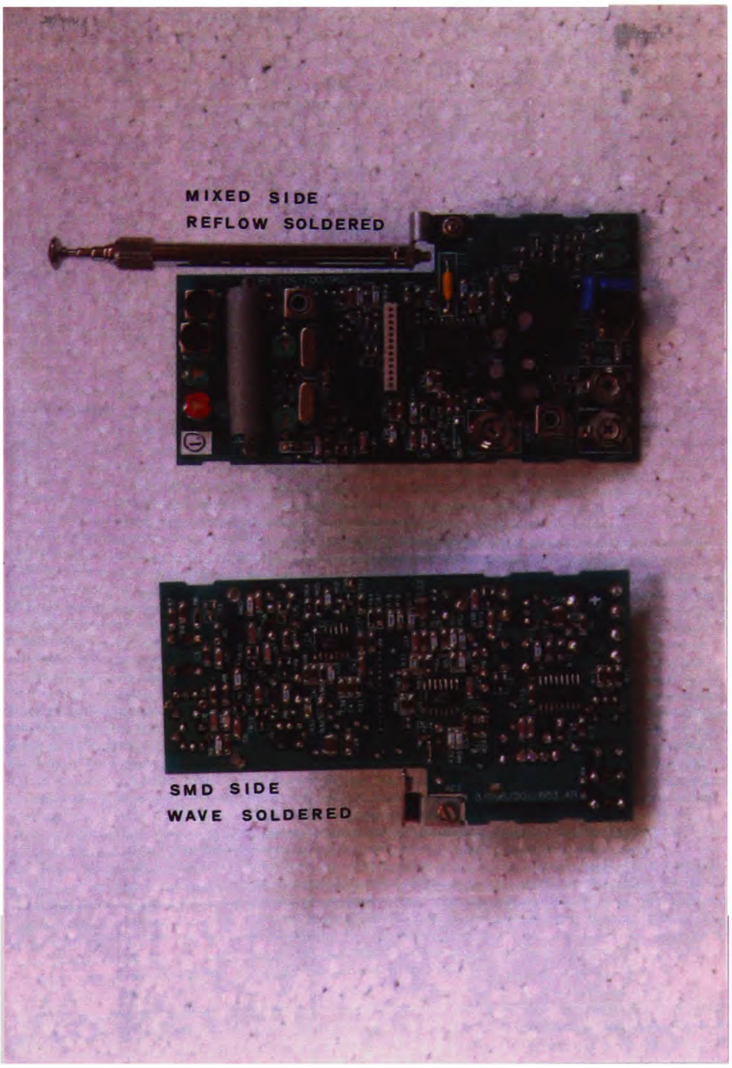


Figure 1-4 A printed circuit assembly exploiting SMDs

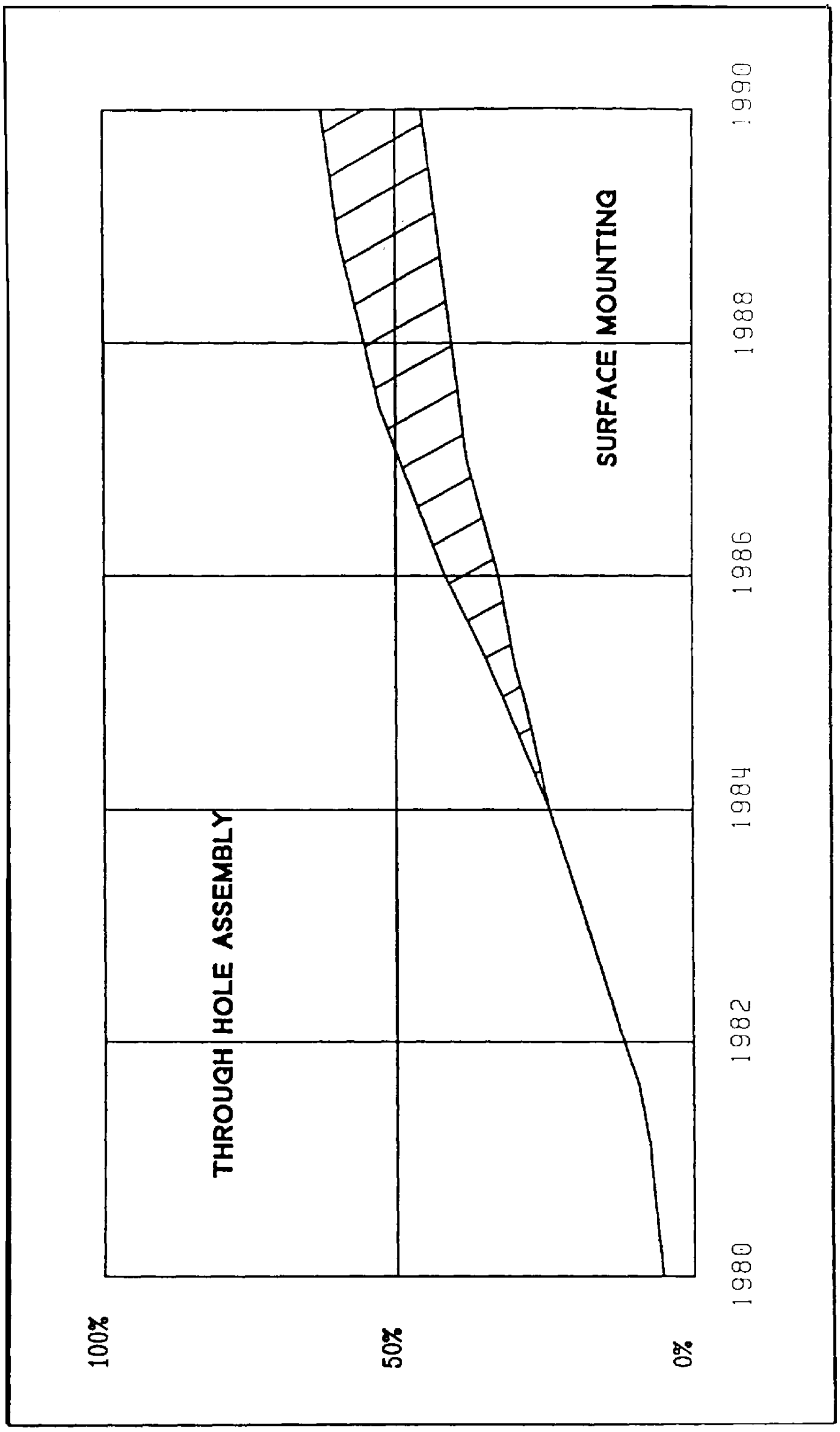


Figure 1-5 Trends in PCB assembly techniques

The popularity of SMAs was becoming increasing evident in consumer electronics. Quite unknowingly most of the UK population owned equipment containing the devices: compact disk players; video recorders; television receivers; pocket radios and cassette players; calculators and personal organisers. Without the technology such products would certainly not have been so readily available.

1-2 Autophon (UK) Limited

Autophon (UK) is a Swiss owned telecommunications company involved in the design and manufacture of telephones and related products. Based in South Wales, the company was experienced in the production of assemblies using through hole insertion and flow soldering techniques. Products were aimed at a relatively low end price market where profits were made by manufacturing high quantities at the lowest possible costs in sympathy with appropriate product quality and performance. A simple telephone typically reached the consumer at a price between 20 and 40 pounds sterling.

The consumer market place was demanding increased functionality within Autophon's products. This, in return, demanded the development of more complicated electronic circuitry requiring a greater number of components and a larger volume of space within the product packaging. There was a point at which an increase in functionality was to demand electronic circuits that would no longer fit into the desired enclosures. Enlarged mouldings, to accept the increase in circuitry, was not an alternative since it

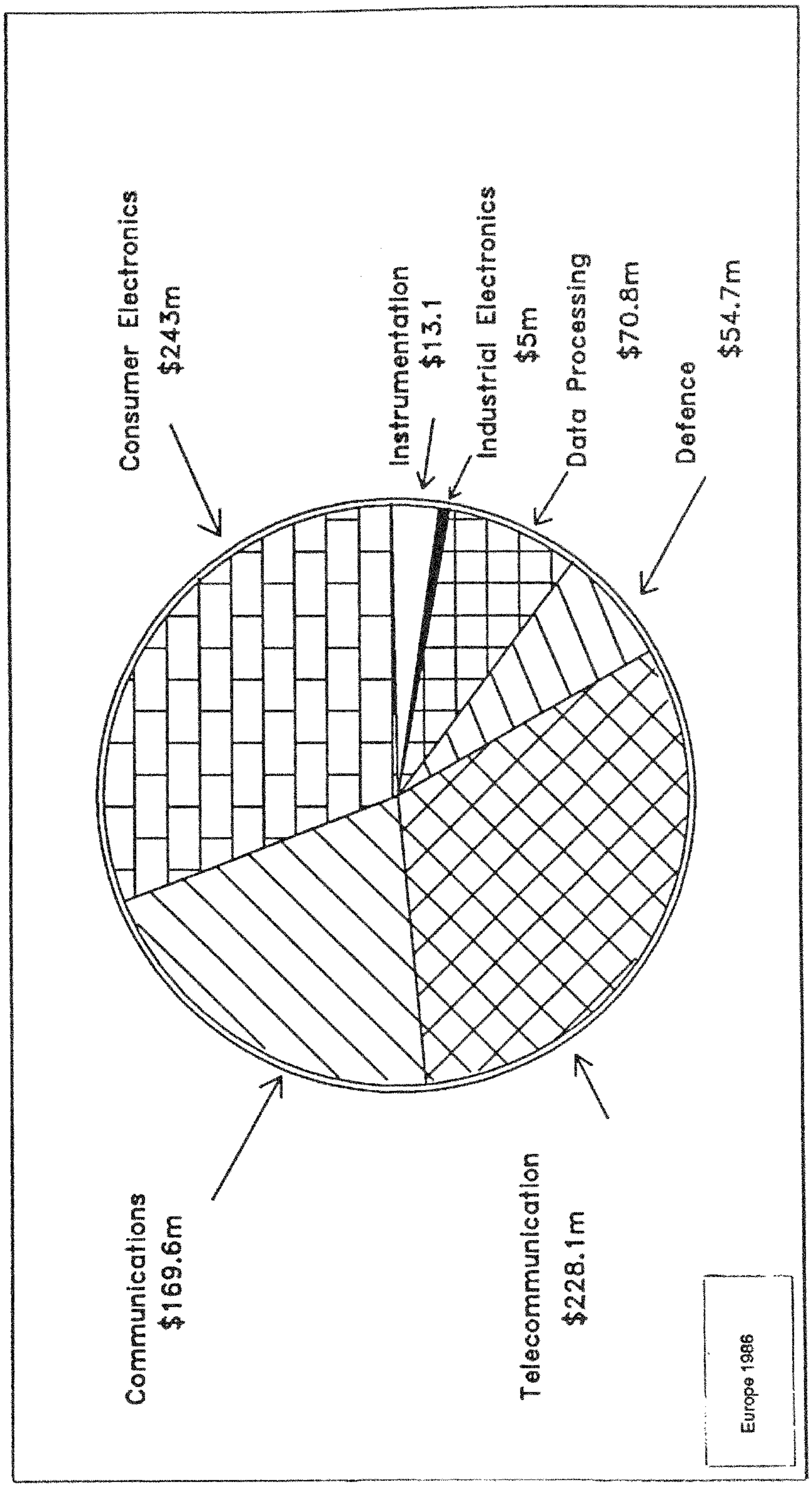


Figure 1-6 SMD application by expenditure

opposed the trend of miniaturisation in consumer telecommunications products and as such would be detrimental to marketability. Along with alternative techniques, such as committing sections of circuitry to custom integrated circuits[3], SMT offered a solution to the most important aspect of restraining physical circuit size. To benefit from the claims of the technology it was necessary for Autophon to be in a position to use it when the time was appropriate. This was envisaged to be during 1988 when scheduled new products would need reduced circuit sizes and advantages could be taken of reduced component costs.

In the light of the advantages SMT offered over conventional technology an urgent need for adoption was felt by Autophon. The first stage was to progress along the learning curve; to acquire a knowledge of the technology, where it was practical to use it, how to best employ it and in what to invest financially.

1-3 Availability of Surface Mount Technology Guidelines

At the time of the study, SMT was relatively new to the UK manufacturing industry and as such had only recently begun to be documented. Since the adoption period can be an expensive and error-prone phase until the process has been adapted to meet its precise requirements, industrial confidentiality was often encountered. Competitors also faced similar problems and were reluctant to disclose details of their techniques.

The Department of Trade and Industry (DTI) organised the Surface Mount Club[4] to promote the advancement of SMT in the British manufacturing industry and also involved SMT in their AMIE (Advanced Manufacturing In Electronics) program[5]. SMT user groups such as the Surface Mount Club encouraged the exchange of information between users who could benefit from such collaboration.

1-3-1 Printed Circuit Board Design

The major source of information concerning the design of printed circuit boards (PCBs) came from companies with a vested interest in the successful adoption of surface mounted techniques by others. These included component manufactures and SMA machinery manufacturers. Some data on PCB design rules could also be purchased from sources such as sub-contract PCB design and assembly houses.

1-3-2 Surface Mounted Assembly Process

It was notable that the majority of guides to the use of SMT were only over-views and it was necessary to determine what aspects in particular were relevant. More detailed studies generally contained information of techniques that had been suitable for a particular user and as such had to be carefully considered as to their suitability. Should assembly work have had to be sub-contracted, the obvious choice would have been to design with their stipulated rules since they were suited to their process and proven. Should there have been process problems after the design stage then the responsibility would have gone totally to the sub-contractor. Generally, a set of design rules best suited to a potential process should be selected and modified when necessary as further experience is acquired.

1-4 Radio Frequency Design

It is possible to achieve radio communications across a wide range of frequencies; high energy signals as low as 10 kHz can be detected across the oceans while satellites make use of directional beams at 12 GHz and above[6].

There is thus no strict divide as to when a frequency may be termed a radio frequency. Instead the purpose of the circuits and the techniques that they employ classify the category, although higher frequencies generally lend themselves more conveniently to the purpose. The antennae are important fundamental components within the radio communications circuit and may be constructed in such ways as to direct the radiated energy or control its polarisation.

The radio communications designer is confronted with a variety of circuit techniques depending on the frequency of operation, modulation process and operating power level of a system. Once an operating configuration has been identified it remains to transform it to a practical physical circuit. It is here that further techniques must be adhered to. The characteristics of components and materials at the operating frequencies, plus effects of interconnection and coupling all become of relevance.

The series inductive impedance of any length of conductor increases proportionally to the frequency of the signal it conducts, yet the signal path between two conductors offers a reduced impedance due to capacitive coupling. Conductors and other materials within the electric and magnetic fields established by these signals can absorb energy from the source or present a further means of coupling. As operating frequencies rise, then such effects become ever more noticeable, demanding that circuits be designed as assemblies and no longer as interconnections of isolated components.

Increasing operating frequencies still further results in effects due to propagation delays along signal paths. Significant propagation delays result in variations of phase along circuit lengths and the frequencies at which the effect becomes of consequence will depend on the physical dimensions of circuits and components. Lumped parameter methods then become displaced by distributed parameter techniques such as transmission line components and filters. Circuit boards designed using such components are referred to as strip-line circuits[7].

SMDs promise several advantages to the radio frequency designer. Removal of lead inductances reduce high frequency impedances between PCB tracks and components, enabling improved and more consistent connections. Radiation or reception of high frequencies at component leads is also minimised. The reduction in size and improved circuit interconnection also extends the frequency range over which circuits may be constructed before adopting strip-line techniques.

This reduced circuit size and close packing may, however, have adverse effects. Closer proximity may result in pronounced circuit interactions, degrading circuit performance due to interferences or instability. The designer must be aware of the implications of the new devices and how they are assembled so as to maximise the benefits that they offer.

1-5 Issues to be Addressed

The purpose of the study was to investigate the process of designing radio frequency based assemblies using SMDs. The smaller size of the components and the resulting smaller assembly sizes were expected to demand different rules for assembly design than those of conventional types. Further to the performance of the components, the influence that they have on the costs and reliability of subsequent assemblies was to be considered. Not only was it envisaged that the adoption of surface mounted assemblies would influence circuit design techniques, but that it would also influence the methods by which development work must be carried out. Designers must not work in isolation due to the greater requirement for manufacturing compatibility. It was thus proposed that the constraints imposed on the designer should be investigated, plus the practicality of circuit development using SMDs. Issues of manufacture would cover all relevant stages from assembly methods to circuit test and rework.

The initial phase of the scheme was to be the compilation of a set of guidelines based on initial research into all of the above mentioned aspects for the design of radio frequency products using surface mounted techniques. It was proposed that, to achieve the subsequent approval and updating of the guide, a design project should be chosen as a test vehicle. The project was to involve all aspects of circuit and assembly design and the product was to be suitable for manufacturing at high volumes using surface mounted techniques.

The project was intended to conclude in a definitive document concerning the design of radio frequency products using surface mounted devices for subsequent adoption by Autophon (UK) Ltd.

1-5-1 Statement of Objectives

It was decided that the design project was to be a cordless telephone, conforming to the British Telecommunications Technical Guide no. 47, CT-1.5 specification[8], for the UK market. (The identification and justification is recorded in chapter four). The following work was thus projected.

1. To critically review the relevant radio frequency techniques and circuit designs specifically at the frequencies used by low band cordless telephones. This would include traditional methods and computer aided design techniques, and would identify where SMDs may prove beneficial.

2. To perform an appraisal of SMT. The benefits or disadvantages of the surface mounted components would be considered along with manufacturing constraints which must be imposed on design.

3. Based on the research, to lay out an initial set of design rules for the development of a radio frequency product using surface mounted techniques for high volume production. The document would include methods of developing and prototyping circuits with surface mounted components.

4. To identify and justify the specific test vehicle which would require the adoption of surface mount techniques to become a marketable product. It would involve all of the relevant aspects of design and manufacture concerning SMT.

5. To prove and further develop the design rules through the undertaking of a major design project based on the above test vehicle.

6. To produce a definitive document for the guidance of radio frequency design for subsequent radio frequency assemblies incorporating SMT at Autophon.

7. To review the study and identify further issues that are relevant to the field of investigation.

Chapter 2

Radio Frequency Techniques applicable to Low Band Cordless Telephones

2-0 Introduction

At the project outset it was apparent that to design radio circuitry and to perform an appraisal of such designs using SMDs it was first necessary to research the fundamental circuit types and design techniques themselves. This chapter reviews the radio requirements of the specifications governing the operation of cordless telephones to UK CT-1.5[8] regulations and compares them with possible alternative techniques. Noise reduction techniques, which are workable within the defined operating constraints, are considered along with antenna systems. The review identifies the practical circuitry necessary for subsequent studies of circuit performance within SMAs. The specification of designs for cordless telephones are also discussed in the light of the review. Practical factors influencing the design and construction of circuits operating at radio frequencies are considered, especially component performance limitations, and the areas where SMDs could present benefits are suggested. Finally, the role of computer aids within the design environment are considered in terms of SMD radio frequency circuits.

2-1 The Cordless Telephone

The cordless telephone uses a duplex radio communications link to remove the spatial restriction imposed by conventional hard-wired types. The radio links form the connection between the cordless handset and the base station, which is connected to the Public Switched Telephone Network (PSTN). The communication distance between the two is dependent on the power of the radio frequency transmissions, interference and the propagation path itself, but is designed to allow operation over distances of several tens of metres between the handset and base station. Under favourable conditions it is possible to hold conversations at distances of over one hundred meters. Of course once the signal has reached the PSTN it can use normal services as would be expected from any telephone.

Cordless telephones must operate so as to cause minimal interference to other users of the frequency spectrum; thus must conform to requirements laid down by regulatory bodies. Specifically, low band cordless telephones sold for use in the United Kingdom must satisfy the Department of Trade and Industry Radio Regulatory Department Radio Specification, MPT 1322. In addition to satisfying regulations regarding the emissions of electromagnetic radiation from the telephone, it must undergo a stringent and complex regulatory procedure (as detailed in chapter four) to gain approval for connection to the PSTN. This involves receiver performance and operation security, acoustic, noise and signalling responses, plus safety regulation congruity.

2-1-1 Cordless Telephone Radio Performance Requirements

The technical requirements for the operation of low band cordless telephones are detailed in British Telecommunications PLC Technical Guide No. 47[8], which contains the requirements for radio emissions, MPT 1322. It also contains the requirements for receiver performance and operation security that is necessary to satisfy the approvals procedure.

Cordless telephones are allocated frequencies in two bands. The base station remains connected to the PSTN and transmits radio signals in the medium frequency (MF) band over one of eight designated channels. The portable cordless handset transmits on a corresponding channel in the very high frequency (VHF) band. The frequency designations are shown in figure 2-1. Cordless telephones must use channel frequency pairs which are set at manufacture. The channel 7 VHF carrier is optional due to the possibility of interference from the 27th harmonic of its lower channel.

To make efficient use of radio frequency communication links it is necessary to transfer base band intelligence, such as speech and data, to a higher frequency carrier. The modulation process used by cordless telephones is frequency modulation (FM) and figure 2-1 also includes details of the maximum permitted frequency deviation within each frequency band to signals within the allocated modulation bandwidth. Details concerning baseband deviation frequency response are included in section 2-2-1. Figure 2-2 summarises the

Channel Number	Base Unit Transmit Frequencies	Handset Transmit Frequencies
1	1.642 MHz	47.45625 MHz
2	1.662 MHz	47.46875 MHz
3	1.682 MHz	47.48125 MHz
4	1.702 MHz	47.49375 MHz
5	1.722 MHz	47.50625 MHz
6	1.742 MHz	47.51875 MHz
7	1.762 MHz	47.53125 MHz *
8	1.782 MHz	47.54375 MHz

** 47.44375 MHz is an alternative frequency*

Channel Spacing	20 kHz	12.5 kHz
Peak Deviation	4.0 kHz	2.5 kHz

Figure 2-1 Cordless telephone frequency allocations

requirements of the cordless telephone radio circuitry under normal operating conditions.

2-2 Frequency Modulation Techniques

An FM signal is generated when a radio frequency carrier is varied in sympathy with baseband information amplitude fluctuations. In 1922, John Carson[9] showed that the FM signal consisted of a carrier frequency component and a series of sideband pairs spaced at integral multiples of the modulating frequency. The amplitude of the sidebands and the carrier are found from the solution of the Bessel integral[10] and are known as the Bessel functions.

Although an FM signal has an infinite number of theoretical sidebands, a good working rule for the spectrum requirement of an FM signal is given by the empirical expression quoted by Carson:

$$BW = 2BW_m(1 + M)\ \text{Hz} \ldots\ldots \textit{equation 1}$$

BW_m is the modulation signal bandwidth and M is the modulation index. In the system bandwidth calculation only sidebands with significant power are considered, with those of less than 1% of the unmodulated carrier amplitude generally being ignored.

An FM carrier modulated to large deviations may occupy very large bandwidths. FM broadcast channels use typically 150 kHz for high quality music and stereo transmissions. Lower deviations result in lower bandwidth requirements and because of the relatively low channel spacings allocated to the

Receiver*

	Handset	Base Station
Sensitivity (microvolts)	1	1
Adjacent channel rejection	50 dB	50 dB
Intermodulation rejection	60 dB	50 dB
Spurious response rejection	45 dB	45 dB
Blocking level	70 dB	80 dB

Transmitter*

	Handset	Base Station
Maximum carrier power	10 mW	10 mW
Maximum frequency error	2 kHz	2 kHz
Maximum adjacent channel power	1 uW	1uW
Maximum spurious radiation	50 nW in the bands: 87.5 MHz - 118 MHz 135 MHz - 136 MHz 174 MHz - 230 MHz 470 MHz - 862 MHz 250 nW outside these bands	34 dB (uV/m) at 30 m between 0.5 - 30 MHz

**Test conditions for the measurement of performance parameters are detailed in TG 47 which calls MPT 1322*

Figure 2-2 Cordless telephone radio performance requirements cordless telephone, for example 12.5 kHz for the VHF link, the modulation used is termed narrowband FM. The low deviation, and correspondingly low modulation index, produces only a few significant sidebands. It can be shown that the low system bandwidth trades signal to noise performance compared with wideband FM transmissions[11].

2-2-1 Frequency Modulation Transmitters

The block diagram of a VHF transmitter, as typically employed within a cordless telephone handset, is shown in figure 2-3. It shows typical stages whose characteristics and circuit realisations are considered below to identify their suitability within the product and subsequently within assemblies using SMDs.

In the figure, the FM signal is derived by feeding the modulating waveform to the control input of a voltage controlled oscillator (VCO). The VCO centre frequency is set by a crystal and varied with a varactor diode. An inductor/capacitor (LC) based oscillator does not have the frequency stability necessary to satisfy cordless telephone requirements unless when incorporated within a feedback frequency controlled system. Such a system, using a phase lock loop (PLL)[12], could offer extra high performance with regards to oscillator phase noise and the facility for digitally controlled tuning. PLLs, however, are not used for the reasons discussed in section 2-6.

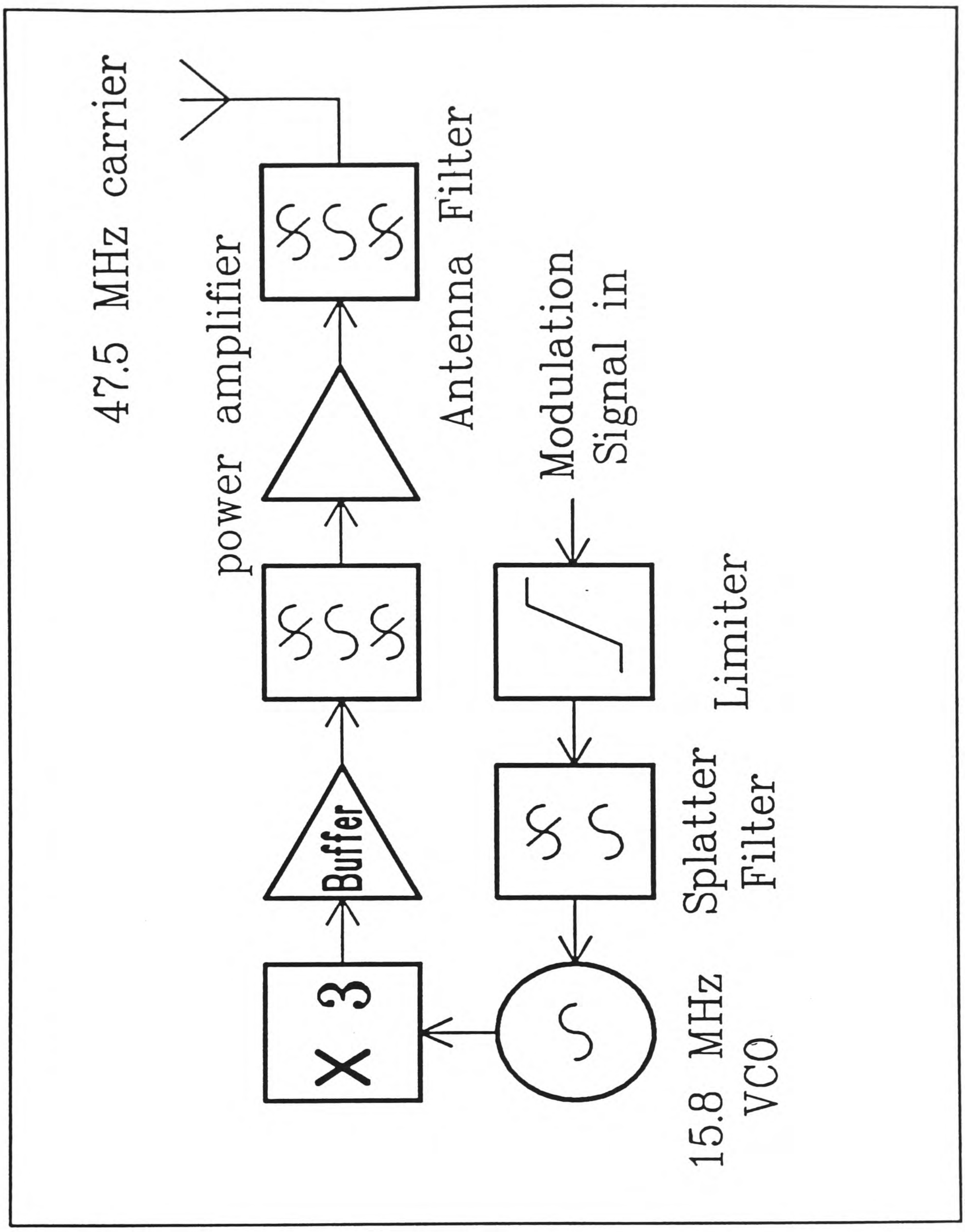


Figure 2-3 Block diagram of cordless telephone VHF FM transmitter

The VCO shown, using a fundamental resonant crystal at 15.8 MHz, can be deviated linearly ± 850 Hz. This deviation is increased to the necessary ± 2.5 KHz with a frequency multiplier utilising the characteristics of a non-linear device[13].

Due to the relationship between FM and phase modulation (PM) signals as depicted by the equation:

$$\theta(t) = \int w \; dt \;\ldots\ldots \quad \textit{equation 2}$$

it is possible to generate an FM signal by an indirect technique. Suitable methods include incorporating a voltage controlled phase shifter, a comparator frequency modulator[14], or an Armstrong modulator[15]. The low level of linear phase shift achievable (typically ± 45°) limits the usefulness of indirect FM generation and offers no advantage in the cordless telephone environment.

The limiter and 'splatter filter' shown in figure 2-3 are used to restrict the magnitude and bandwidth of the modulating signal, conforming to the allowed modulation frequency response as illustrated in figure 2-4.

The signal power output from the modulating stage is relatively low, typically less than 1 mW and amplification is necessary to generate a transmission signal of adequate power at the antenna. Amplifiers are also beneficial as buffers, isolating the modulating circuitry and oscillators from the effects of impedance level changes in subsequent stages and at the antenna. Linear amplification is not a requirement of

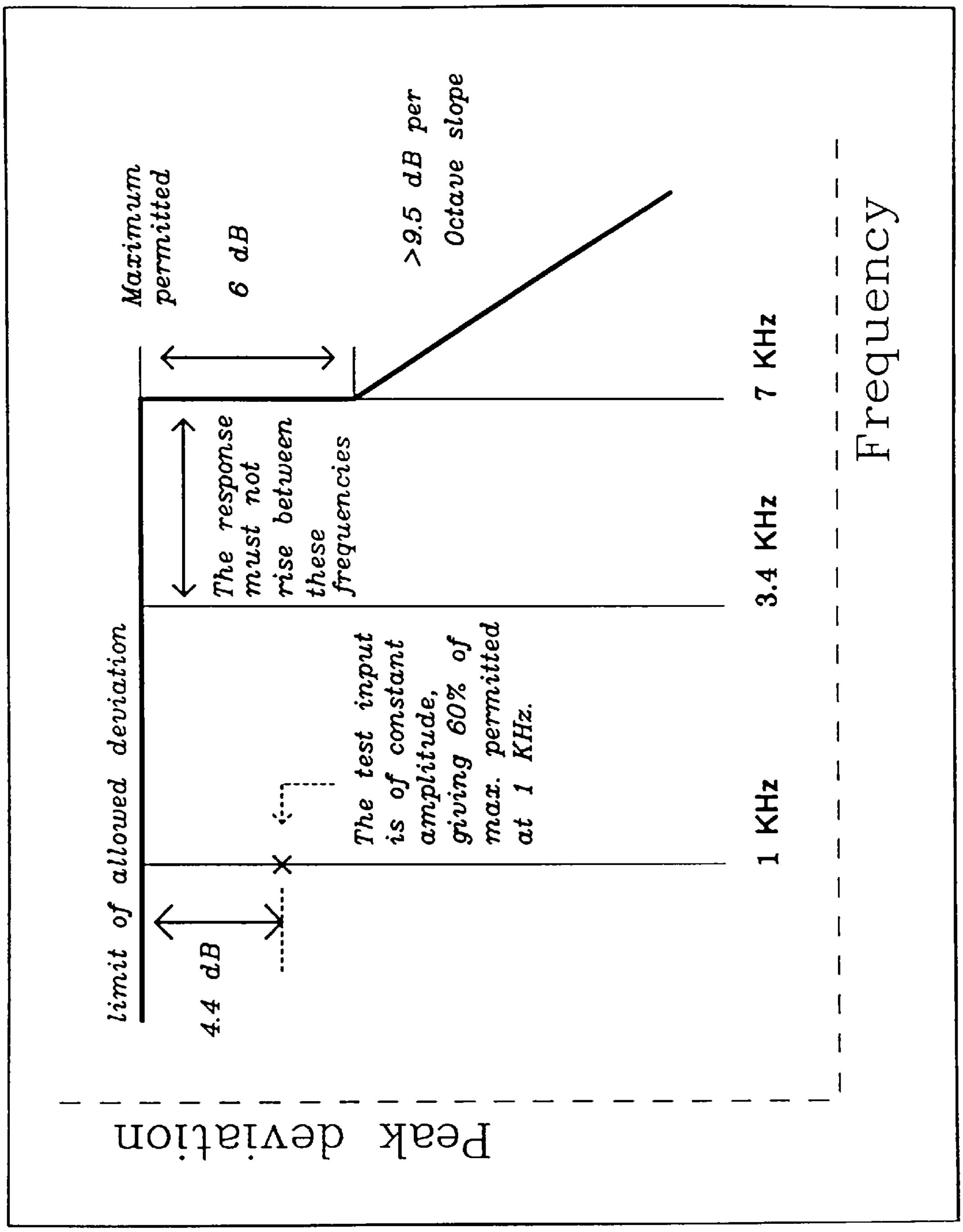


Figure 2-4 Cordless telephone modulation frequency response restrictions

the FM transmitter and so it is possible to design highly efficient power amplifiers. Non-linear power amplifiers typically utilise class C operation which is theoretically 100 % efficient. Class D,E,F,G,H and S[16] also offer very high efficiency in practice, but are less common due to higher circuit complexity and operation difficulties at higher frequencies.

Filters are essential to attenuate unwanted frequency components so that power radiated at these frequencies is below specified levels. A second function of such filters is the transformation they offer to circuit impedance levels. Impedance matching is necessary between cascaded amplifiers and between the final amplifier stage and the antenna. Correct matching is important to maximise the efficiency of the circuit operation within the carrier bandwidth.

2-2-2 Frequency Modulation Receivers

A double conversion superheterodyne base station receiver block diagram is shown in figure 2-5. The superheterodyne principal, patented in 1934 by Armstrong[17], is employed extensively due to its superior alignability and stability. The superheterodyne receiver mixes the receive frequency to an intermediate frequency (IF) which remains constant for the system. This allows IF filters to be set at one single frequency while the input may be tuned over a range of frequencies. The input is selected by the local oscillator which mixes with the wanted frequency, translating it to the system IF. Since the IF filters are single frequency they may

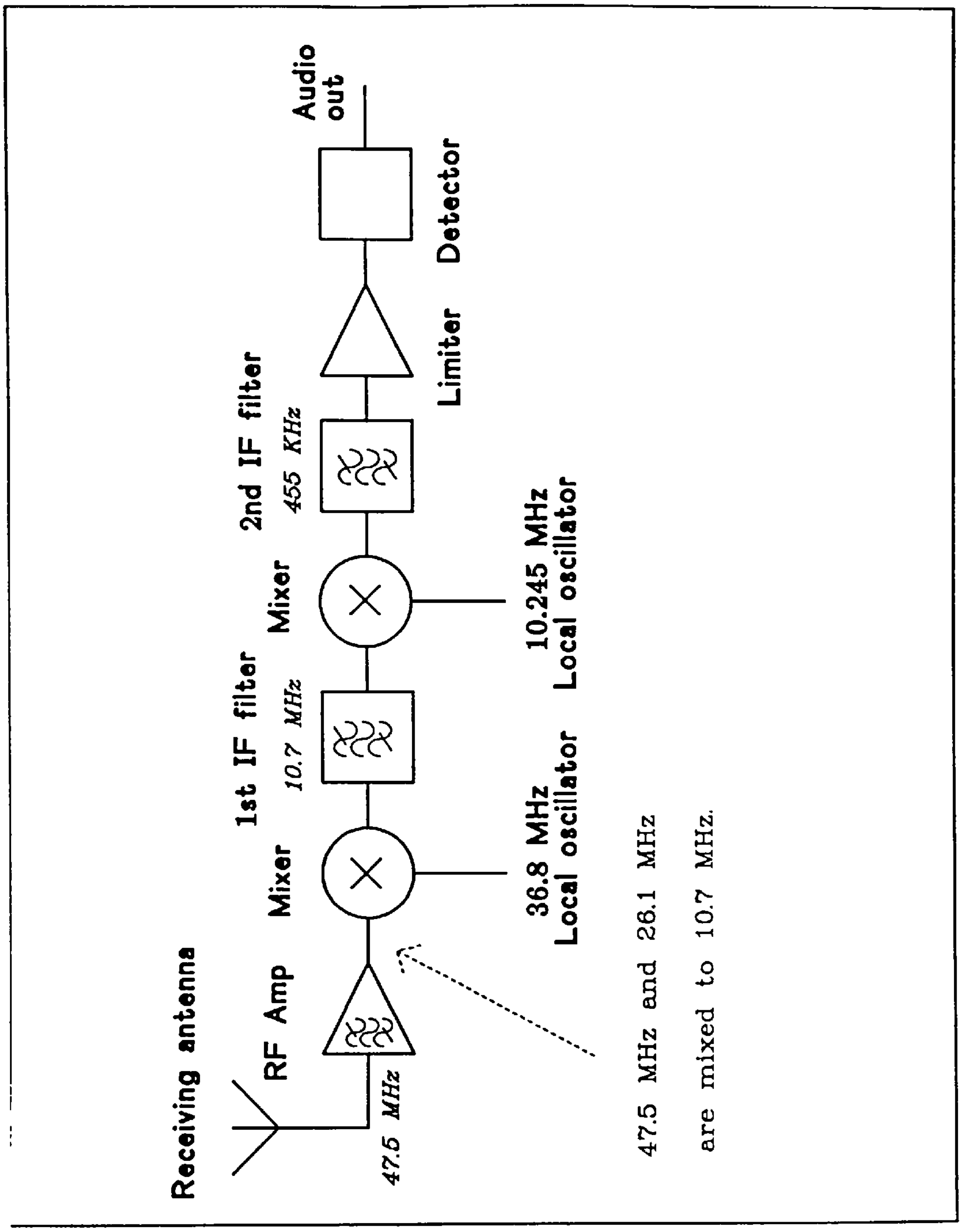


Figure 2-5 Block diagram of a double conversion base station VHF FM receiver

be designed to a very high standard, and high gain in the IF amplifier will not result in instability should feedback exist between the IF output and the receiver input. This is so because the frequencies are unrelated. In systems requiring tuning over a range of frequencies, the tuning of the local oscillator is ganged with the tuning of the input filters. The input filtration is important in superheterodyne receivers since the mixer responds equally to the image of the desired signal as noted in the figure.

It is common to use a radio frequency (RF) amplifier to amplify wanted signals to levels that may be detected by the following system. In doing so it should add as little extra noise to the system as possible; that is, have a low noise figure. It is well known that the overall system noise figure may be improved by employing a low noise, high gain front end. Due to non-linearities in the system, many inter-modulation processes are possible, causing undesirable signals to result at the IF[18]. Since all inter-modulation products are unwanted components, the RF amplifier should be designed to be linear in nature and the front end to have a high rejection to frequencies outside of the desired pass-band.

The IF filter is responsible for rejecting frequencies close to the carrier, such as signals from an adjacent channel. The choice of IF is made after consideration of the carrier frequency and possible sources of system interference. A high value of IF results in a larger spacing between wanted and image frequencies and thus simplifies front end filtering requirements. Filtering of adjacent channels is, however, easier with a lower IF because the filter quality factor (Q)[19] is minimised. For minimum signal distortion, the IF filter should have good phase linearity in the pass-band.

The action of the limiter is to amplify the IF signal and remove amplitude fluctuations which are due to noise alone. Should the receiver detection system be sensitive to amplitude undulations they will be detected and the noise immunity of the system will suffer. By amplifying the IF signal into limiting, amplitude fluctuations are substantially reduced and amplitude modulation (AM) rejection improved.

The detector circuit converts carrier frequency deviations to fluctuations of voltage or current. Figure 2-6 shows a Travis detector, an example of a slope detector which uses the amplitude characteristics of a tuned circuit to convert frequency deviations to amplitude fluctuations which are then peak detected as by an AM detector. The Travis circuit uses two simple slope detectors in push-pull mode to enable greater linear working range and rejects even order harmonic distortion. The slope detector is a form of tuned circuit frequency discriminator and other common types are the Foster-Seely[20] and ratio-detector[21].

Cordless telephones typically use a quadrature detector for demodulation. The technique receives its name from the necessity to generate a reference signal in quadrature with the unmodulated intermediate frequency. A version of quadrature detector is shown in figure 2-7, with its transfer function. The detector that is illustrated operates by converting the limited IF to a pulse width modulated form. A product detector can also be used at the same point to demodulate the signal[22]. The quadrature detector's sensitivity may be increased by raising the loaded Q of the quadrature coil circuit, with the sacrification of detector linearity. It is possible to replace the quadrature circuit by a ceramic discriminator which has the characteristics of a pre-tuned LC circuit.

The phase lock loop may also be used to demodulate FM. In this case, with the loop locked to the frequency modulated IF signal, the demodulated output is derived from the loop error signal[23].

2-3 Amplitude Modulation Techniques

Figure 2-8 compares a frequency modulated tone with an equivalent amplitude modulated signal in both the time and frequency domains. As long as the AM depth, m, remains between $0 < m \leqslant 1$, the bandwidth of the AM signal is twice the base band frequency. It is possible to remove its carrier component (f_o), resulting in double sideband suppressed carrier (DSBSC) modulation[24] and also to remove one of the sideband envelopes to give a single sideband suppressed carrier (SSBSC) signal[25].

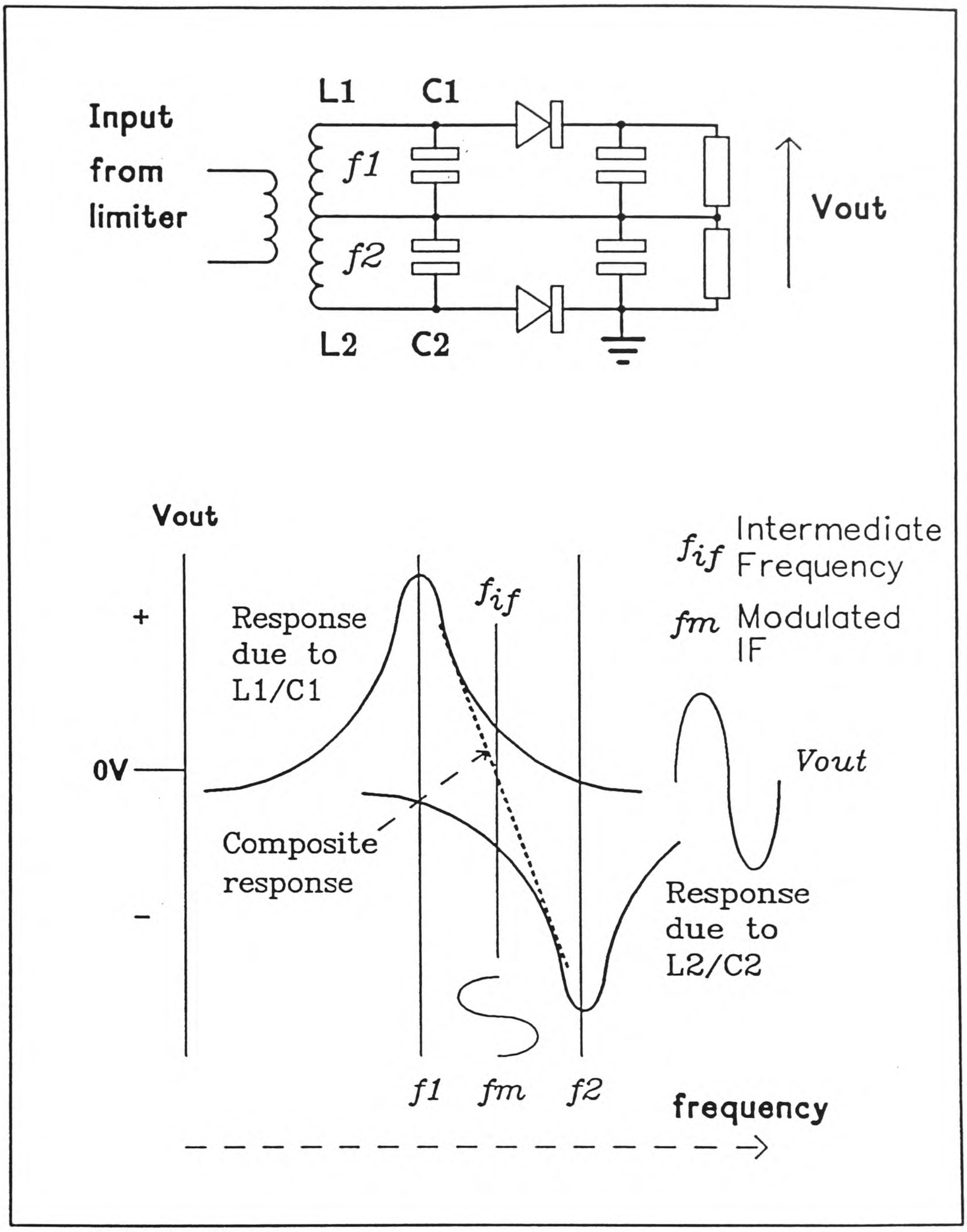


Figure 2-6 Travis detector used to demodulate FM signals

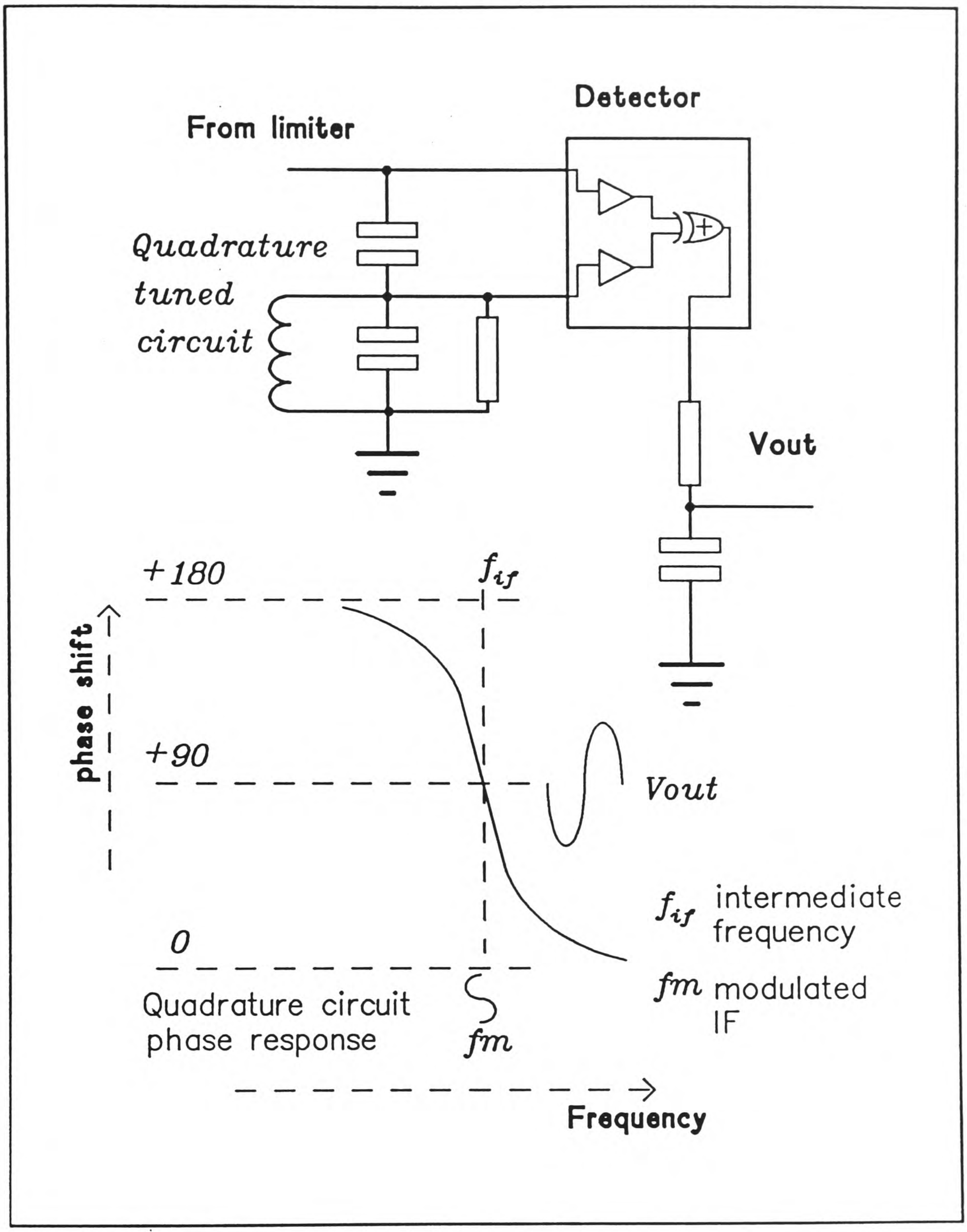


Figure 2-7 A version of quadrature detector used to demodulate FM signals

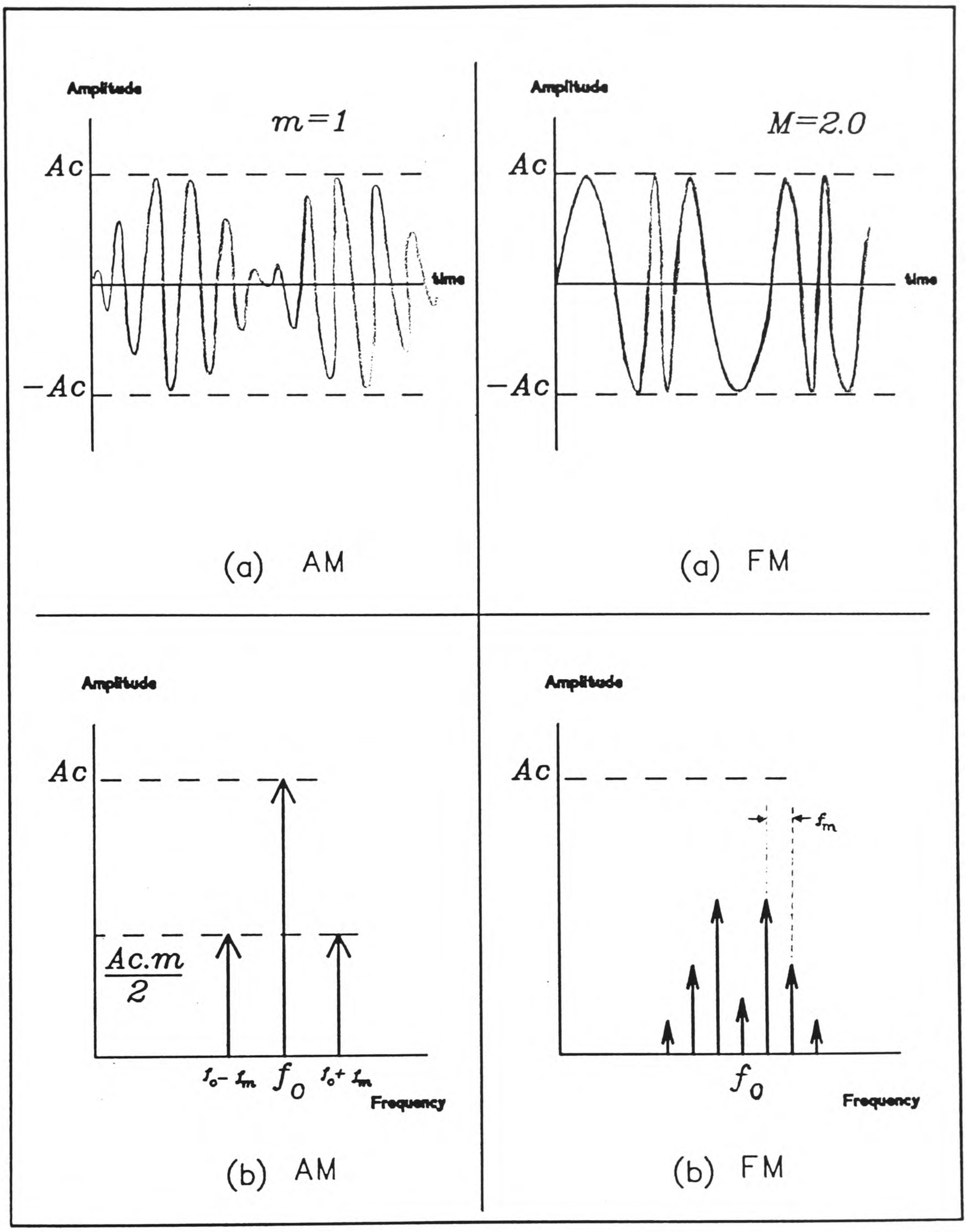


Figure 2-8 Comparison of AM and FM signals in the time and frequency domains

As shown by Shannon[11], AM signals trade their smaller bandwidth requirement for a reduced signal to noise performance over an equally powered FM system. Since the signal amplitude carries the modulation information, AM systems are also more prone to impulsive noise such as that from automobile ignition systems

SSBSC represents the optimum use of bandwidth and transmission efficiency. During periods of speech silence, no transmit power is required at all. It can also be shown that SSBSC is superior to FM at very low signal to noise levels, below the FM threshold[26].

AM techniques are not currently used within cordless telephones due to the specification for frequency modulation. It is necessary, however, to compare typical AM circuits before a complete discussion of the specifications can be undertaken.

2-3-1 Amplitude Modulation Transmitters

A typical AM transmitter block diagram is shown in figure 2-9. The buffer and power amplifiers may be operated in saturation mode, such as class C, at less than half peak power capability with no modulation signal present. The modulating signal is typically applied to both of the amplifiers since it is simpler to approach 100% modulation using this technique, where the level applied to the driver is not normally as high as that applied to the power amplifier. The audio transformer placed in the collector load

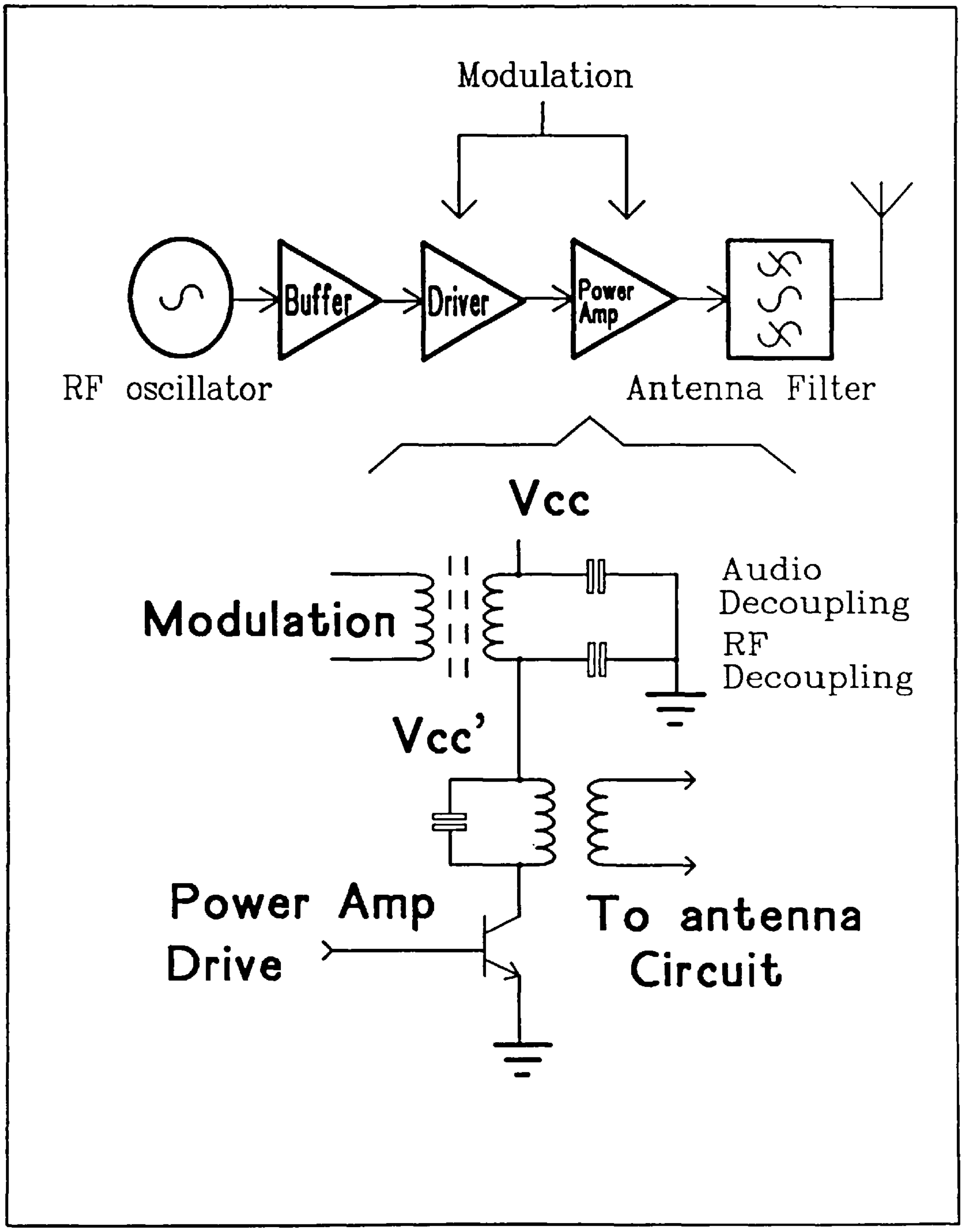


Figure 2-9 Block diagram of a typical AM transmitter

is a common method of achieving modulation. Assuming a constant RF load of R_L, the output power is given by equation three, where Vcc′ may vary between 0 and 2Vcc.

$$P_{out} = \frac{Vcc'^2}{R_L} \text{ Watts...... } \textit{equation 3}$$

DSBSC and SSBSC signals are generated at low power levels. The power amplifiers must maintain the signal amplitude and phase integrity and must, therefore, be linear amplifiers. Class B amplification is preferable to class A in most applications due to its improved efficiency.

DSBSC signals are generated by double balanced modulators[27]. Single sideband modulation is achieved by one of three techniques. The *filter method,* the *phasing method* or the *third method,* where each has its unique advantages[28]. Figure 2-10 shows the third technique, or Weaver method, being used to generate a single sideband signal to illustrate the typical circuit complexity involved. All forms of AM require less bandwidth than practical FM systems and the filters associated with the transmission of the modulated carrier can also be designed with proportionately reduced bandwidth.

2-3-2 Amplitude Modulation Receivers

The superheterodyne configuration is equally common to both FM and AM systems. IF filters are designed for flat amplitude characteristics as opposed to the requirement of linear phase response for low distortion in the FM receiver. Figure 2-11

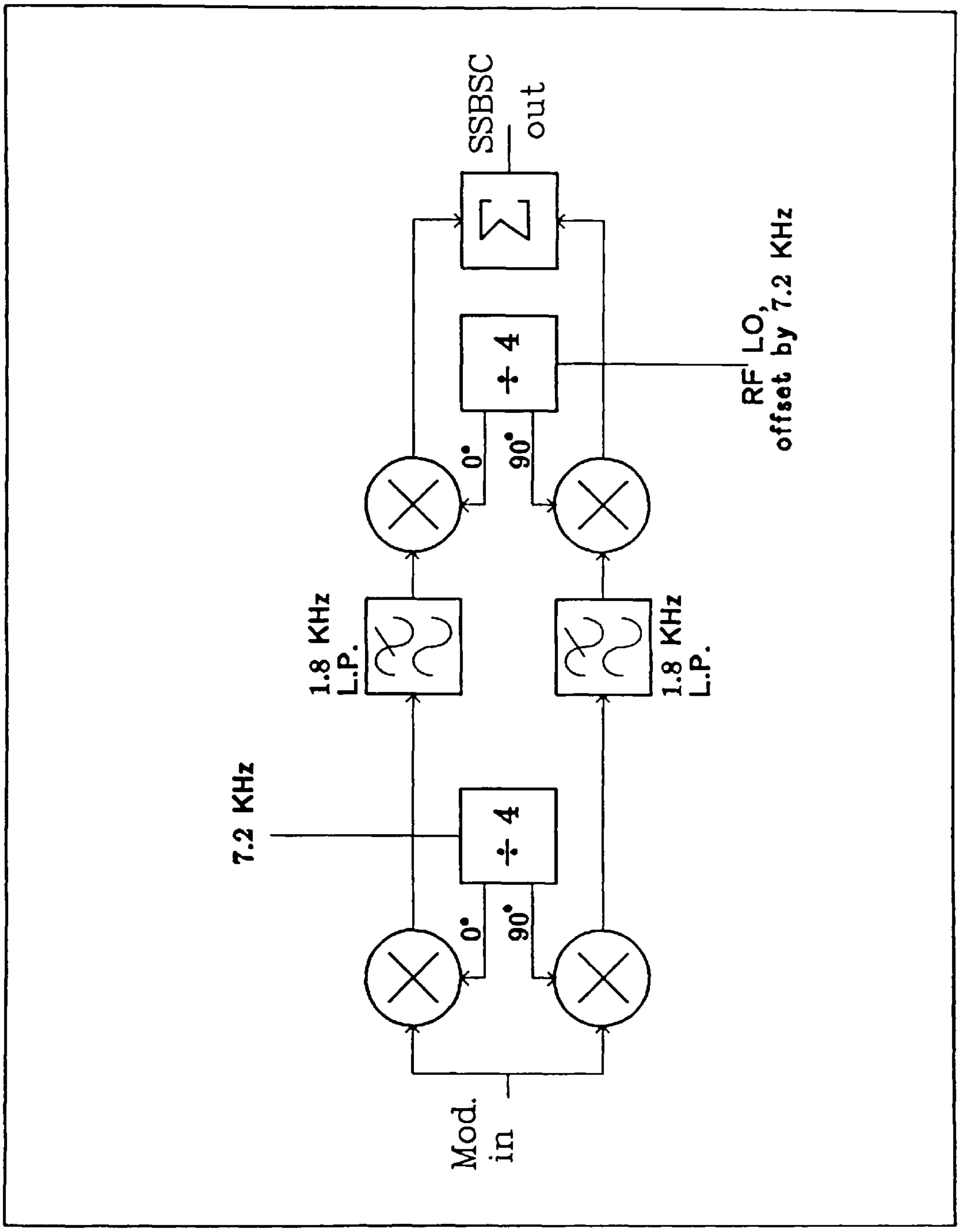


Figure 2-10 SSBSC generated by the Weaver (or third) technique

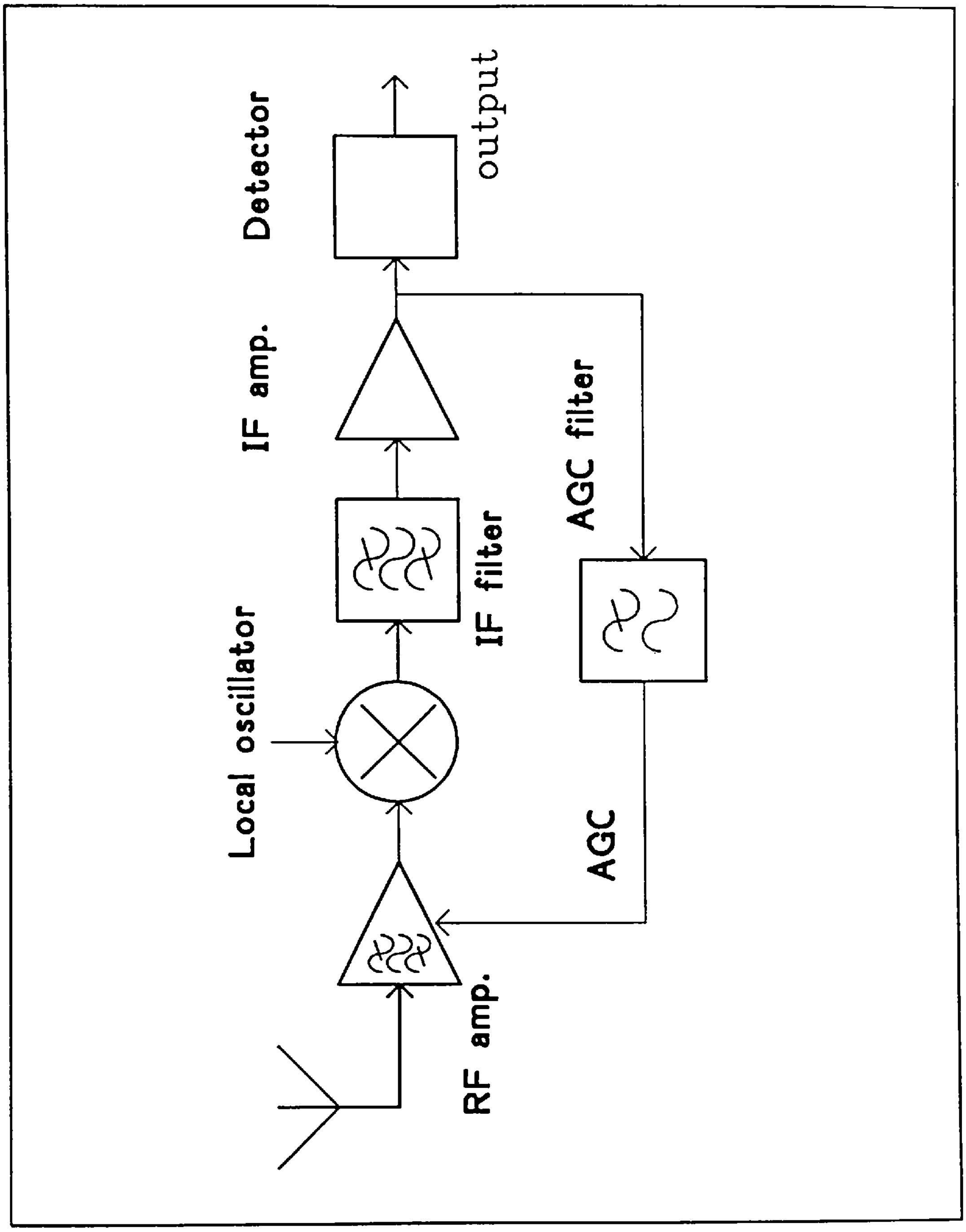


Figure 2-11 Block diagram of a single conversion AM receiver

shows the block diagram of a typical single conversion AM receiver.

The receiver employs an amplifier in the place of the limiter in the FM system since limiting would be detrimental. Unlike the FM system, where the received signal amplitude plays no part in determining the amplitude of the recovered audio, the received audio level varies with reception strength. It is typical for some form of automatic gain control (AGC) to be used to compensate for fades in reception and to prevent overload of the amplifiers under conditions of strong signal. The control signal is obtained from the IF level which must be filtered so that the modulated fluctuations are not fed back.

Detection of full AM signals is achieved with a simple diode detector. DSBSC receptions may use the same technique once the missing carrier component has been re-inserted. As with the generation of SSBSC, its reception requires a much greater complexity compared to the simplicity of the diode detector.

2-4 Noise Reduction Techniques

The performance of a modulating system is limited by the available bandwidth, the transmission power level and the channel background noise. To maximise the performance of a communications channel it is necessary to maximise the signal to noise ratio of the system within the channel constraints. Speech, in its natural form, uses a large dynamic range of amplitudes and hence does not maximise the available signal to noise performance. What is required is a process to artificially increase the usage of the available signal range so as to increase the perceived performance of such a speech channel.

2-4-1 Pre-emphasis

The type of noise that the FM system is susceptible to is phase noise. Phase noise causes frequency noise fluctuations as described by equation two. The noise spectrum of interest is that of the frequency noise because the FM detector responds to changes in the instantaneous frequency. Frequency noise is the differential of the phase noise and assuming white phase noise, as is typical across small sections of the frequency spectrum, the corresponding FM noise has the characteristic shape of figure 2-12a.

The noise spectrum is commonly compensated for by the use of pre-emphasis and de-emphasis. The base band signal's frequency content is altered in sympathy with the noise spectrum upon transmission and corrected upon reception. The effect of the noise compensation process is illustrated in figure 2-12c. Pre-emphasis uses a mixture of FM and PM, and the cordless telephone speech modulation is more correctly defined as angular modulation when the technique is utilised.

Audio systems contain the majority of signal energy at or below 500 Hz and the energy decreases rapidly above this frequency. By pre-emphasising the generally lower amplitude,

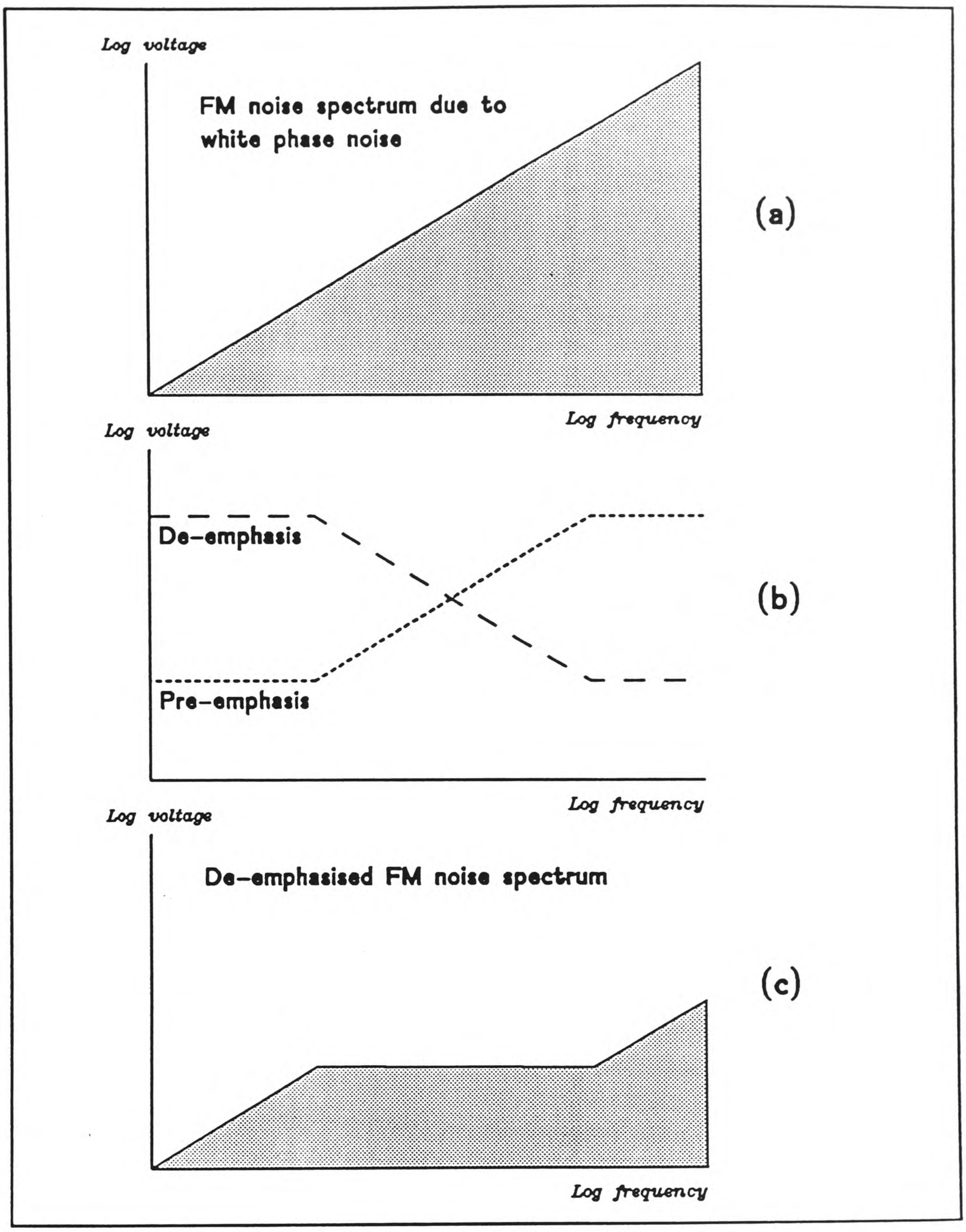


Figure 2-12 The effect of pre/de-emphasis on FM noise

higher frequency content of the modulating signal an effective noise reduction occurs at the receiver due to the de-emphasis. The cordless telephone, using a pre-emphasis zero at 1 kHz typically shows a 5.8 dB signal to noise improvement over an identical system with the process removed.

2-4-2 Companding

By raising the average level of the base band amplitude, the channel signal to noise capability will be more efficiently utilised. This can be achieved by passing speech through a non-linear element with a defined characteristic such as a logarithmic amplifier. Figure 2-13 illustrates the speech expansion process with such a response. The process increases small signals and reduces large ones. Compression reduces the dynamic range during transmission and expansion at the receiver, with an anti-logarithmic amplitude response, reduces low levels of interference and noise still further.

Cordless telephones sold in the UK at the time of the investigation did not use companding techniques. It was possible to obtain approval to class B noise performance [BS6305] without the extra circuit cost necessary to include companding functions. However, with the addition of a syllabic rate compander[29] it has been seen to be possible to obtain class A performance by reducing the noise power to the telephone line by 10 dB to -75 dBmP. The signal to noise performance of a radio link could be improved by over 40 dB to low level signals using the device, although large level

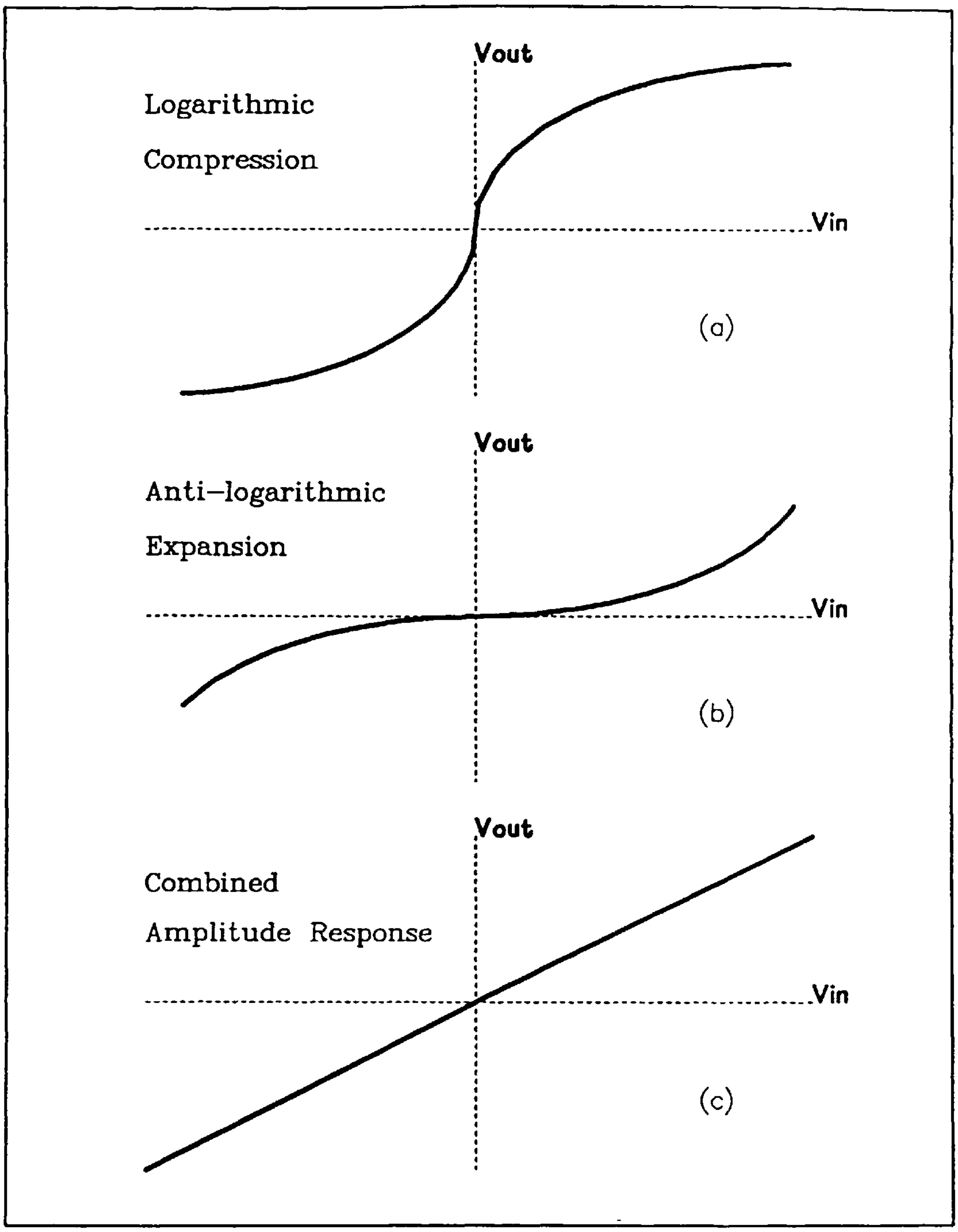


Figure 2-13 An example of companding using logarithmic circuit elements

modulating signals underwent no signal to noise improvement due to the nature of the technique. Figures 2-14 and 2-15 show comparisons of the apparent signal to noise measured when a syllabic rate compander was added to a cordless telephone. This subjective signal to noise ratio was measured as the signal power under conditions of normal modulation (60% maximum deviation, 1 kHz) to the noise power in the absence of modulation.

2-4-3 Digital Coding

Analogue base band information may be coded into digital format. The quality of the conversion is dependent on the resolution; 8 bit coding is typical for telephony and 14 to 18 bits for high fidelity reproductions. The digital format introduces quantisation noise but this is generally insignificant for the particular system. Analogue to digital converters also use compression techniques to reduce quantisation noise at low signal levels. To avoid aliasing it is necessary for the sampling rate of the conversion to be greater than twice the highest base band frequency.

Digital transmissions are superior to analogue transmissions because of their immunity to noise. It is possible to transmit digital code bits at full modulation level since the amplitude is constant; so maximising the signal to noise ratio of the transmission channel. The re-constructed analogue signal is still accurate even when receive noise is high enough to make analogue communications poor. The penalty for the improved channel performance is bandwidth because the

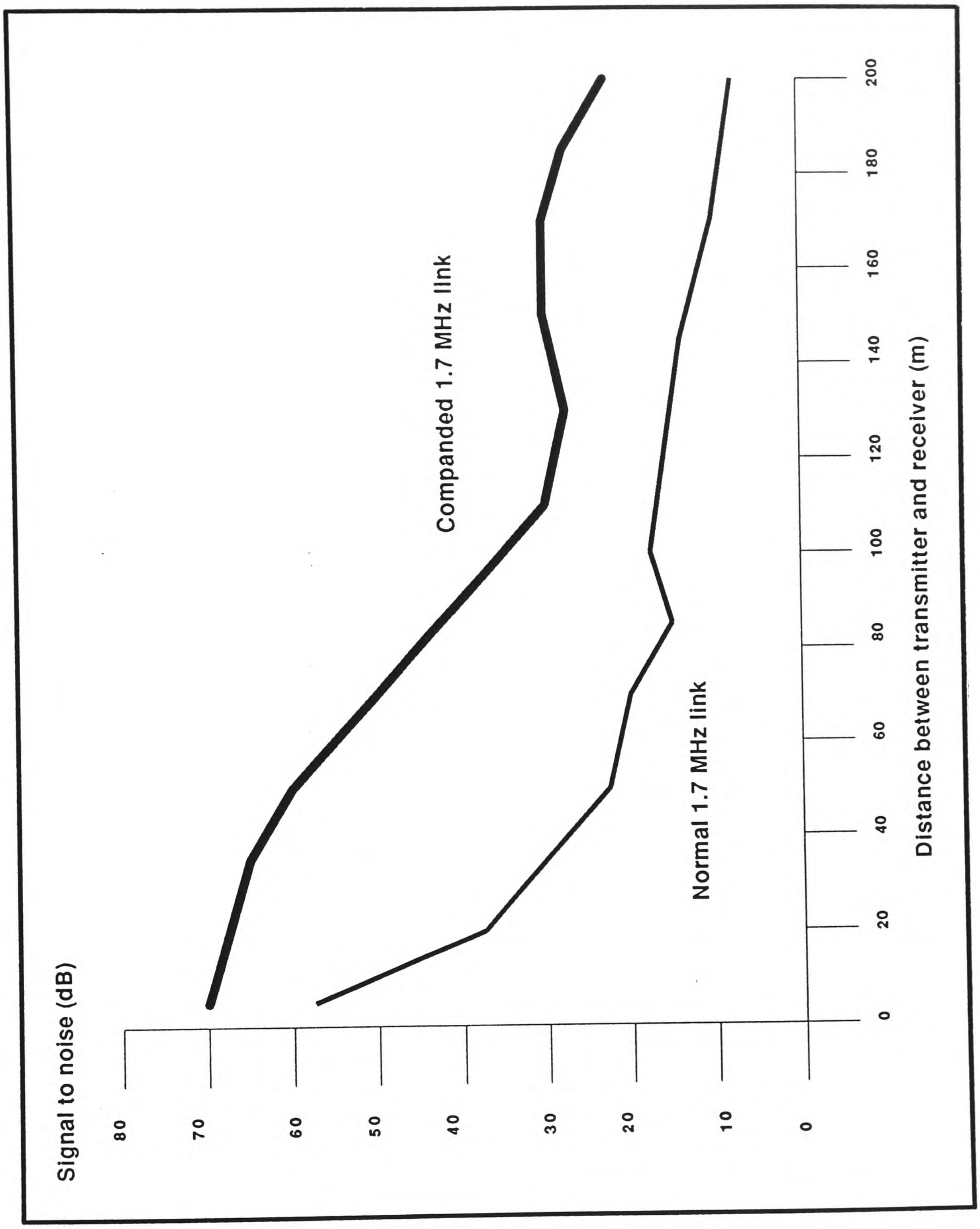


Figure 2-14 The perceived signal to noise performance improvement of the MF cordless telephone link using syllabic rate companding

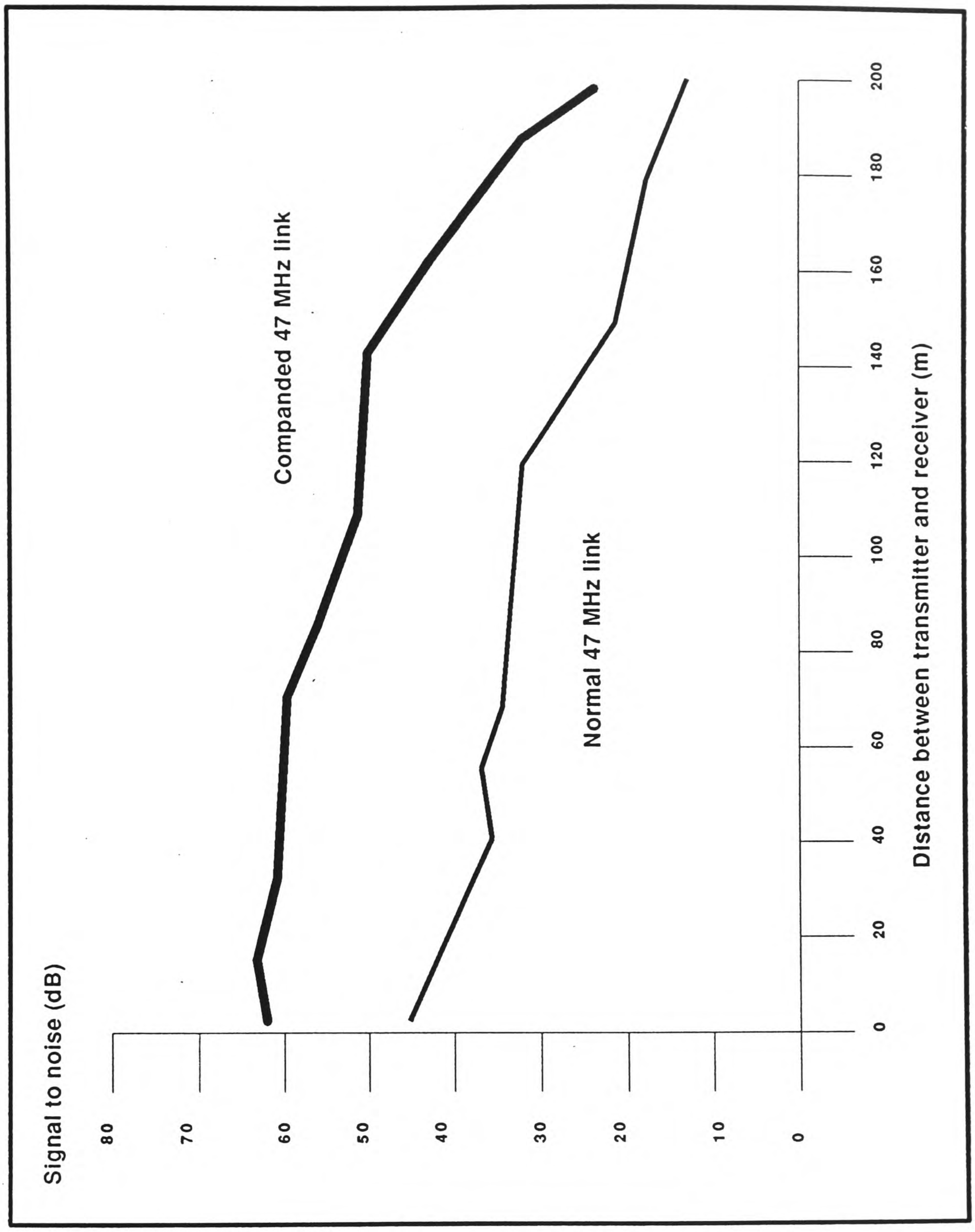


Figure 2-15 The perceived signal to noise performance improvement of the VHF cordless telephone link using syllabic rate companding

digital transmissions require a bandwidth equal to that of the base band signal multiplied by the number of coding bits. Digital coding is not practical within CT-1.5 telephones due to the narrow channel bandwidth available.

2-5 The Electromagnetic Link

Radio systems are practical because of the propagation of electromagnetic signals. The electromagnetic link is fundamental to the communications system and as such must be included as part of the overall discussion. The interface between electrical power and this link is the antenna, the design of which effects the system performance.

The electrical power delivered to an antenna is dissipated in the form of electromagnetic radiation and also in the form of losses such as heat. Antennae whose physical lengths are designed to be comparable with their electrical lengths have high efficiency and the power delivered to them tends to be totally radiated. The radiation pattern of the antenna determines the direction of propagation of the electromagnetic energy, which at the extremes may be isotropic or beamed. An isotropic antenna radiates power equally in all directions; such an antenna does not exist in reality although may be approximated. By focusing electromagnetic rays, using a parabolic reflector, they may be directed in a beam and hence power density remains constant over a large distance; this requires structures large in comparison with the radiated wavelength and parabolic reflectors are used mainly at microwave frequencies. An antenna used for transmission performs identically when used for reception with respect to its electrical impedance and radiation pattern and for this reason it is necessary only to discuss its performance as a transmitting device.

2-5-1 Electrically Short Antennae

The antennae of interest at the frequencies used by low band cordless telephones are termed electrically short antennae as it is not practical to use antennae of the same order of size as the electrical wavelength of the radiated signal. Short vertical antennae are used for both transmitters in the cordless telephone and by the VHF receiver, while a loop antenna is suitable for reception of the MF frequency at the handset. The electrically short antenna may be characterised by its high capacitive reactance and low radiation resistance[30]. The exact level of impedance is determined by the antenna height above its earth plane and its surrounding materials. For example, a lossy earth plane will cause power to be dissipated in itself, hence reducing the radiation efficiency and increasing the apparent resistance.

The theoretical radiation resistance (R_s) for an electrically short vertical antenna of length l at a frequency with wavelength, over a perfect earth plane, is given by[31]:

$$R_s = \frac{790\, l^2}{\lambda^2}\ \Omega \ \ldots\ldots \textit{ equation 4}$$

The reactive component may be resonated with an inductance of equal reactance, thus presenting a purely resistive antenna load. The series resistance of this choke should be kept as low as possible to minimise circuit losses.

A second antenna used commonly for the reception of low frequency signals is the loop antenna. The receiving loop antenna operates by detecting the magnetic component of the electromagnetic wave rather than the electrical component which a length of wire responds to. The theoretical radiation resistance of a loop of area a is given by equation five[32], where the dimensions are small compared to the wavelength of interest.

$$R_{loop} = \frac{31200\ a^2}{\lambda^4}\ \Omega \ \ldots\ldots \ \textit{equation 5}$$

The loop antenna finds use more often as a receiving antenna due to its very low radiation resistance. The receiving loop antenna, or loopstick, uses a ferrite core to concentrate the magnetic flux linking its windings and increase the sensitivity of the receiver using the antenna. The radiation patterns for the magnetic loop and electrically short vertical antenna are similar. Each radiates equally around a 360° plane and has nulls orthogonally to this. The pattern is the familiar 'dough-nut' shape as is illustrated in figure 2-16. Inspection of the diagram shows that the two antenna radiate or receive electromagnetic waves of opposite polarisation.

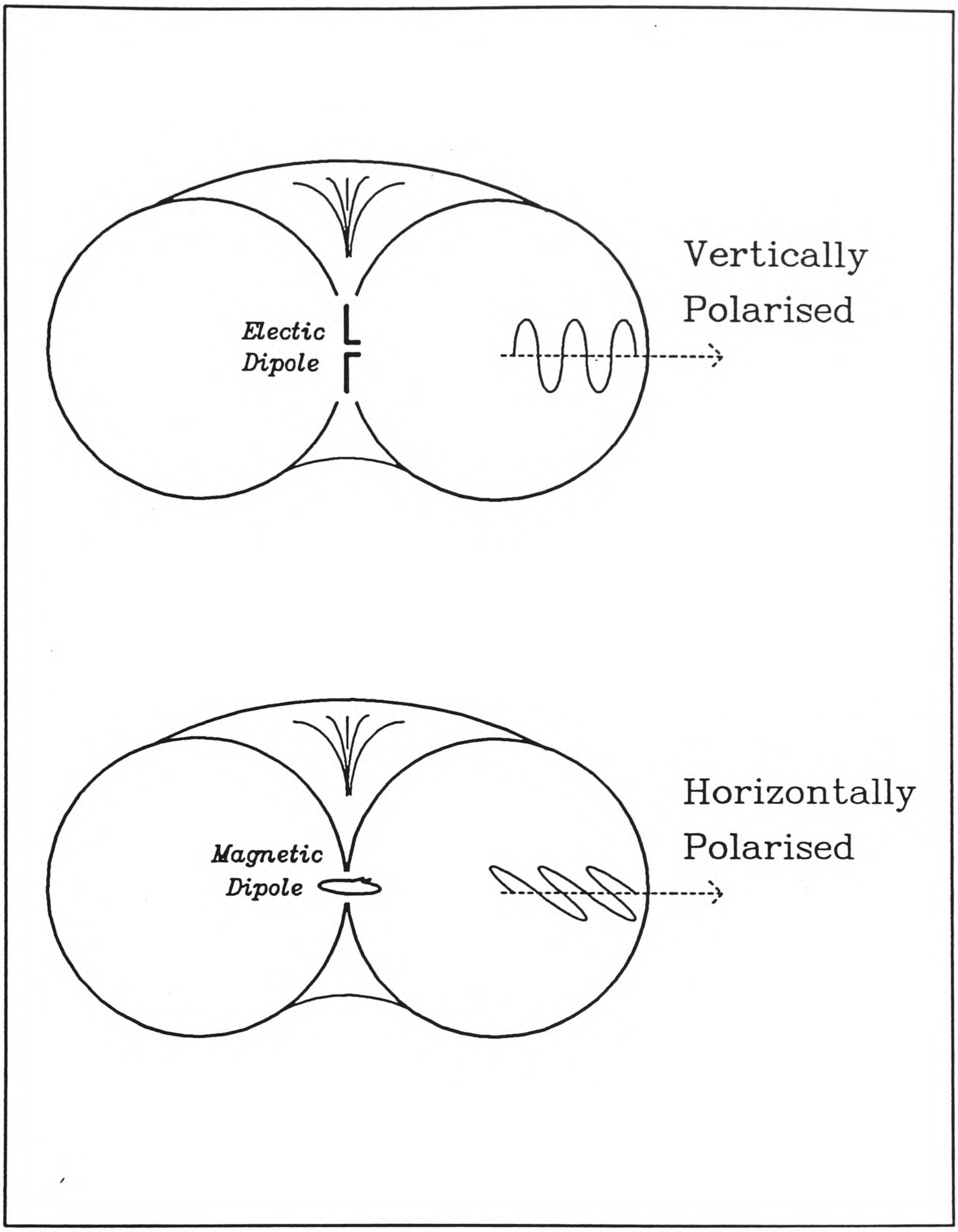


Figure 2-16 Radiation patterns for electric and magnetic dipoles

2-5-2 Leaky Feeders

Under ideal conditions, the MF and VHF cordless telephone radio links are very similar in terms of range performance. This is not, however, the case when the telephone is used within the business environment because of greater interference from office equipment within the VHF band. The attenuation of VHF signals also tends to be greater due to the types of building materials encountered. The use of a leaky feeder[33], an imperfect co-axial cable laid around the building, to receive the VHF radio signal and conduct it to the base station has advantages in this type of environment. Reports suggest that the average advantage of a leaky feeder within the cordless telephone system, compared to an antenna, can be equivalent to around 50 dB signal strength improvement[34].

2-6 Discussion of the Radio Frequency Techniques used by CT-1.5 Cordless Telephones

Narrow band FM, as defined for use by the cordless telephone, compromises the requirement for a narrow communication bandwidth with the requirement for acceptable signal to noise performance. The inherent advantages of using FM as opposed to comparably powered forms of AM are the signal to noise advantage and its immunity to impulsive noise. Single sideband techniques would have optimised the use of the frequency spectrum designated to the cordless telephone and transmission power efficiency would also have been improved due to the removal of a continuous carrier frequency component during periods of silence. Savings in power would be considerably reduced in practice, however, due to the increased current consumption required by complex circuitry involved in the generation and detection of such signals. Cordless telephones spend a high percentage of time in a standby state and the receiver power consumption tends to be the most critical.

The constant detected signal amplitude from the FM receiver is convenient within the telephone environment. AM systems require AGC to counteract fading and to ensure correct loudness ratings at the telephone line and handset ear-piece. A long AGC time constant of 250 mS would be necessary to pass sub-audio data signals, as used by CT-1.5 cordless telephones, without distortion.

Phase lock loops could be used within cordless telephones to perform frequency modulation and detection. The use of the technique would be suitable if channels could be selectable, because of a PLL's frequency programming capability. CT-1.5 cordless telephones are allowed to use only two selectable channels which may be accomplished by switching between oscillator crystals. The capability of the PLL is not required by the cordless telephone, and the cost of using such a technique cannot be justified.

FM receivers used within cordless telephones employ quadrature detection because of the suitability of the circuitry to the narrowband FM system. The detector is available within receiver integrated circuits such as the

LM3361 as discussed in chapter five. The component count is minimal and in some circuits the tuned network may even be replaced by a ceramic discriminator which requires no adjustment.

The noise performance of the cordless telephone, using pre-emphasis and de-emphasis, complies with the requirements of class B specifications[BS6305]. The improved noise performance and perceived operation quality obtainable by the inclusion of compander circuitry has not been used to benefit available products. The reason is probably due to the market into which the telephones are sold. The added circuit cost and space requirements associated with an operating performance beyond the required specifications increases selling price and possibly the telephone size. Cordless telephones are consumer products which, unfortunately, sell mainly on their price competitiveness rather than their ultimate performance. The addition of circuitry that is not absolutely necessary is also restricted by physical space limitations. SMDs will aid in increasing design diversity and performance by easing this boundary.

The MF transmission from the base station requires a long antenna at the unit to radiate effectively. The length of this antenna is restricted to 3.0 m by the operating specifications but is unsightly and not always appreciated by the user. Poor telephone performance may occur due to the inadequate positioning of this antenna and, in some cases, the user unwittingly removing the wire. Although the low efficiency of this antenna necessitates a high powered transmitter amplifier at the base station this is not troublesome since the unit is mains powered under normal conditions. By using closely spaced frequencies in the 47 MHz band it would be possible to share antennae, although there would be various difficulties in this approach. It would be advisable to keep the handset telescopic antenna fully extended to obtain maximum call range and the circuit complexity in the handset, which should be small and light, would have to be increased. The receiver would require a second conversion stage, and the circuitry would demand the addition of an antenna duplexer.

The eight low band cordless channels are becoming over-crowded and will become superseded by CT-2 telephones[35][36]. The CT-2 specification allows forty selectable channels within the 864-868 MHz frequency band [MPT 1334]. The small antenna sizes practical at these frequencies also remove the fundamental antenna problems encountered by the low band cordless telephones. The use of low band cordless telephones in the office environment, even with leaky feeders, is restricted by the low number of channels available and the inter-modulation interference that can be caused by operating a number of cordless telephones concurrently. The digitally coded CT-2 cordless telephones are robust to interference and are much better suited to a business environment: the use of a leaky feeder arrangement should also benefit the performance of these telephones.

Cordless telephones employ a large number of electronic components, much more than the standard telephone where the handset may contain only transducer elements. Low band cordless telephones tend to be bulky, inconvenient and even unsightly. Circuit integration and component miniaturisation are the basic steps to overcoming these problems and developing more convenient, attractive and profitable products. SMDs offer possibilities for size reductions in RF circuits and, in the light of the circuit requirements of cordless telephones, are considered further in chapter three.

2-7 Physical Circuit Realisation

Electronic circuits begin as circuit diagrams. Circuit diagrams identify the inter-connection of various electronic components to perform a function and the printed circuit board (PCB) is used almost exclusively to perform the inter-connection function. The PCB, when used to construct circuits operating at speech frequencies, is an almost ideal inter-connection mechanism. It has essentially zero impedance between connection nodes and infinite impedance between unrelated circuit points. Circuits that operate at low frequencies may require no additional information than this diagram to enable physical circuits to be constructed which achieve the design specifications. This is not directly the case when the circuit must perform at high frequency, low current or in low noise modes as in the case of cordless telephones.

As the signal frequency increases, the PCB diverts from the ideal and the impedance between nodes becomes of significance. The choice of PCB substrate material is a factor of ultra high frequency (UHF) design because the dielectric constant and loss factor will effect circuit performance[37]. At very high frequencies, when tracks become of significant length when compared to the electrical wavelength of the signals, it becomes possible to make use of transmission line components. Strip-line techniques may be used within the radio circuits of CT-2 telephones but are not applicable to CT-1.5 cordless telephones.

Although not included as part of the circuit schematic, the PCB is a physical part of the circuit and as such must be accounted for. At the time of initial circuit design the exact circuit realisation is unknown and it is possible only to work with rules that minimise the detrimental effects that it can cause, whilst also taking advantage of its useful properties.

2-7-1 Physical Circuit Design and Interference

The first stage of preparing the circuit realisation is to identify blocks that can function in isolation or that must be isolated from others. This may be necessary when one circuit block will cause interference to or be susceptible to another. Interference may be in the form of critical noise frequency components due to switching or the inherent operation of circuits such as oscillators. Undesirable coupling can also result in instability when it causes positive feedback.

Interference coupling between two circuit blocks is caused by a number of means. The possible modes are capacitive, magnetic, electromagnetic, by conducted paths, by common impedances or by a mixture of more than one of these means. Inter-circuit coupling, due to fields set up between circuits, may be minimised either by spatially separating circuits or by modifying the path of the field with a screen, shield or earth plane. In the case of common impedances, improvements can be made by using a star earth arrangement to reduce the flow of interfering currents between unrelated circuit blocks. Interfering signals conducted between the circuits, for example along power supply lines, may be decoupled or filtered.

The miniaturisation of circuits using SMDs was expected to increase coupling between circuits due to capacitive and magnetic means because of the reduced circuit sizes. The use of an earth plane to present a sink to electrostatic flux may be necessary to give reduced and more predictable coupling in some circumstances. The sensitivity to electromagnetic coupling at components leads promised to be reduced by SMDs, but, due to the long wavelength signals used by low band cordless telephones, this was probably negligible. Closer component packing suggested a reduction in the availability of PCB area for tracks, and the design of optimum circuit layout may then suffer unless multi-layer PCBs are used. For example, if there is no area available to separate noise currents from common impedance routes then the performance of miniaturised circuits may be poorer than similar leaded assemblies.

Interference due to a variety of the above causes were encountered during the development of the cordless telephone test vehicle and are recorded in chapter five.

2-7-2 The Influence of Components on Radio Frequency Circuit Design

The components used within a circuit design operating at high frequencies may not perform as the ideal circuit elements depicted within the circuit schematic. As operating frequencies increase, component lead inductive reactance becomes increasingly significant as does stray terminal capacitive reactance. Active and passive components alike must be selected according to their suitability for operation in the desired frequency range. The performance of passive devices will be dependent on their constructional material characteristics and their construction form. Models of practical capacitors and inductors are included in appendix 2 of appendix C and highlight the performance that should be designed for with such components. The reduction of lead inductance offered by SM capacitors promised a major high frequency performance advantage compared to leaded types and the devices are investigated in chapter three.

2-8 Computer Aids

Computer aided design techniques allow for more efficient development of electronic assemblies. Design time efficiency is a critical factor in many projects, especially when high equipment complexity is involved. Computers are used extensively throughout the development cycle with tasks ranging from solving simple calculations through to complete circuit simulation and PCB layout.

The computing facilities available at the Autophon location were typical of the powerful systems available for electronics development. A suite of Mentor Graphics utilities running on an Apollo Domain network[38] included the functions necessary for schematic capture, digital and analogue circuit simulation and PCB design. The specific packages involved were NETED[39], QUICKSIM[39], MSPICE[39] and BOARDSTATION[39] respectively.

2-8-1 Circuit Simulation

MSPICE is based on the well known SPICE[40] analogue simulator, which has circuit models of high accuracy, proven and upgrade over twenty years of use. MSPICE allows a variety of circuit simulation possibilities from initial DC operating point analysis through AC frequency responses, transient analysis and noise modelling.

A great benefit from analogue circuit simulation is the ability to observe the behaviour of circuits under extremes of circuit tolerance and circuit operating temperature. The

Monte-Carlo[41] analysis subjects a circuit to a large number of simulations using components within specified tolerance spreads. The results from such analysis give information as to the performance spread of a circuit due to its component tolerance and the results are of great importance in predicting the circuit yield to be expected during manufacture.

Circuit simulators can exercise circuits, but cannot design them. It is not possible to achieve reliable simulation of circuits unless all of the circuit components are present and their models are accurate. This may require the knowledge of circuit elements not depicted on the circuit diagram which include inter-component coupling, lead inductance and skin effects. Should the circuit layout be known, it is a complex and time consuming task to calculate or measure such factors and the advantages of circuit simulation become lost. What simulation is useful at is predicting the performance of the ideal circuit against which the practical circuit may be gauged. The introduction of various impedances to the theoretically ideal circuit will highlight what layout guides must be followed to maintain acceptable physical working.

It is possible to employ integrated circuits in place of many discrete devices but both integrated circuit and active parts can cause difficulties with simulation. Simulators require exact models of circuit elements to perform accurately and a new model has to be created when a new component or integrated circuit is used. The introduction of such a new model requires creation and proving which often represent unacceptably large resources in time. There are, however, a variety of models that exist in SPICE user libraries and new devices are becoming introduced with their simulation model ready prepared by their manufacturers.

2-8-2 Printed Circuit Board Layout

The computing facilities available at Autophon were suitable for designing surface mounted assemblies. Of importance were the facilities to distinguish between SMDs and leaded components used within designs and particularly for the PCB design software to be capable of incorporating specific design rules for both types. For example, the footprint for each component is different; the SMD does not have a through hole for each termination, restricting inner-board tracks, and is often mounted onto the opposite side of the PCB. BOARDSTATION allowed design rules to be created as necessary and was suitable for all possible components to be encountered.

Auto-routing algorithms require double sided or multi-layer boards whereas single sided boards are designed manually using links where necessary to cross tracks. Auto-routing algorithms guarantee only the correlation between PCB and schematic inter-connections. The priority for low inductance connections or special routing is not catered for and where high frequencies are involved, or where critical circuits must be laid out, it is beneficial to do so with manual intervention.

2-9 Conclusion

From the discussion of the operation, circuit methods and performance defined for the CT-1.5 telephone it is seen that FM is well suited to the application. Compared to equally powered AM methods, FM offers a signal to noise improvement and does not require AGC. Suppressed carrier AM techniques suggest higher transmission efficiency due to the lack of carrier component in the absence of modulation, but this advantage would be offset by increased reception complexity.

The transformation of these circuits to SMAs does not suggest any change in the suitability of the basic circuit techniques as circuit integration might show. The main foreseen advantages are in miniaturisation and component performance improvements. Miniaturisation of basic circuits would not only allow smaller portable telephone equipment but also offer greater functionality to be achieved without increasing size. Operating limitations do not allow improved performance through digital techniques because of narrow-band requirements, although companding functions have demonstrated improved utilisation of the FM channel spectrum. Although, at the time of writing, such a function had not been offered in a CT-1.5 telephone, circuit miniaturisation allows such optimisations to be considered.

The inherently better high frequency performance of SMDs, due to reduced lead inductance, is considered further in the following chapter, specifically at cordless telephone operating frequencies.

Chapter 3

Surface Mount Technology

3-0 Introduction

The chapter introduces surface mount technology (SMT) and its various assembly techniques. The influence that the devices and their assembly methods have on design, development and manufacture are discussed and compared with that of more conventional leaded circuits. Advantages offered by the components in radio frequency designs are suggested along with a frame work within which the process of designing assemblies incorporating surface mounted devices (SMDs) should function to reduce any difficulties associated with the new technology.

3-1 What is Surface Mount Technology ?

A large number of electronic components are available in a format suitable for surface mounting and tend to be smaller and lighter than their leaded equivalents. Instead of wires used to connect through the printed circuit board (PCB), the SMD has terminations which are soldered directly to contact areas (component footprints) on the substrate. Typically, the SMD will also have a flat surface which is suitable for lifting and positioning by a vacuum pick-up bit. Such a pick-up method is used by automatic component placement machines and may also be used for manual component handling. Figure 3-1 shows a pick-up head and common components in surface mount format. The preset resistor, for example, is supplied with a silicon membrane over its adjustor which allows immersion in solder and also provides the flat surface for assembly.

SMDs have to withstand high thermal stress during soldering and new components and materials are constantly being developed to meet the requirements. The resulting range of devices that are available vary from conventional devices, such as the quartz crystal in the illustration, with re-configured terminations to allow them to be surface mounted, to specialised miniaturised packages conforming to SMD manufacturing standards. The benefits offered by the crystal would be its automatic onsertion capability and the removal of PCB drill holes with a corresponding increase in usable area on the underside of the board, or internal board layers. The technique is also common for a variety of bulkier components such as switches, relays and connectors, although larger and heavier devices may require extra mechanical support from through hole fixings. Such components tend to have less standards governing their construction and make second sourcing a potential problem.

The initial lack of standardisation in SMDs resulted in the development of packages driven by market share and demand, but the JEDEC (Joint Electronic Device Engineering Council) is involved with the refining of component standards. Package specifications for the majority of devices now exist, although there is still concern regarding component manufacturing tolerances[42].

The chip device, as shown in figure 3-2, is the usual form of the surface mount resistor and capacitor. The illustration details the nominal package dimensions of common component

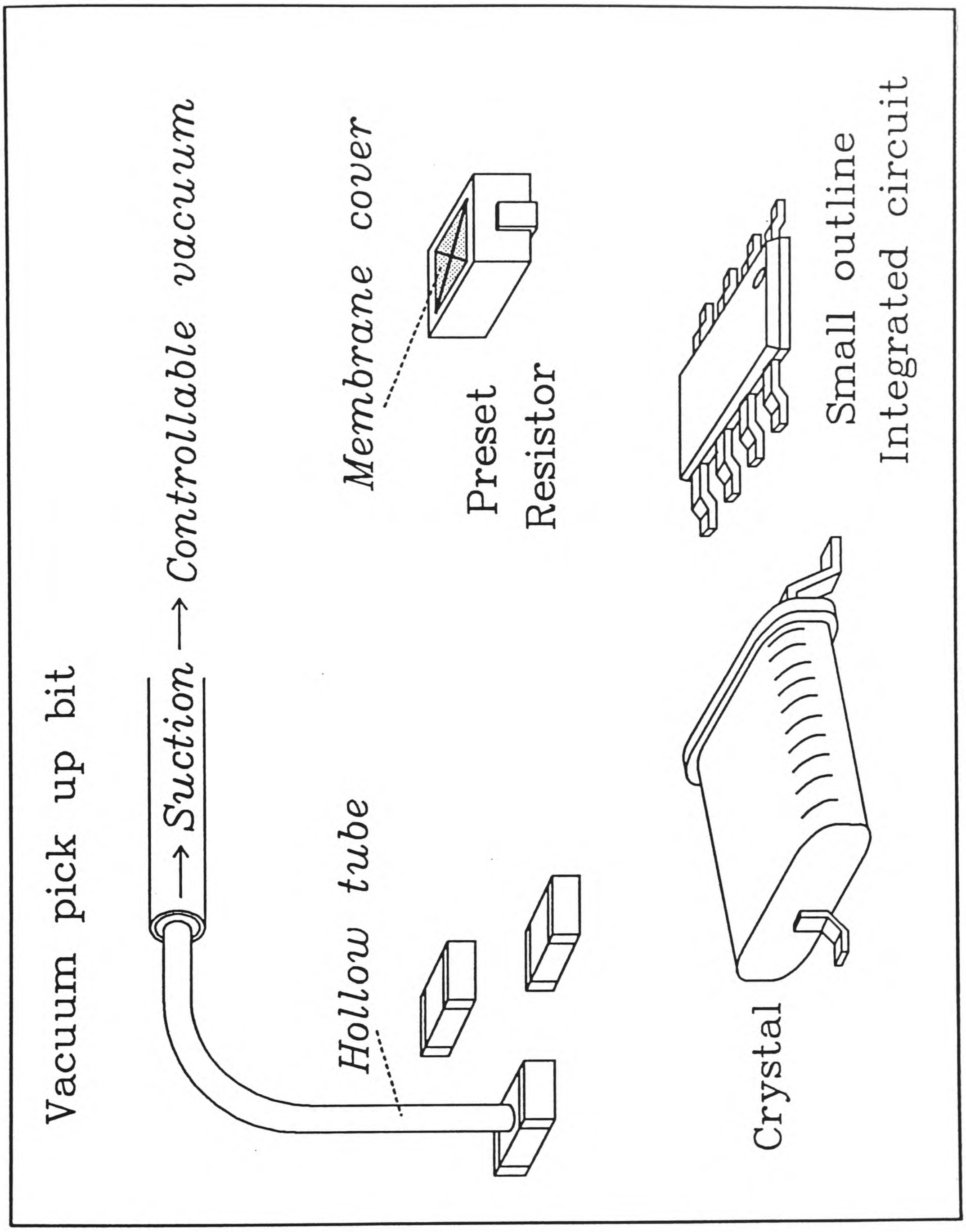
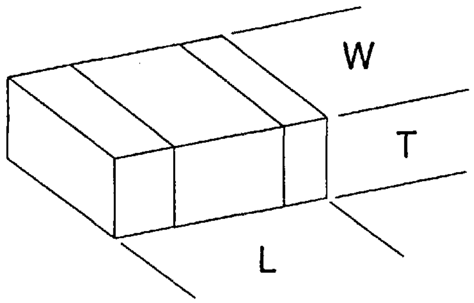


Figure 3-1 Vacuum pick-up bit and common surface mount components

Chip component



The thickness of the chip capacitor is dependant on the capacitance value

Size Type	L (mm)	W (mm)	T (mm)	Typical range of capacitive components available (pF) COG 50 V	Y5U 50 V
0805	2.0	1.25	0.7 - 1.25	0.5 - 1000	1000 - 68000
1206	3.2	1.6	0.7 - 1.25	0.5 - 2400	1000 - 220000
1210	3.2	2.5	1.0 - 1.5	2200 - 4700	~330000
1812	4.5	3.2	2.0 max	3900 - 6800	470000 - 680000
2220	5.7	5.0	2.0 max	5100 - 16000	1000000 - 1500000

Figure 3-2 Common chip component details

sizes and compares a typical range of ceramic capacitors values offered by a component manufacturer. The COG dielectric is stable with temperature and aging but has a lower dielectic constant than the Y5U type. The latter is used to achieve high capacitance values in small packages but tend to be employed only in decoupling type applications due to instability. The 1206 size is the industrial standard and the 0805 is used when space saving is essential. Smaller components are available and are particularly useful for microwave capacitors but demand specialist handling and assembly. Capacitor miniaturisation is limited by the value of capacitance required from the package and also by the end terminal separation demanded by voltage breakdown requirements. The chip format is particularly suited to resistors that are laser trimmed at manufacture or after they have been mounted in their assembly. A zero ohm resistor is supplied for used as a 'jumper' in single sided circuit designs.

Figure 3-3 shows the package dimensions of common low power active devices such as transistors, diodes, LEDs, voltage detectors and voltage references. The SOT-23 outline is used by the majority of low power components below about 300 mW whereas the SOT-89 can handle a power dissipation of around one Watt. The SOT-23 has been found to be an ideal, low cost package for high frequency transistors up to 2 GHz[43].

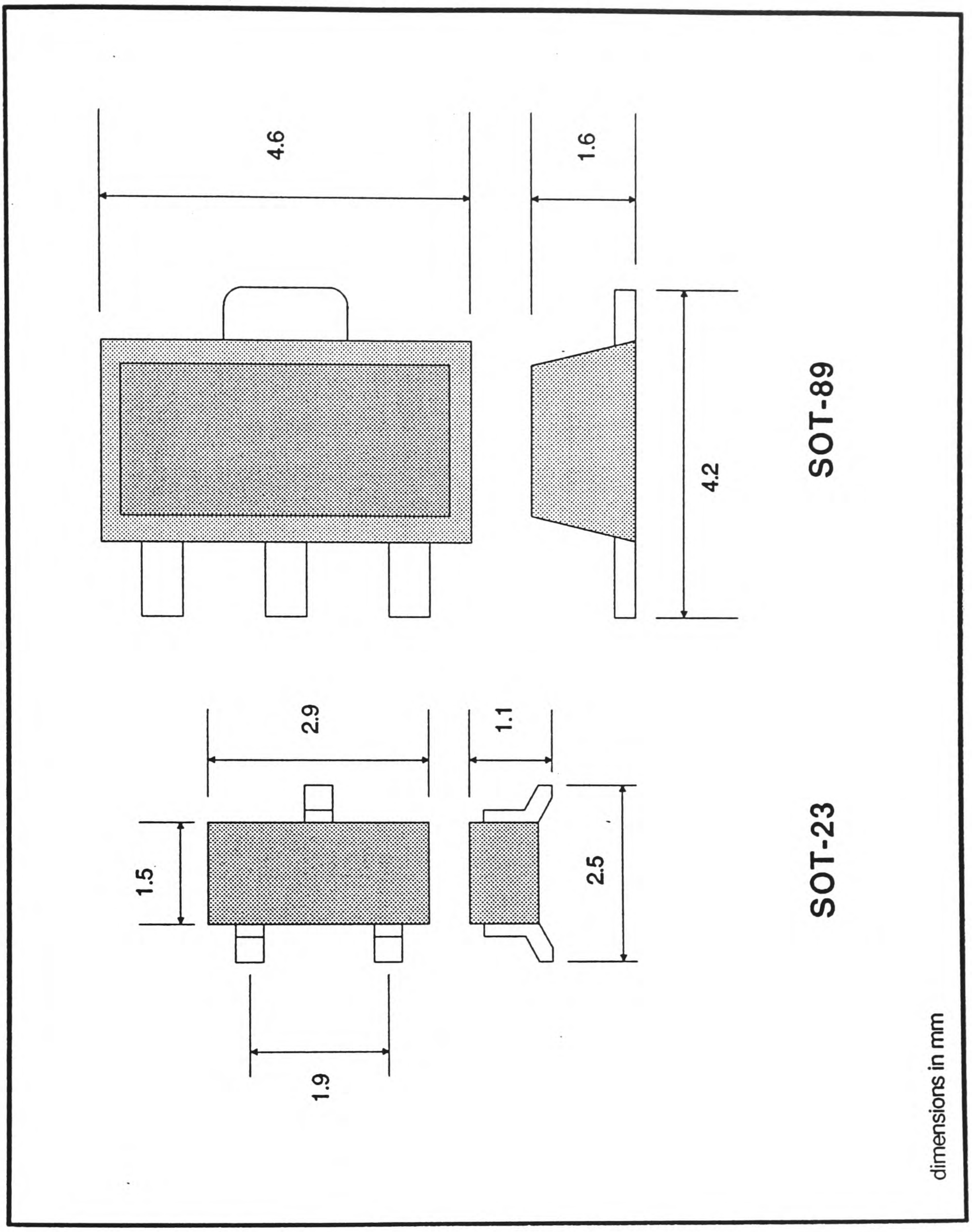


Figure 3-3 Common low power active component packages

Typical integrated circuit outlines are illustrated in figure 3-4. Low pin count devices are supplied in the small outline (SO) package which is a miniaturised version of the dual in line (DIL) component with a 50 mil (1.27 mm) pin pitch and 'gull-wing' leads. The SO package allows up to 16 pins while the SO-wide package, a 7.8 mm wide version, allows up to 28 pins. Higher pin counts are achieved by utilising all four sides of the component as shown by the quad flat pack in the illustration. The flat pack has 'gull-wing' leads whereas the second type, the plastic chip carrier (PCC), uses a 'J-bend' lead which allows solder connections to be made under the device body and component packing density to be optimised. The leadless chip carrier (LCC) is similar but, instead of leads, has metallic terminations at the edge of its ceramic body. LCCs can only be soldered to ceramic based substrates because of the un-matched temperature coefficient between its body and normal PCB materials. PCCs have less temperature coefficient mis-match and their lead flexibility absorbs the small temperature induced forces. Small ceramic components such as ceramic chip capacitors have dimensions that are too small to result in damaging forces caused by temperature.

The breadth of SMD availability is increasing continuously. Many new formats are also becoming standardised for higher pin count devices up to and beyond 100 pins. Component availability at present includes, for example, trimmer devices, inductors, electromagnetic interference (EMI) suppression filters, ceramic intermediate frequency (IF) filters and discriminators, oscillators, hall-effect

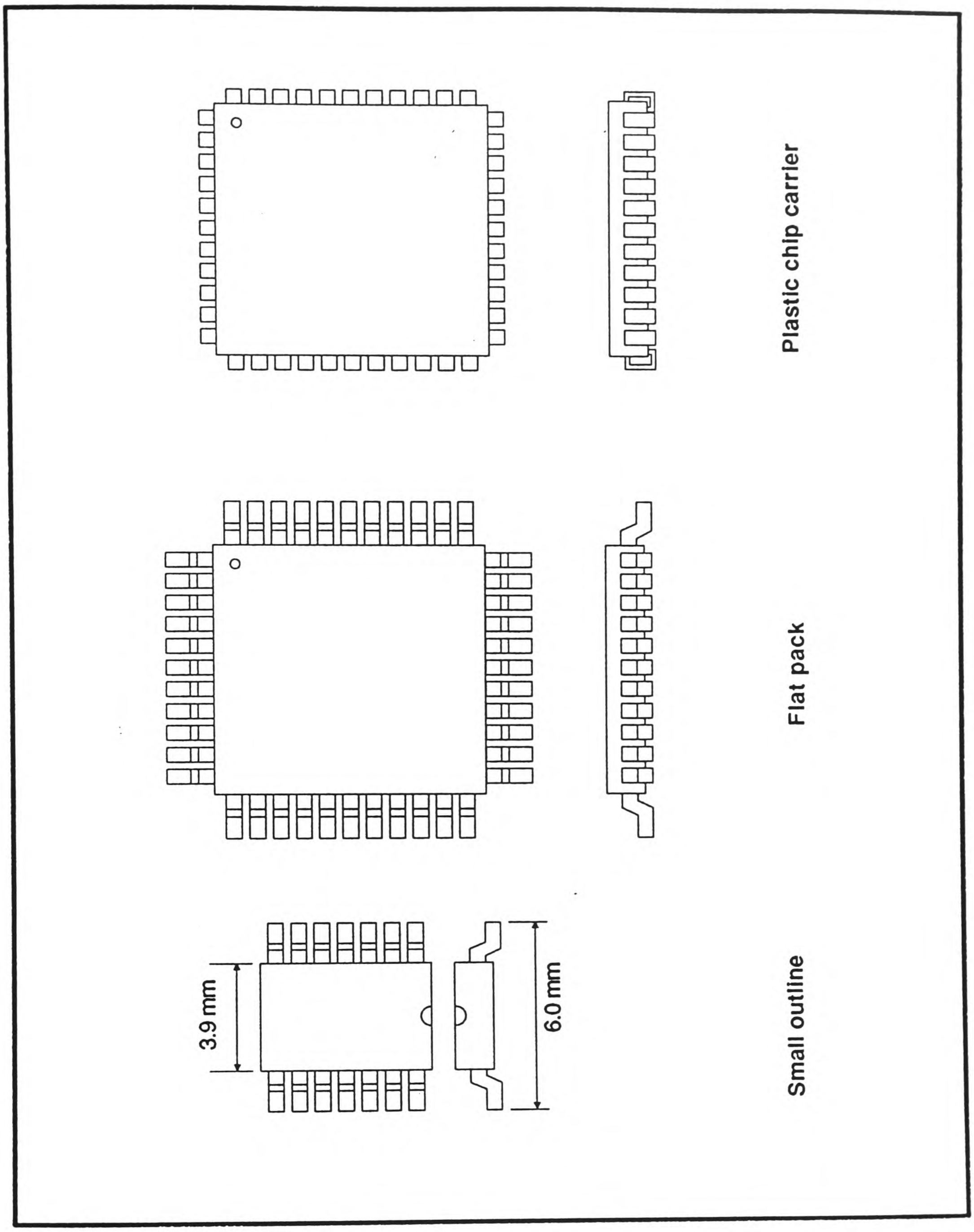


Figure 3-4 Common integrated circuit packages

switches, thermistors, component networks and radio frequency (RF) transformers. Metal Electrode Face-bonded (MELF) components[44], employing a tubular device construction, are also particularly commonly used for passive devices and diodes by Far East assembly manufacturers.

SMDs can be cheaper to produce and transport than conventional components because of their reduced size and weight, and lack of leads in many cases. At the time of the study, popular parts such as small signal SOT-23 transistors and chip capacitors were already often cheaper and this trend has continued as various other varieties became used in larger quantities, making their production ever more cost effective. More 'exotic' SMDs such as crystals and relays, which were supplied in small quantities and often required extra processing, could be several times more expensive than the conventional component. This made their use unattractive in some applications and typical situations are discussed further, with cost comparisons, in chapter five.

3-2 How are the Devices Assembled ?

SMDs may be soldered onto a PCB substrate by a variety of techniques and can be mounted onto either side of the board, or even both. Figure 3-5 shows the variety of assembly possibilities and the soldering methods by which they are achieved. The two soldering techniques, wave and reflow, are introduced in the following sections. In addition to these main methods it is possible to solder SMDs by hand with fine tipped or hot air soldering irons, and larger integrated

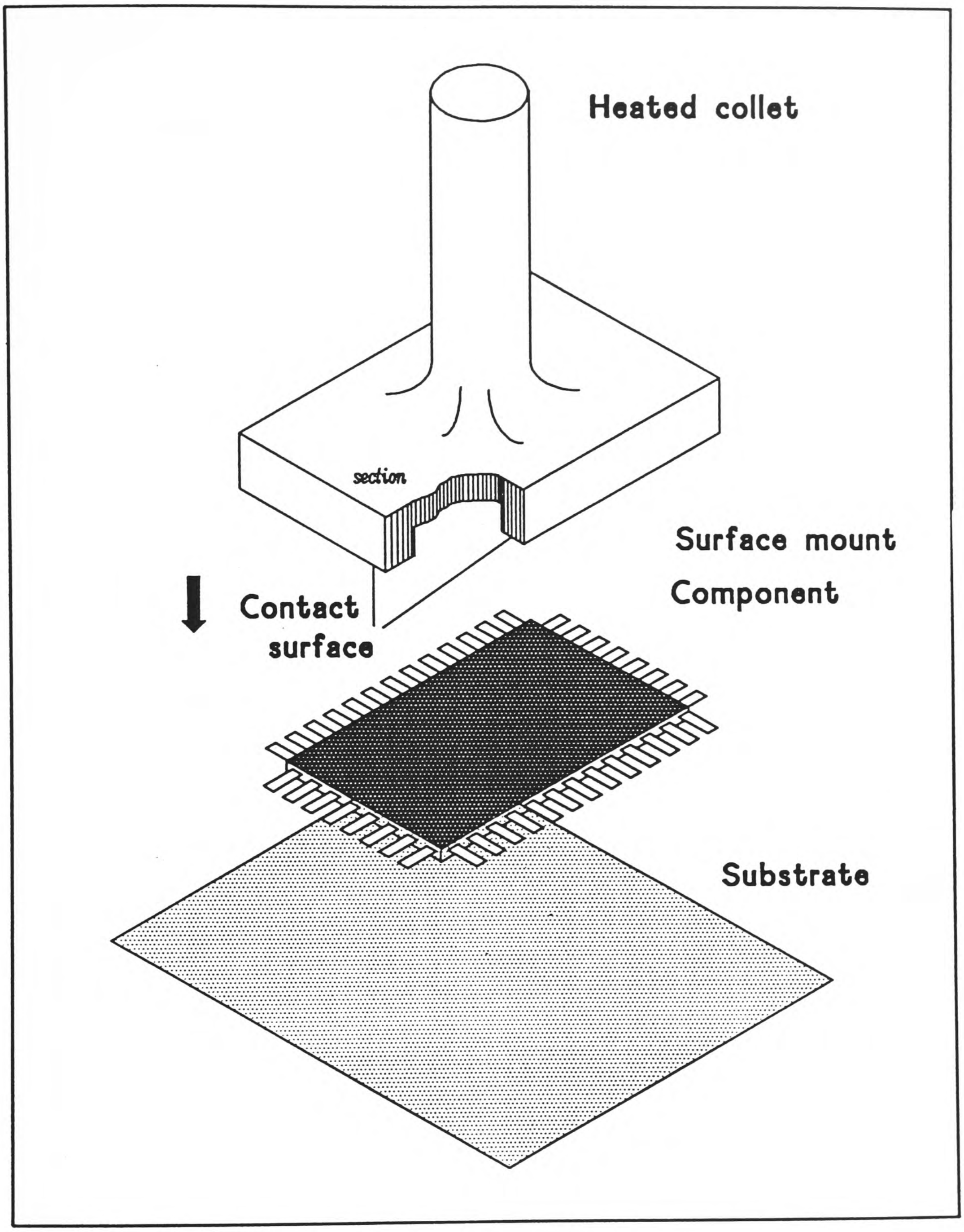


Figure 3-5 Surface mount assembly possibilities and their appropriate soldering techniques

circuits are often soldered individually with a heated collet such as shown in figure 3-6.

3-2-1 Wave Soldering

Wave soldering, also known as flow soldering, is achieved by passing a PCB and its components through a solder bath similar to types used to solder conventional, leaded assemblies. The SMDs are held in position on the PCB during soldering with glue positioned under their bodies, away from the solder bond points. The typical wave soldering machine suitable for surface mount uses a turbulent wave followed by a smooth, laminar wave as illustrated in figure 3-7. The initial turbulent wave (or chip wave), has enough agitation to drive off all flux residues and trapped gases, and improves wetting (the take up of solder) across the PCB. The laminar wave is then used to complete the formation of solder fillets and eliminate bridges. It is a requirement that SMDs to be wave soldered must be designed to withstand immersion in the solder wave and that the solder wave is allowed to form a bond between its terminals and the PCB footprint. For these reasons not all SMDs are suitable for soldering by the wave process and will be stated as not by their manufacturers. These devices will, however, always be suitable for soldering by the second method called reflow soldering.

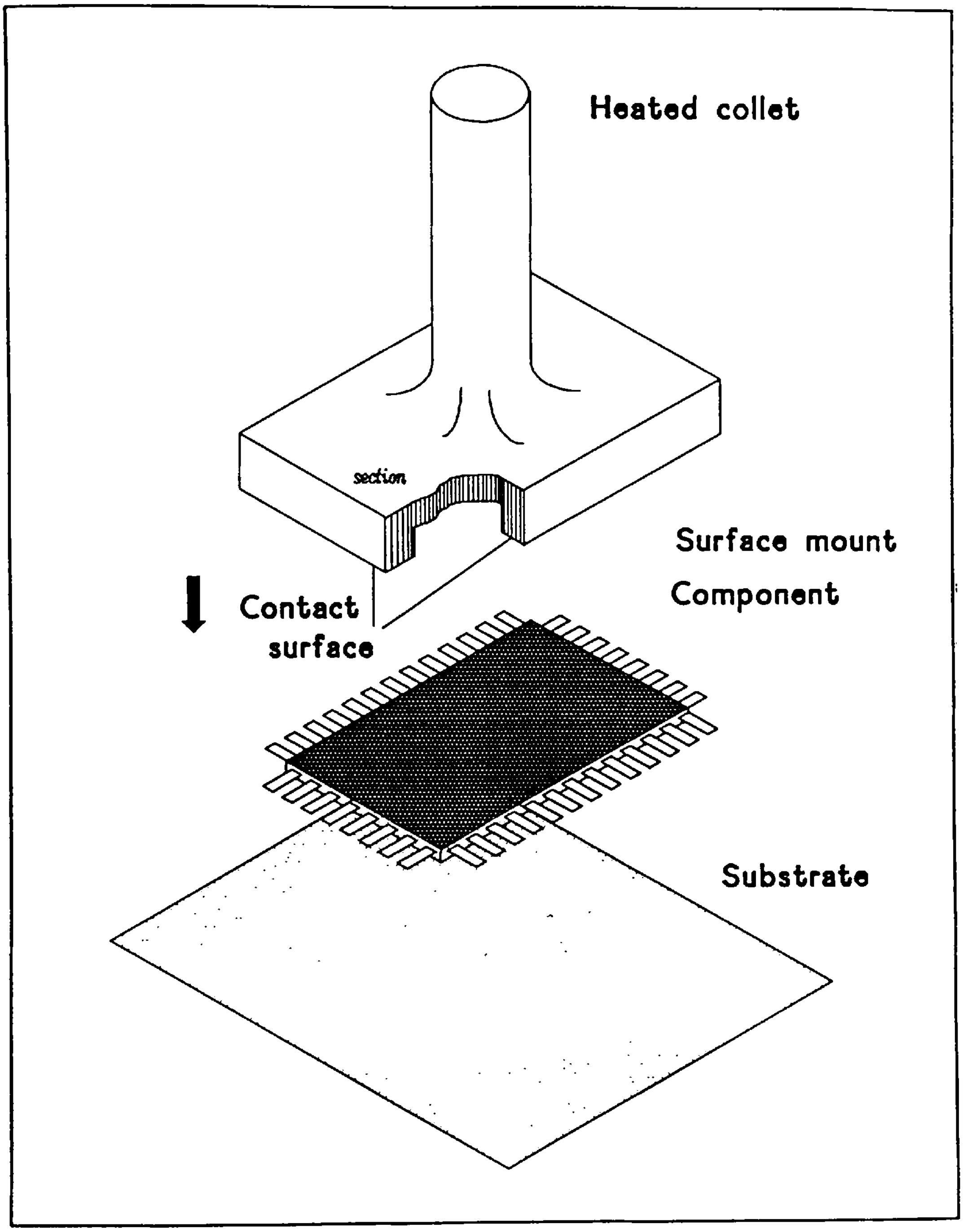


Figure 3-6 Heated collet used to solder high pin count integrated circuit

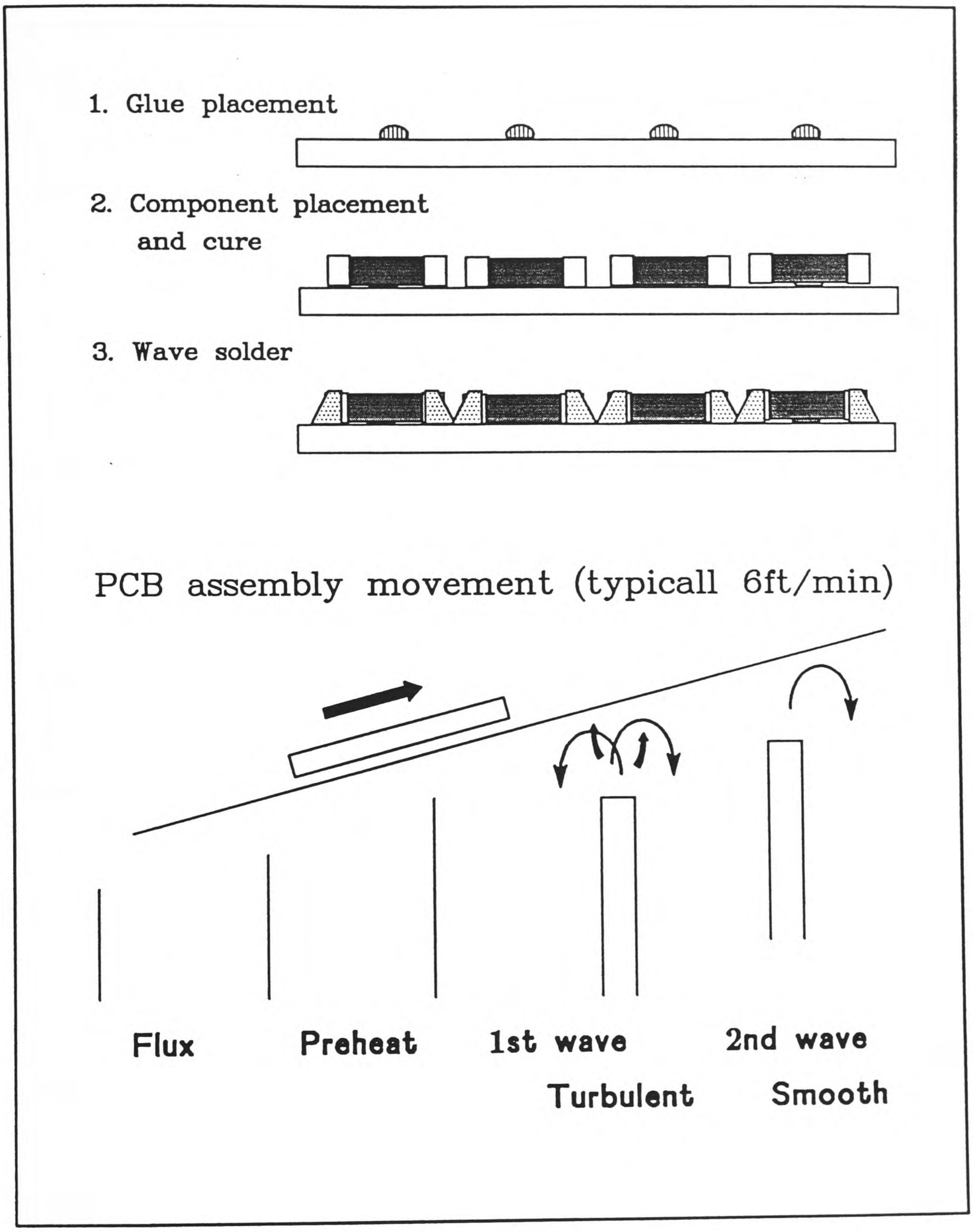


Figure 3-7 Wave soldering of surface mount assembly with a turbulent wave

3-2-2 Reflow Soldering

SMAs are reflow soldered by two main techniques known as vapour phase (VP) and infra-red (IR) soldering. A third technique uses laser light energy to individually reflow solder each SMD terminal[45]. The laser soldering process can take longer to perform than alternative means but allows accurate reflow soldering without the need to heat the PCB and component bodies. Figures 3-8 and 3-9 show the VP and IR processes respectively. Solder paste is applied to the PCB by screen printing where joints are required, and holds the components in position during soldering. The solder paste, a viscid mixture of balls of solder and flux, forms the solder joint when the assembly is heated sufficiently. The VP technique provides a rapid and even heating by means of the latent energy released when the fluorocarbon vapour cloud condenses on the assembly. A pre-heating phase is normally employed before the reflow process to avoid thermal shock resulting from too rapid heating.

Infra-red soldering systems are suited to pass-through processes and contain a number of heating zones so that the temperature of the PCB may be controlled as it progresses. By matching the soldering temperature profile to the assembly, the IR method achieves the desired result. An example of a typical soldering temperature profile is shown in figure 3-10. The radiation technique results in less even temperatures across assemblies with some colour sensitivity, although this sensitivity is minimised by using IR radiation in the 6-10

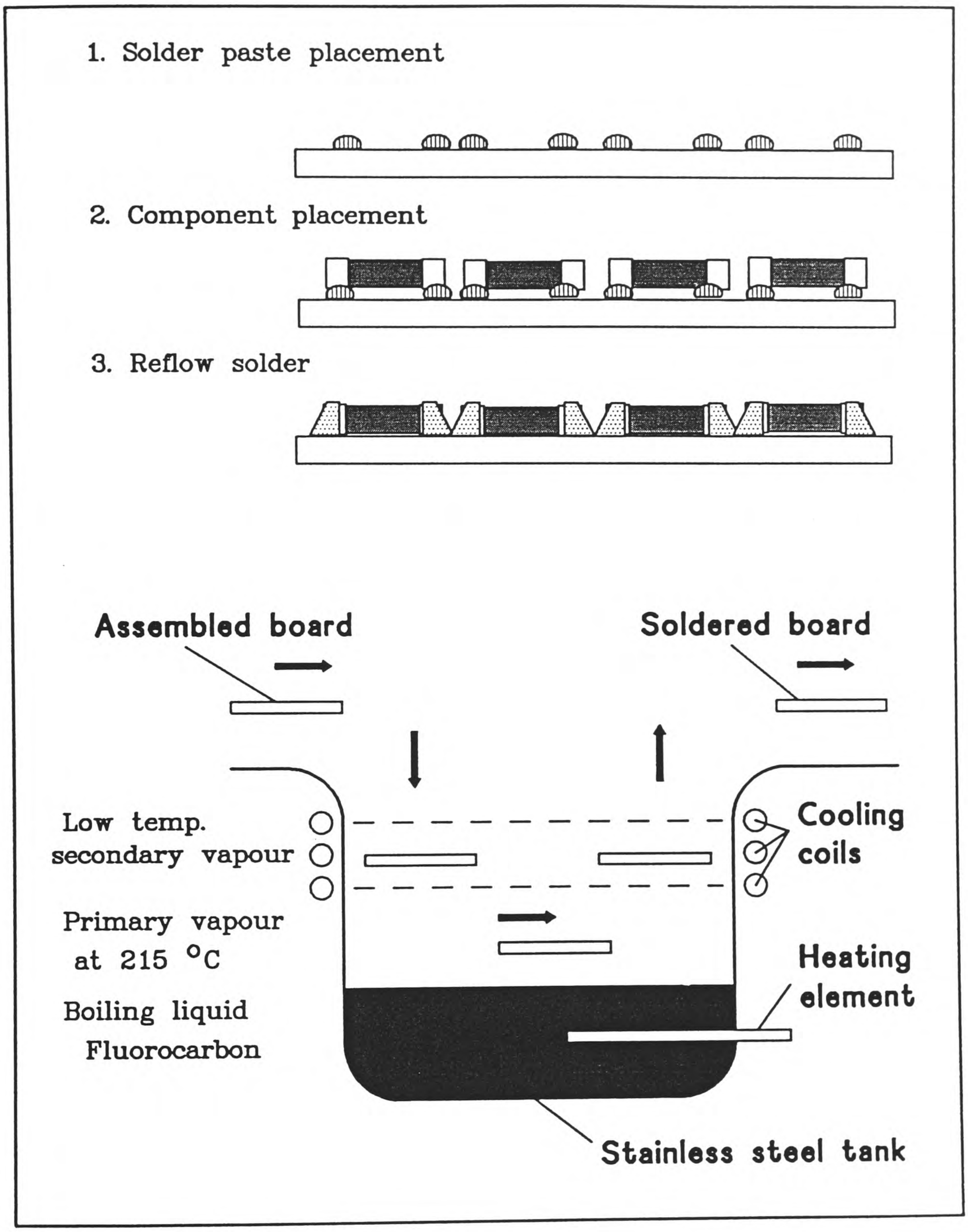


Figure 3-8 Vapour phase soldering of a surface mount assembly

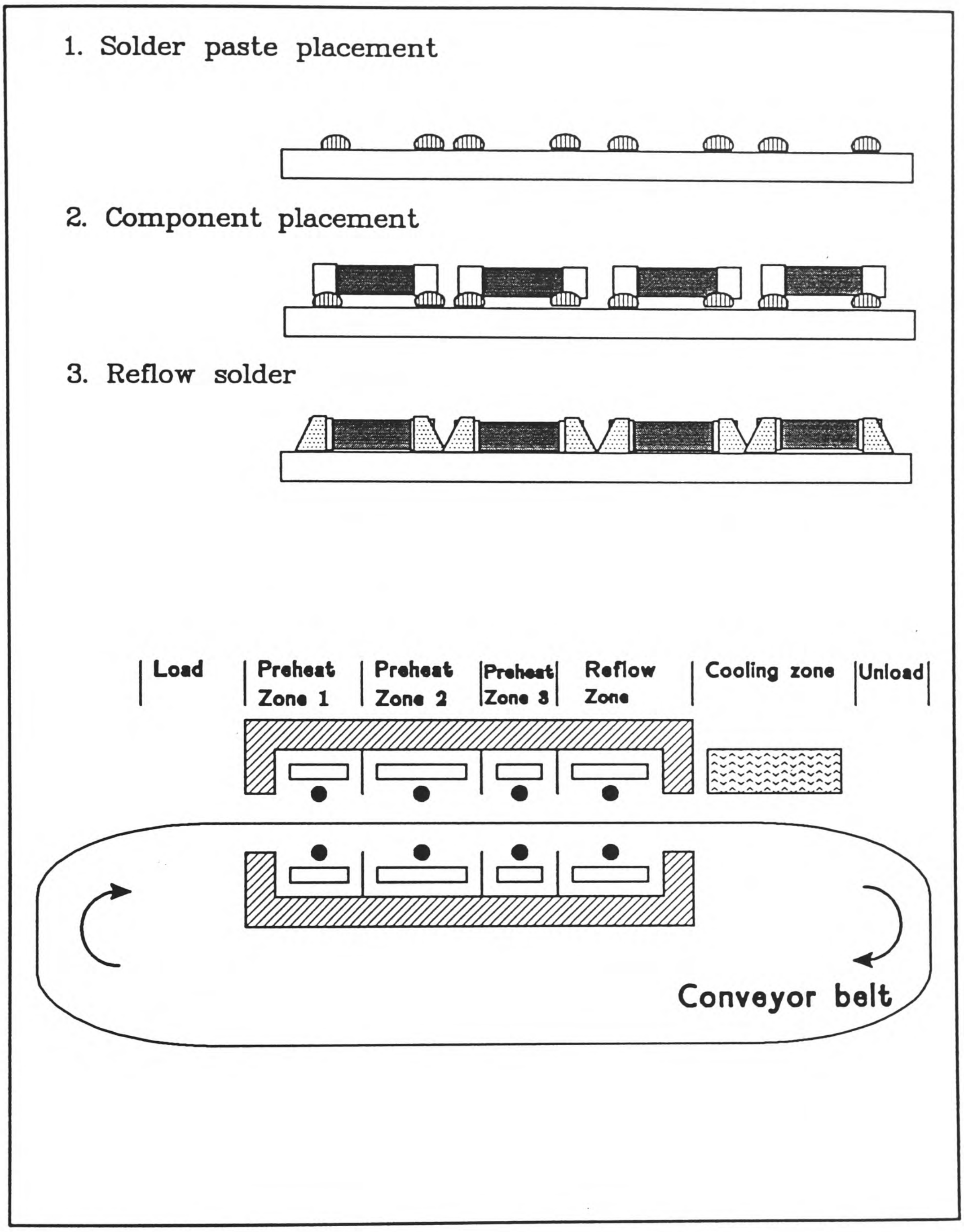


Figure 3-9 Infra-red soldering of a surface mount assembly

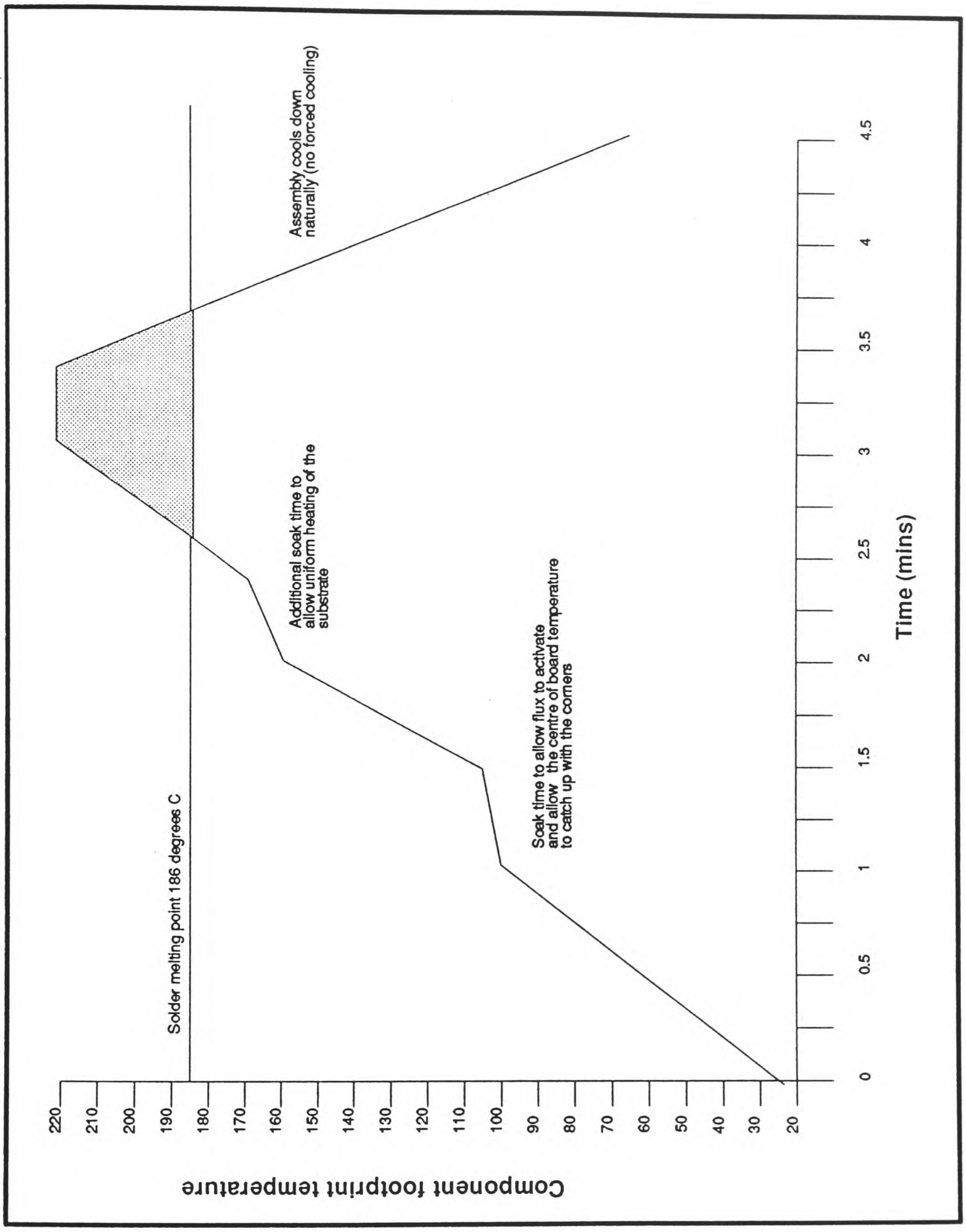


Figure 3-10 Typical infra-red soldering temperature profile

micron region[46]. Hot spots can occur and paper based substrate materials are less suited to the infra-red reflow technique since they can char or warp.

3-3 The Impact of Surface Mount Technology on Design and Manufacture

The use of SMDs of typically one quarter the size and one fifth the weight of leaded equivalents enables smaller and lighter assemblies to be manufactured, or alternatively more functions to be included in the same outline. Circuits can be assembled onto PCBs that require no drill holes for component leads, by automatic assembly machines requiring a fraction of the factory space demanded by leaded inserters, resulting in products that are cheaper to produce to levels of reliability unobtainable by leaded assemblies. The potential of SMT is clearly attractive as confirmed by the increasing number of manufacturers adopting it to some level, especially for new products.

SMT brings with it important decisions to be taken by managers and various concerns for circuit and PCB designers, component buyers, production personnel, and test and quality assurance engineers. The actual, practical impact of the technology is dependant on the type and range of a companies products, their assembly requirements and ultimately the way that the transition to surface mounting is managed.

In developing a set of design rules, the following areas of concern must be considered:

Suitable manufacturing capability, especially soldering requirements and component onsertion.
Component selection, availability and cost.
PCB design rules.
Personnel training.
Testing of assemblies at in-circuit and functional levels.
Rework of faulty assemblies.

3-3-1 Manufacturing Capability

The facilities needed to assemble the new devices are necessarily complicated due to the handling difficulties of small SMDs. A human operator cannot be expected to place more than between 300-600 components per hour and so automatic onsertion equipment is generally essential. The complexity of the component placer must suit the projected needs, and factors most likely to influence the selection will be the placement rate, whether it can place glue needed for wave soldered assemblies, its accuracy, and the range and quantity of component packages that it accepts. Some onserters feature component checking during placement which is useful in assuring that the correct component has been supplied but less so for general testing because SMDs are normally supplied pre-tested. While three leaded assembly machines are required for the placement of axial, radial and DIL components, only one onserter is necessary. This will result in factory space efficiency except of course when the onserter is an additional requirement to the other three.

Reflow soldering is in principle the most suitable method for surface mounting because it does not restrict the range of SMDs used as does wave soldering. Unfortunately it is not practical when products require a number of components that are not available in SM form, are not readily available or are too expensive for the product. IR soldering also has drawbacks because it does not allow FR2 paper based boards to be used very successfully due to warping. It may also cause hot spots on densely populated assemblies. Should the VP technique be acceptable for a product or part of the assembly then the safety implications of the toxic and expensive chlorofluorocarbons (CFCs) generally used, and the environmental issues they raise must be addressed[47]. Wave soldering is commonly used by companies moving over gradually to SM because it allows soldering of both leaded components and SMDs. Either a suitable wave soldering machine must be purchased or modifications to existing equipment must be made.

3-3-2 Component Selection

The selection of components used within a consumer product will be a compromise between their performance, cost, availability and assembly advantages. Although some SMD parts may appear more expensive, the excess cost may be compensated for by improvements in performance or production reliability. Component selection can be performed only after consideration of their suitability to the soldering process and any cleaning requirements that are present. Termination material for chip capacitors is an example of a further component related consideration. Chip capacitors are constructed with silver-palladium or nickel barrier terminations[48] which give the devices good solderability and resist demetalisation (the dissolving of the termination during soldering).

3-3-3 Printed Circuit Board Design Rules

The PCB design is essential to the success of the surface mount process. New components using smaller pin pitches, or the size reduction of circuitry with higher component density, can demand an increase in the accuracy and etch resolution of PCBs. PCB flatness is also more critical because components have to lie on the substrate and the solder levelling process[49] is generally used for boards with SMDs. Higher packing density demands also higher regard for thermal PCB management[50]. The solder process has a profound effect on the layout of the circuits because the basic footprint requirements of wave and reflow soldering are different. The wave soldered board needs larger termination areas to attract the solder from the bath, and component orientations must be compatible with the wave flow direction so that connections are not 'shadowed' by the component body. Reflow solder footprints may be smaller, higher component packing density may be achieved and the devices have no orientation restrictions. It is essential, however, that the footprints are designed so that the surface tension of the molten solder is equal at each joint. The surface tension has a useful aligning effect for badly positioned components, but unequal forces can cause chip devices to stand up on to one end, an occurrence often referred to as 'tombstoning'. PCB footprints for common wave soldered devices are included in the design rules in appendix C.

3-3-4 Personnel Training

SMA production techniques bring with them new technologies to the manufacturing environment, demanding new skills and the knowledge of processes and materials. Reflow soldering, for example, requires the screen printing of solder paste and wave soldered SMAs require component gluing. The component pick and place machine is often used to place the glue but a dedicated glue dotting machine will remove the burden and so increase component throughput. Glue can sometimes be screen printed but can cause printing screen clogging problems, and glues that can be cured at low temperatures tend to have limited shelf lives. One of the greatest demands of SMT is the need for training in awareness of these new requirements and this need extends from insertion machine operators through assembly designers to managers.

3-3-5 Board Testing.

SMDs are inherently more reliable than leaded components because their construction has less parts that can fail. The assembly is also more robust due to lighter weight devices and their rigidity when positioned. The reliability can not, however, be assumed from the technology because the technology brings with it new forms of failure modes that quality control personnel must be aware of. Handling is particularly important because of cracking in devices that can result from rough handling or damaging forces at the onsert machine[51]. Assembly cleaning issues must be addressed especially when wave soldering is employed due to the possibilities of flux residues becoming trapped under SMDs and causing failures in the field as they decompose.

When a leaded circuit has been soldered it is typically tested to verify the correctness of assembly. This can be achieved by either in-circuit techniques, functional tests or both. In-circuit testing is performed by probing circuit nodes and testing for correct component placement. A bed of nails tester, which uses either pointed or specially shaped probes to connect to designated circuit points or component tails is shown in figure 3-11. The testing of SMAs must be planned during the PCB design stage, and ideally during the circuit design stage. This is because component lead tails are not available to probe and test points must be allocated where necessary. Component terminals should never be probed directly because of the possibility of closing an open circuit by the action or causing component damage. Double sided SMAs represent a further complication to board testing. Either vias are needed to route all signals to test locations on one side of the board or a 'clam shell' probe arrangement is necessary as also illustrated. In-circuit test points demand PCB area and can have an adverse effect on the density of a circuit. Functional testing of circuitry is a means of

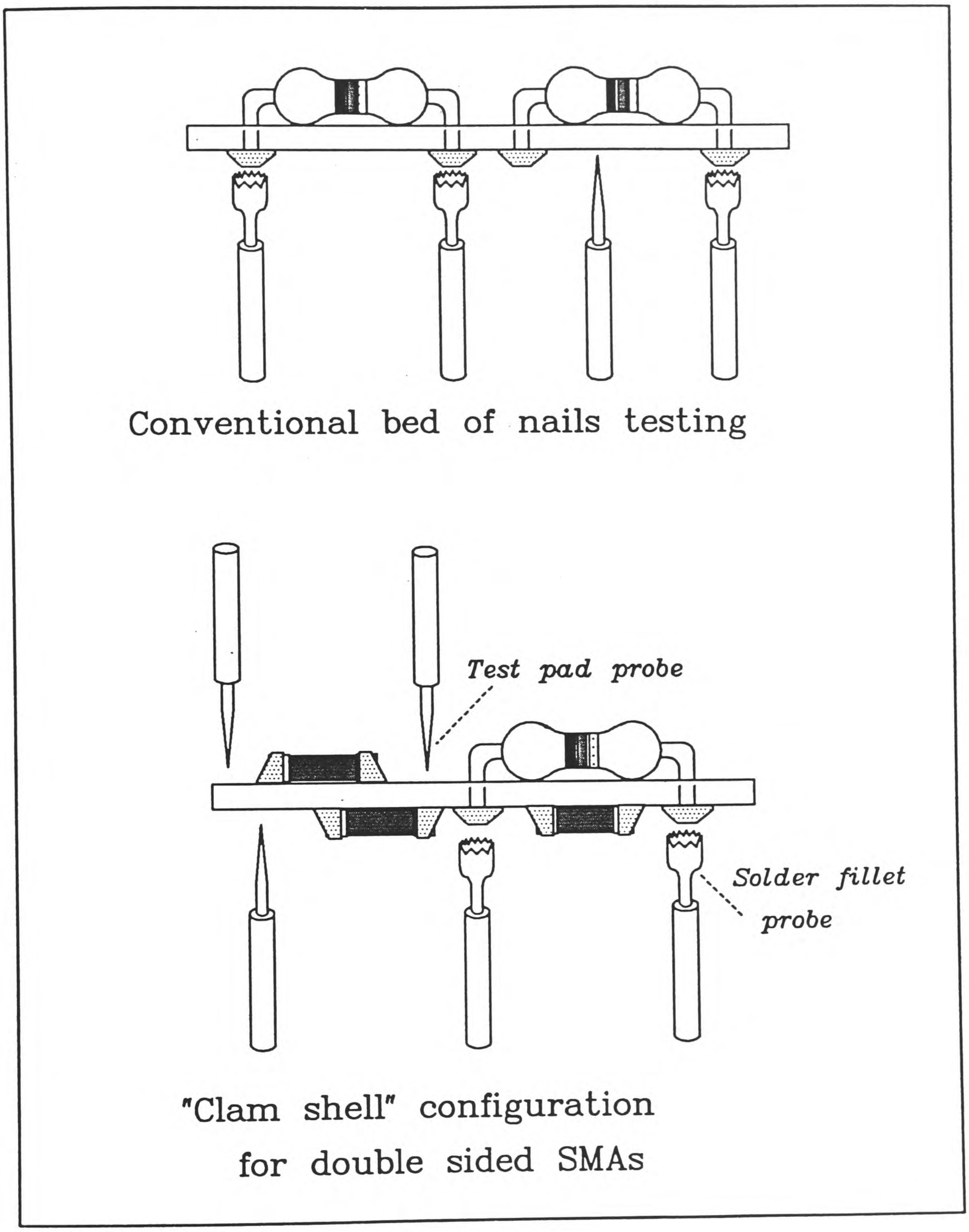


Figure 3-11 Conventional bed of nails test probes and a double sided "Clam shell" configuration

reducing probe area requirements and should be considered when appropriate[52].

The ultimate goal of SMAs is high throughput, zero defect soldering. With high accuracy placement, well designed PCB assemblies and a soldering process that suits the requirements, this goal can be approached. Solder joint inspection with optical magnifiers is often used as a means of on-going quality control although is made more difficult when circuits employ PCCs because the solder connections are partially obscured by their bodies.

3-3-6 Assembly Rework

Rework of PCBs will inevitably result due to a process error, human error or component failure. When the failure rate is low enough then it may be economical to discard the board or else repair must be carried out. Again SMDs demand a change of strategy because they are often glued in position or have many legs that must be de-soldered together so that their relatively delicate copper footprints are not damaged. Glues used for wave soldering weaken when the component is heated and so do not cause a major repair problem but it is almost essential to use a dedicated rework machine, operated by directing hot gas or infra-red radiation at the device, to remove high pin count components.

3-4 How do Surface Mounted Devices Affect Radio Frequency Design ?

The miniaturisation of hand-held equipment such as cordless telephones is one advantage that SMDs can offer. In addition, the improved reliability inherent in the components due to less constructional parts reflects an overall equipment reliability improvement. The lack of lead inductance was foreseen to be the major high frequency advantage and this aspect was examined in greater detail.

The multilayer ceramic capacitor is used throughout radio circuitry because of its low value of series inductance. In order to confirm the reduction in this parameter, the self resonant frequency (SRF) of typical 1206 size multilayer ceramic capacitors were measured and compared with results obtained from leaded equivalents. The measurements were carried out using a spectrum analyser, tracking generator and high impedance probe as illustrated in figure 3-12. The results were recorded with zero length track to the components PCB connection and as such represented the optimum that could be achieved in practice. Measurements, reproduced in figure 3-13, show that the inductance of the leaded capacitors were higher by a factor of approximately 3.5 although the exact factor was dependant on the circuit board thickness and the leaded component insertion accuracy. For example when the 1 nF leaded capacitor was not closely inserted to the board and left 1 mm additional lead length on each side, the self resonant frequency reduced to 18.2 MHz,

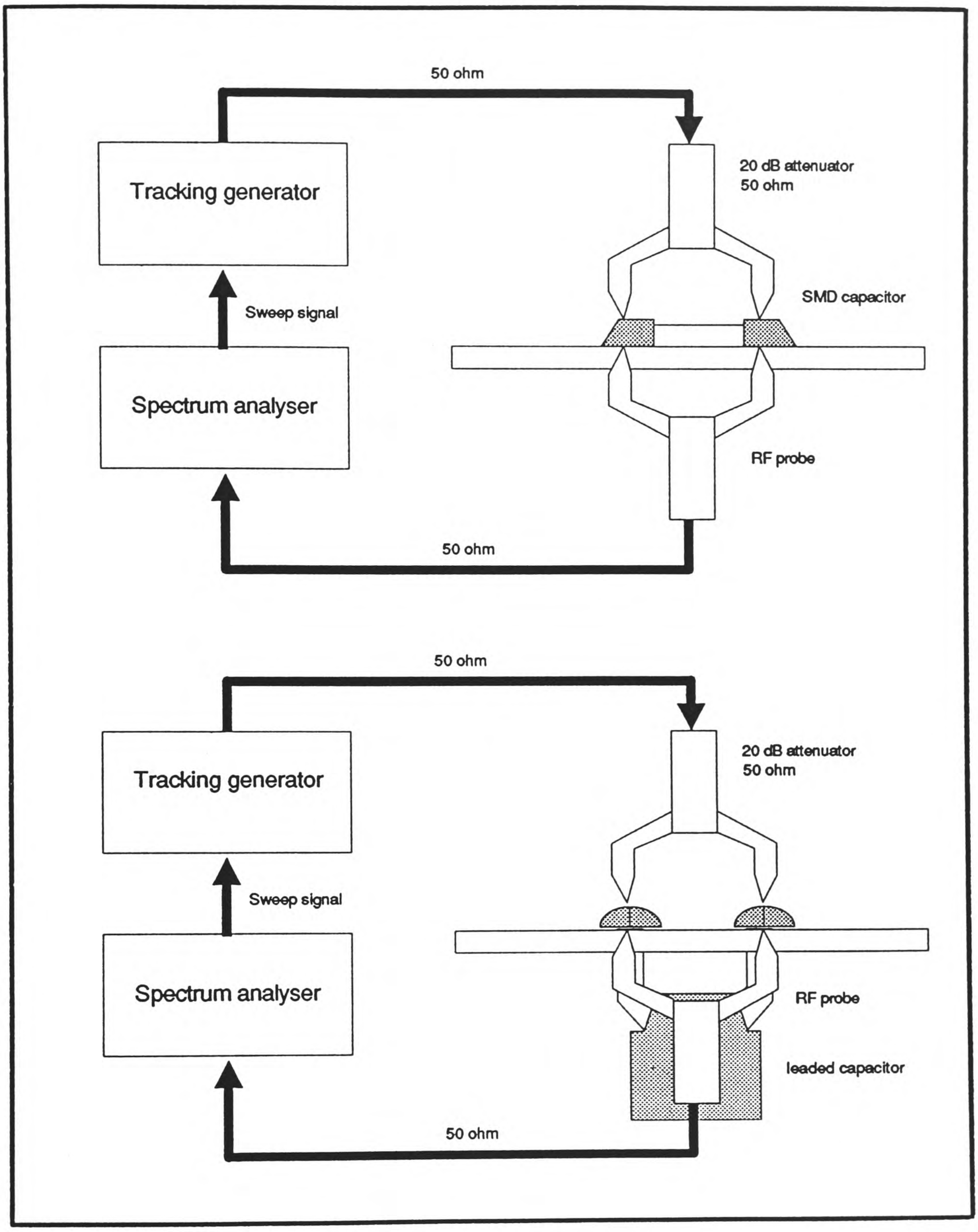
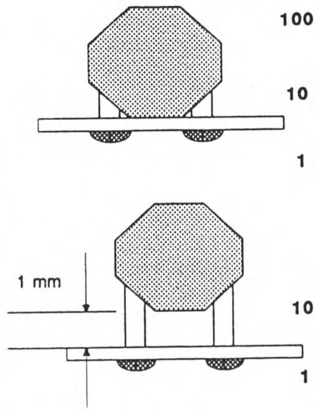


Figure 3-12 Capacitor self resonant frequency measurement configuration



	Leaded capacitor				Surface mount capacitor			
	Measured Self resonant frequency	Q of device at resonance	Calculated inductance and ESR		Measured Self resonant frequency	Q of device at resonance	Calculated inductance and ESR	
	MHz	Q	nH	ohms	MHz	Q	nH	ohms
100 nF	6.2	4.2	6.6	0.06	13.5	1.7	1.4	0.07
10 nF	21.4	6.3	5.5	0.11	37	2.6	1.9	0.16
1 nF	78.4	22	4.1	0.09	125	10	1.6	0.13
10 nF	18.2	8	7.6	0.11				
1 nF	62	25	6.4	0.10				

Figure 3-13 Capacitor self resonant frequency measurements

an increase in lead inductance of approximately 2 nH. The values of self resonance measured were typical of the values quoted by component manufacturers and such a curve is compared with the measured values in figure 3-14[57].

From the results it is seen that the SMD has a higher SRF and so can be used in higher frequency circuits. It also offers greater repeatability in a circuit because of the absence of lead insertion tolerance. A third major advantage occurs when the components are used in coupling or decoupling applications. Such a capacitor is chosen to present a minimum impedance at the frequency of interest and this occurs at its self resonant frequency. In order to decouple the 47 MHz transmitter circuit in the cordless telephone a self-resonant 2.2 nF capacitor could be chosen, whereas a 8.2 nF SMD would be self resonant at the same point. Figure 3-14 also shows typical Effective Series Resistance (ESR) values in the frequency range of interest, which tend to be frequency dependent because of dielectric material loss characteristics[57]. The simulated decoupling performance of these two devices are compared in figure 3-15 showing that the SMD offers improved decoupling and, because of its lower Q, gives improved decoupling over a greater frequency range. A badly inserted leaded capacitor will offer a much less effective decoupling path with possibly high Q inductive reactance, capable of degrading circuit stability.

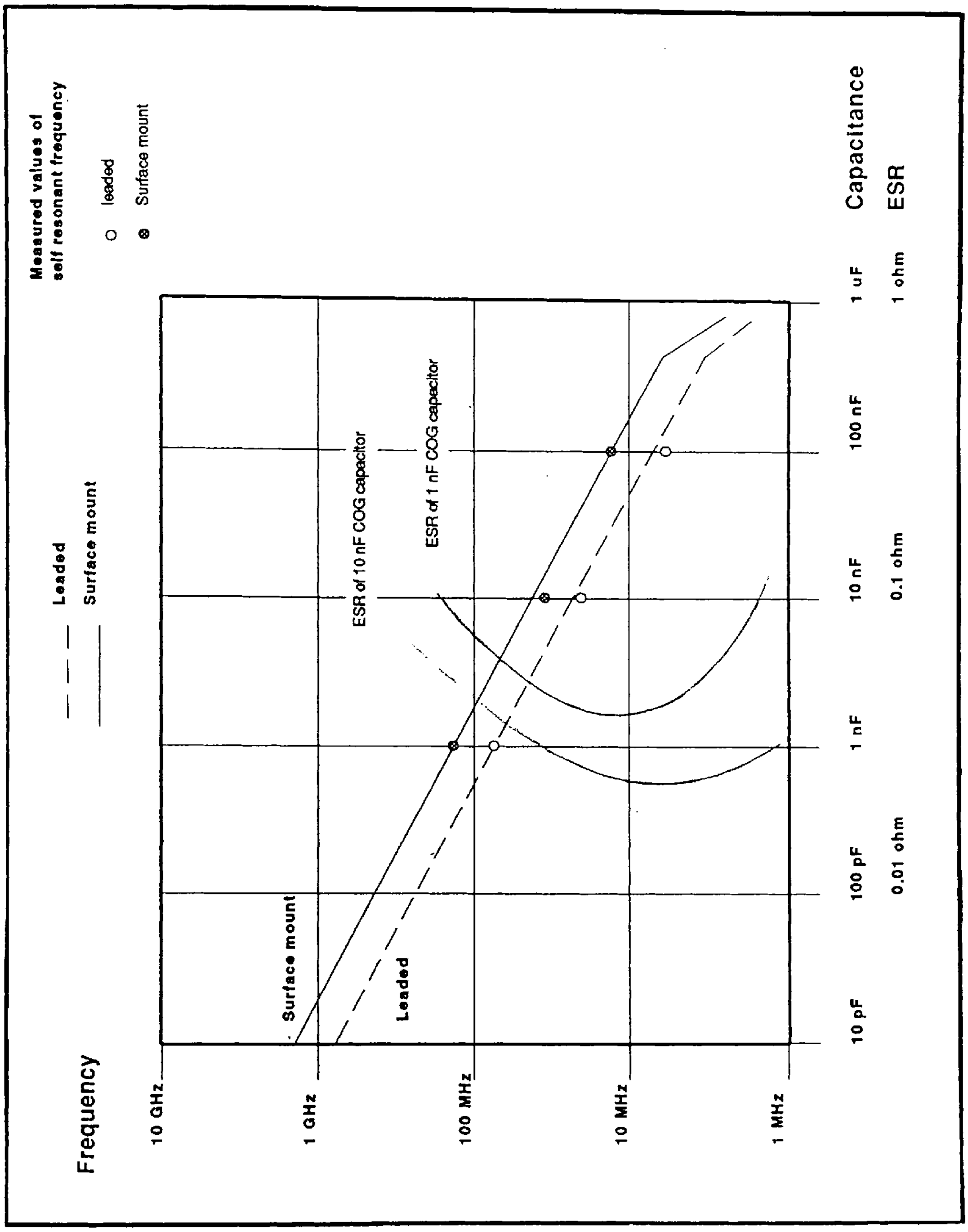


Figure 3-14 Capacitor self resonant frequency measurements compared with typical manufacturers' published data

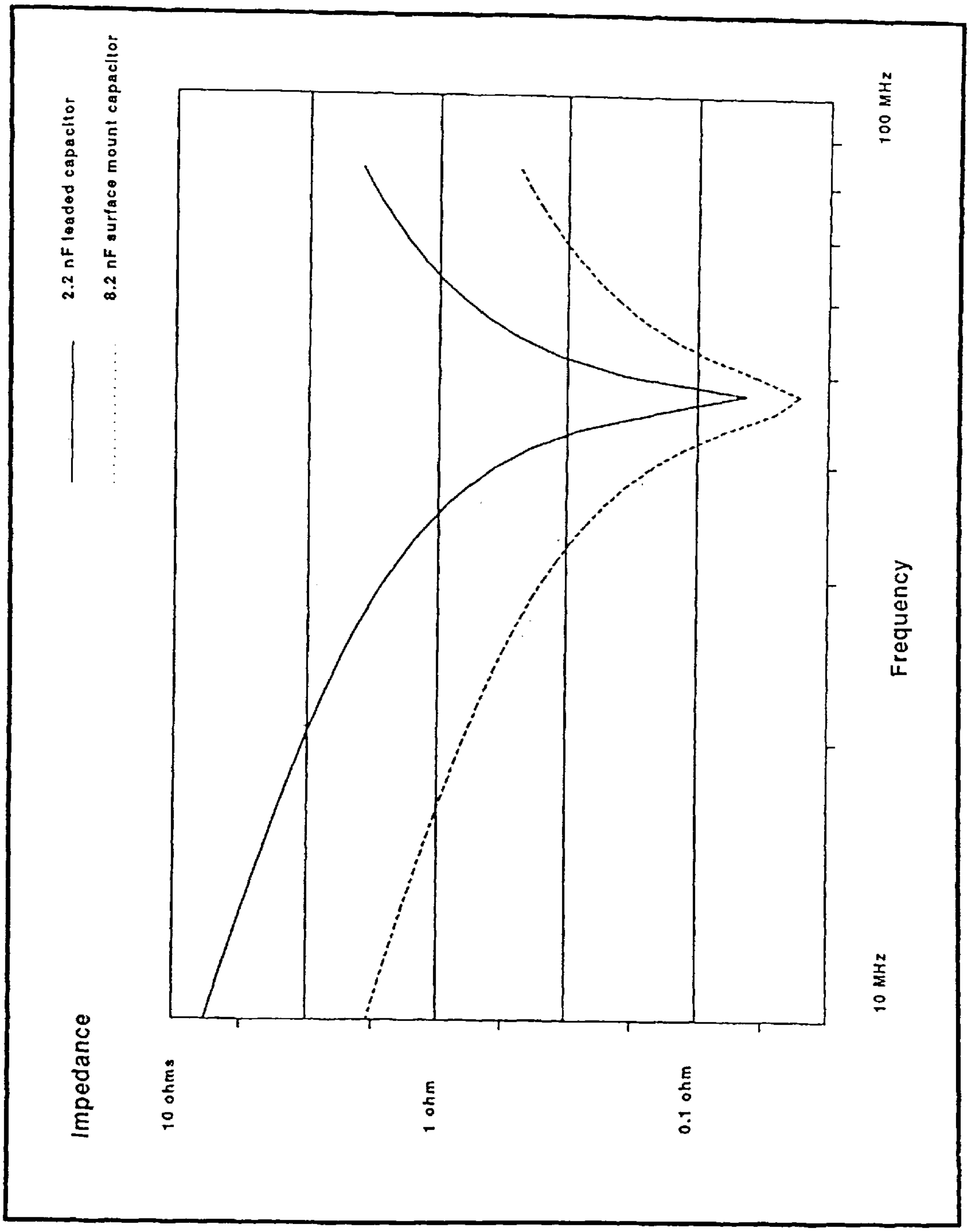


Figure 3-15 Decoupling efficiency comparisons between leaded and surface mount capacitors at 47.5 MHz

Similar tests performed on inductive and resistive components showed good correlation with published data but generally offer little performance advantage due to reduced lead inductance.

Integrated circuit components also have package related characteristics as seen from the following average measurement between the pin characteristics of a 14-pin component[53]:

	SMD package	**Leaded package**
Pin resistance	= 0.74 mΩ	= 16.36 mΩ
Pin inductance	= 1.01 nH	= 7.23 nH
Capacitance between	= 0.13 pF	= 0.4 pF

3-5 Summary

The chapter has introduced the methods by which SMAs are manufactured, tested and repaired. It is clear that the technology influences all aspects of design, development and manufacture to a degree not felt by conventional assembly techniques.

It is essential that no department involved within the SM process operates in isolation and an operating structure with strong communication links forms the basis of successful exploitation of the benefits offered. The inter-relations are considered further in the next chapter when the set of design rules are introduced.

As the measurements documented in this chapter show, ceramic chip capacitors offer a major benefit within medium frequency circuits where their low series inductance can improve decoupling performance and component operating tolerance.

Chapter 4

Surface Mounting Design Guidelines and Justification of the Test Vehicle

4-0 Introduction

The chapter considers the framework of surface mount assembly requirements and discusses the production of a design guideline for their use. The corresponding document is included in appendix C. The design rule set was developed in conjunction with another Teaching Company project (see Preface) where there was also an interest in the production of SMAs.

The choice of the test vehicle, used to further develop them, is justified and the legal approval procedures, used as a measure of design and performance suitability, introduced.

4-1 How May a Design Structure be Implemented to Effectively Utilise Surface Mounted Devices ?

The SM environment is rather more involved than an equivalent leaded one and the inter-relations can be illustrated with a diagram as in figure 4-1. The diagram shows only the major connection paths since all issues are related to some degree, as clear from the discussion in section 3-3. The soldering process, for example, determines the set of PCB design rules, while factory space is influenced by the production equipment and the storage space required by the various component types. The effectiveness of the whole SMT process relies on basic necessary knowledge and training, combined with successful communication between the various process stages.

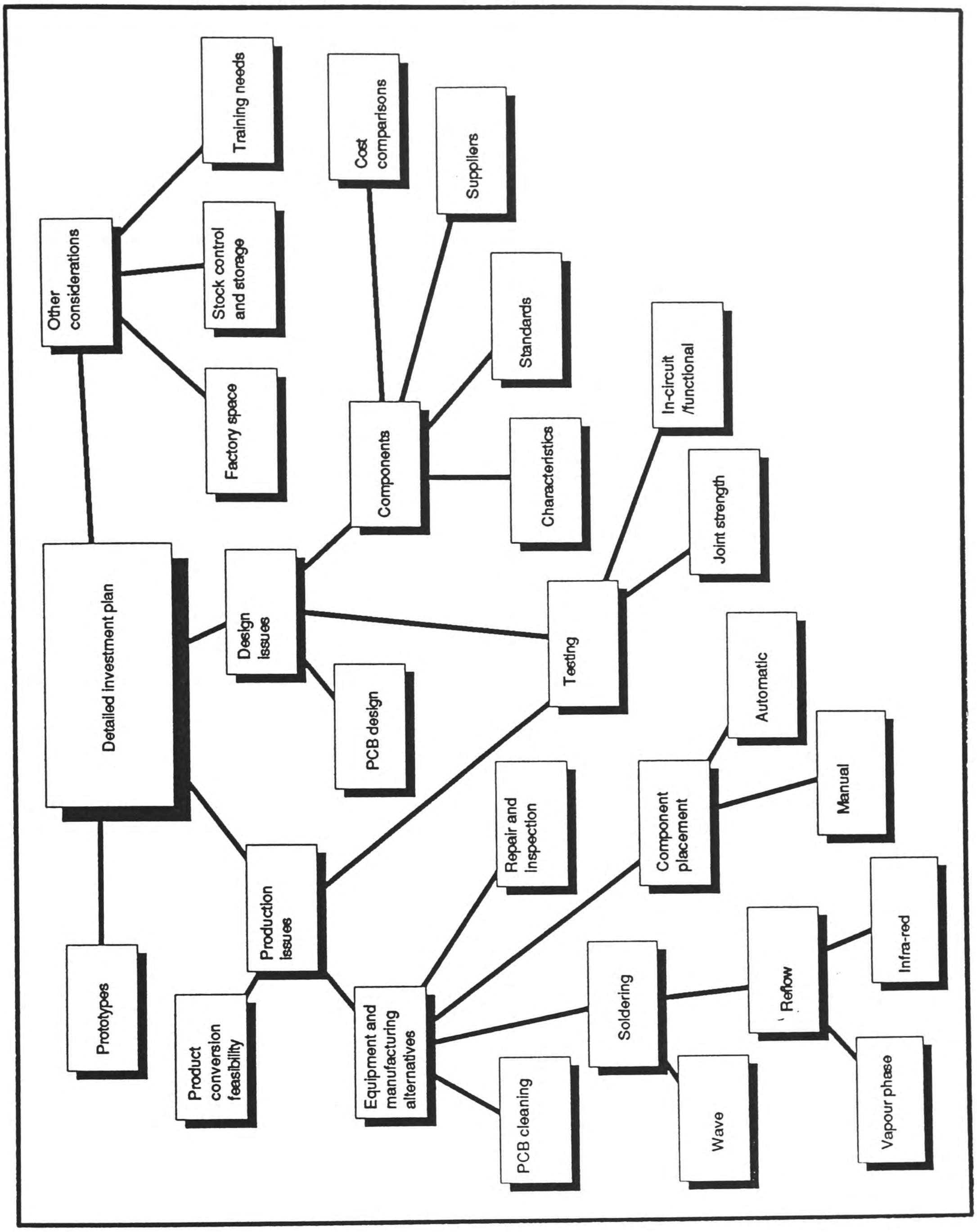


Figure 4-1 Inter-relations within the surface mount environment

There are a number of different techniques possible to assemble circuitry using SMDs and also a variety of possible components to use. The selection of these depends on the criteria of cost, performance, reliability, size, testability and assembly capability. Due to the variability of criteria and capability between users of SMDs and also between products within a company, it was not possible to define an explicit guide to the design of SMAs. Instead a framework suited to the company was necessary.

A set of design rules had to be equipment specific because not all design and production capabilities were available to Autophon. Equipment availability constrains production possibilities, component selection and, in the case of SMDs, influences the design of PCBs. It was thus foreseen that any guideline should be structured to allow the addition of further production capability when it became available, and should also act as an indicator to equipment investment potentials.

A fundamental set of questions was required which could categorise the requirements of a product. They were also necessary to identify unsuitable demands in order that they could be re-considered and brought into line. Such a classification was to allow the selection of design rules in a "pull-down" manner, along with an environment of recommended design procedures.

In order to aid the answering of the questions by the Project Responsible Engineer (PRE), the design guidelines include summaries of all relevant SMD processes. The summaries alone do not include details enabling the answering of all questions: instead it is designed to stimulate discussions with other departments who have the necessary expertise. This encourages communication between these various departments at an early stage of the project.

The questions used to categorise the surface mount solution are as follows:

1. Category of PCB or PCBs to be used.

2. Method of soldering to be employed and any PCB cleaning necessities.

3. Detailed PCB requirements. (Is copper required on both sides of the PCB ? Are plated through holes to be used ? Is an earth plane necessary ? Are ground planes to be used ?)

4. Automatic placement equipment demands.

5. Product testing and rework strategy.

These result in the selection of a specific manufacturing procedure and PCB design rule set. Limitations are thus imposed on the type of components that must be restricted for cleaning or soldering restrictions. The test and rework strategy does not select a set of design rules, but the design guidelines give test recommendations, and it is advisable to establish a test philosophy at an early stage.

Personnel training requirements are not linked to the design rule set but the document highlights the importance of personnel awareness of the requirements of the technology.

The rules are not radio frequency specific because of the general nature of surface mount production, but the guidelines include relevant notes about the performance and use of SMDs in radio frequency applications. The guideline was intended to be dynamic and to be updated when new techniques become available and experiences relevant.

4-2 Project Test Vehicle

The product chosen as a vehicle to test and develop the surface mount design rules was a cordless telephone. Figures 4-2 and 4-3 show the functionality of the circuits included in the handset and the base station respectively. The blocks are those required to construct a basic product conforming to the requirements of the CT-1.5 regulations.

Autophon had designed a cordless telephone to the operational requirements in a conventionally styled package named the **Solo**[55, 56]. This product obtained approval in September 1987 and began production early in 1988. It was produced with leaded circuitry in all audio and RF sections, although used a surface mounted microprocessor on a small sub-contracted handset circuit board. This product thus functioned as a reference for comparison of circuitry and performance.

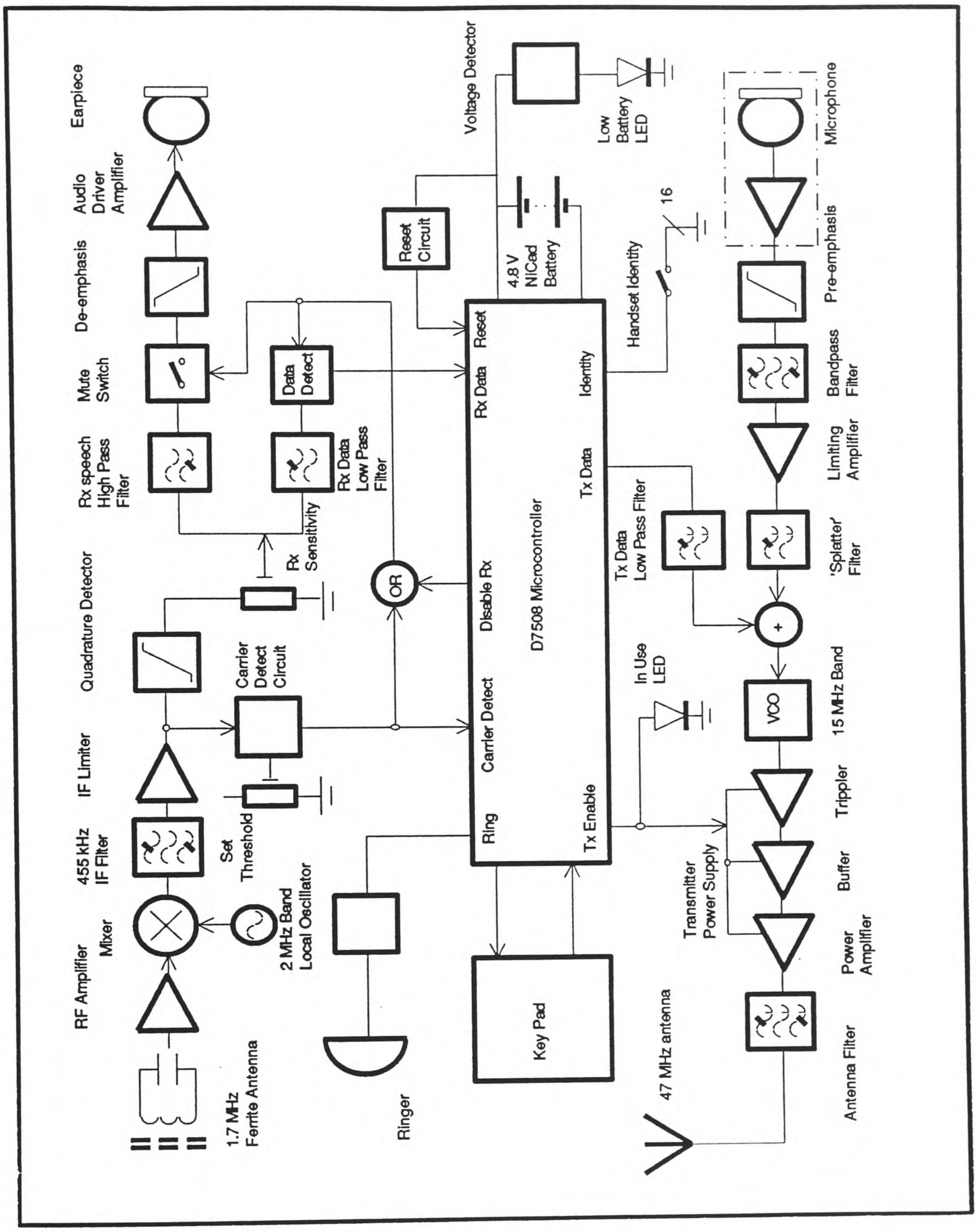


Figure 4-2 Block diagram of the Piccolo handset circuitry

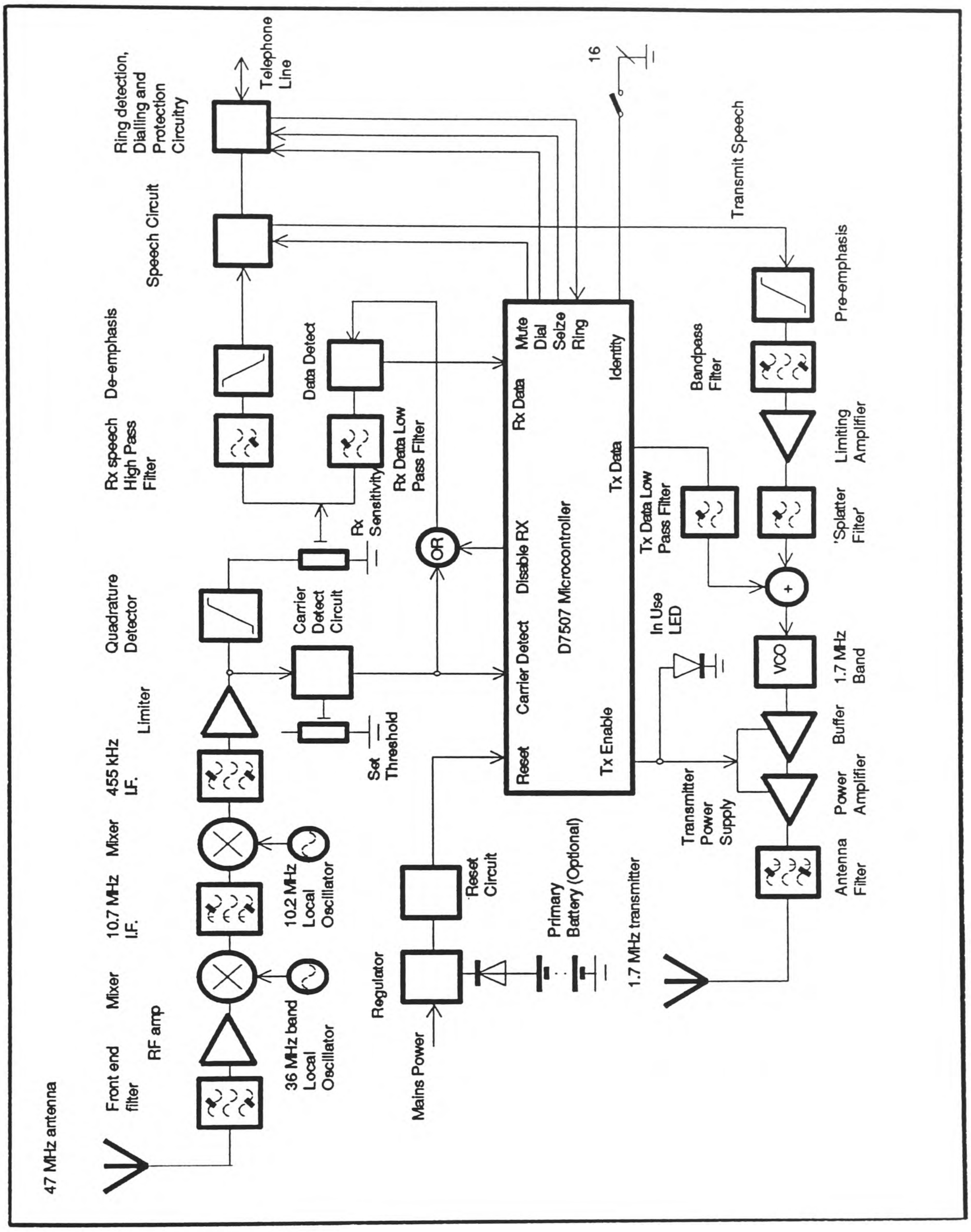


Figure 4-3 Block diagram of the Piccolo base station circuitry

Figure 4-4 Swiss designed cordless telephone handset

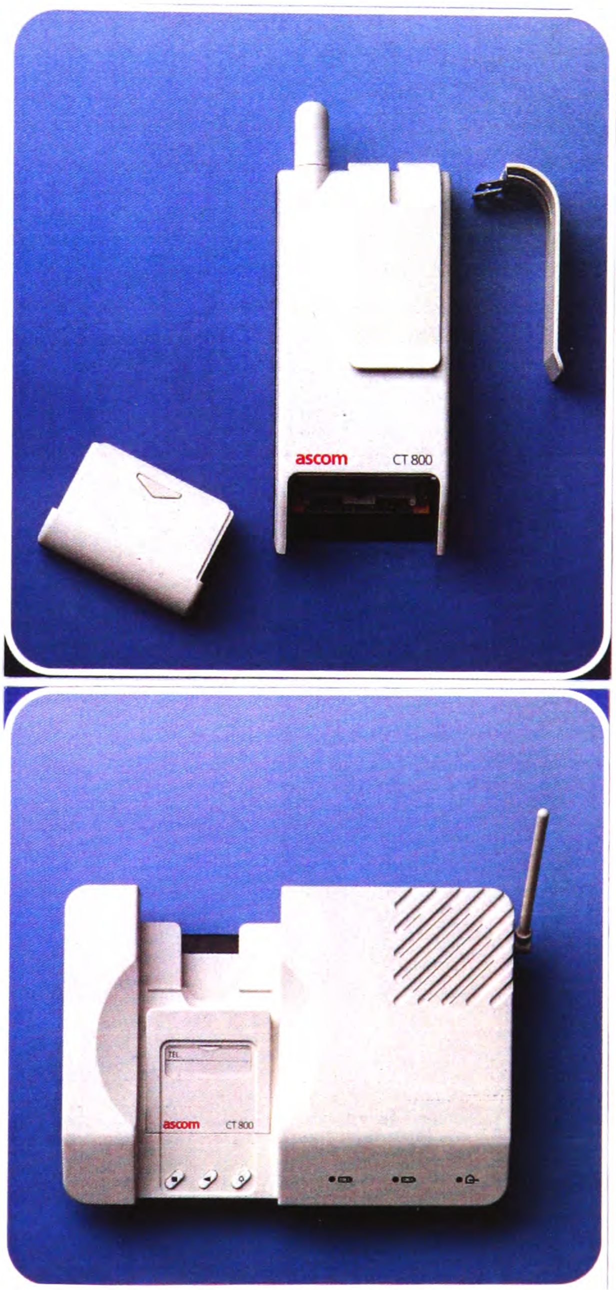


Figure 4-5 View of the back of the Swiss handset with battery pack and the base station

The newer model was to conform to the functional block but was to be designed into the small enclosure of a Swiss designed moulding. The mouldings of the enclosure used for a German UHF cordless telephone are illustrated in figures 4-4 and 4-5. The existing case was chosen because of the savings in design time and tooling costs over the development of a new set of plastics. The combined design and tooling costs typically total between 100,000 and 150,000 pounds sterling. The **Piccolo**[55] telephone, as the UK version was named, used a keypad version without the LCD display seen in figure 4-4.

The CT-1.5 specification demands higher audio performance compared to preceding regulations, along with greater communication security. In order to achieve the security the telephone uses a low frequency data link, below the speech frequency spectrum, which is used for dialling and for regular confirmation of the correct handset/base station pair. A microprocessor is used to control the low band data link, transmitter activation and the interpretation of keypad sequences. Details of the telephone functionality is included in the **Piccolo Users' Guide** attached in appendix B.

The cordless telephone was chosen as the test vehicle because it required the adoption of SM techniques to be feasible within the new enclosure. It required the development of RF circuitry and was a real product to be designed within typical commercial products constraints of price, manufacturability and testability. The success of the product was to be gauged against the approval requirements and the leaded component based **Solo** telephone.

4-3 Approvals and Safety Critical Components

Equipment utilising radio spectrum must be approved before they can legally be sold and operated. Such equipment type approval, or homologation, is necessary to prove operation with minimum interference to other users of the radio spectrum. The approvals to radio operating compliance represented a major necessary project undertaking and its success was to prove the performance of the Piccolo product. The process was also to be of benefit to Autophon through the practical experience it offered of the approvals process. Radio performance type approval is not normally necessary for telephone equipment but will always be necessary for cordless telephones. Beyond 1992, EMC regulations will effect all equipment containing electronic devices and the experience in similar measuring techniques and approvals procedures will become of increased value.

In addition, the Piccolo had to undergo the standard telephone approvals procedure which comprehensively analysed the telephone's performance, its safety compatibility, packing, documentation, instructions and labelling. These approvals requirements are covered in BS6305, BS6317, BS6301, BS415 and, where appropriate, valid points are noted in chapter five.

Safety critical components are those used to isolate potentially damaging voltages from the telephone line. Such voltages may be mains supply potentials or derived by touching exposed conductors against external sources. The **Piccolo** isolation technique is illustrated in figure 4-6, showing the safety critical components which are approved for the function under BS 415. The transformer uses a double secondary winding which maintains isolation from the circuitry in contact with the handset when it is charging. This removes any isolation demands from the handset circuitry itself, performs mains isolation and fails safe under short circuit conditions due to an in-built thermal fuse.

The base station circuitry is connected directly to the telephone network and as such was considered as a part of it and had to be electrically isolated. The plastic case performed the task except for where a connection could be made via the antennae. This isolation was achieved with series capacitors rated to 1000 V ac and approved for the purpose. No equivalent capacitors were found in surface mounting form, probably due to the component lead spacing and construction requirements to provide adequate isolation to high voltages. There was no objection to the use of SMDs within any of the requirements as long as basic safety standards were maintained.

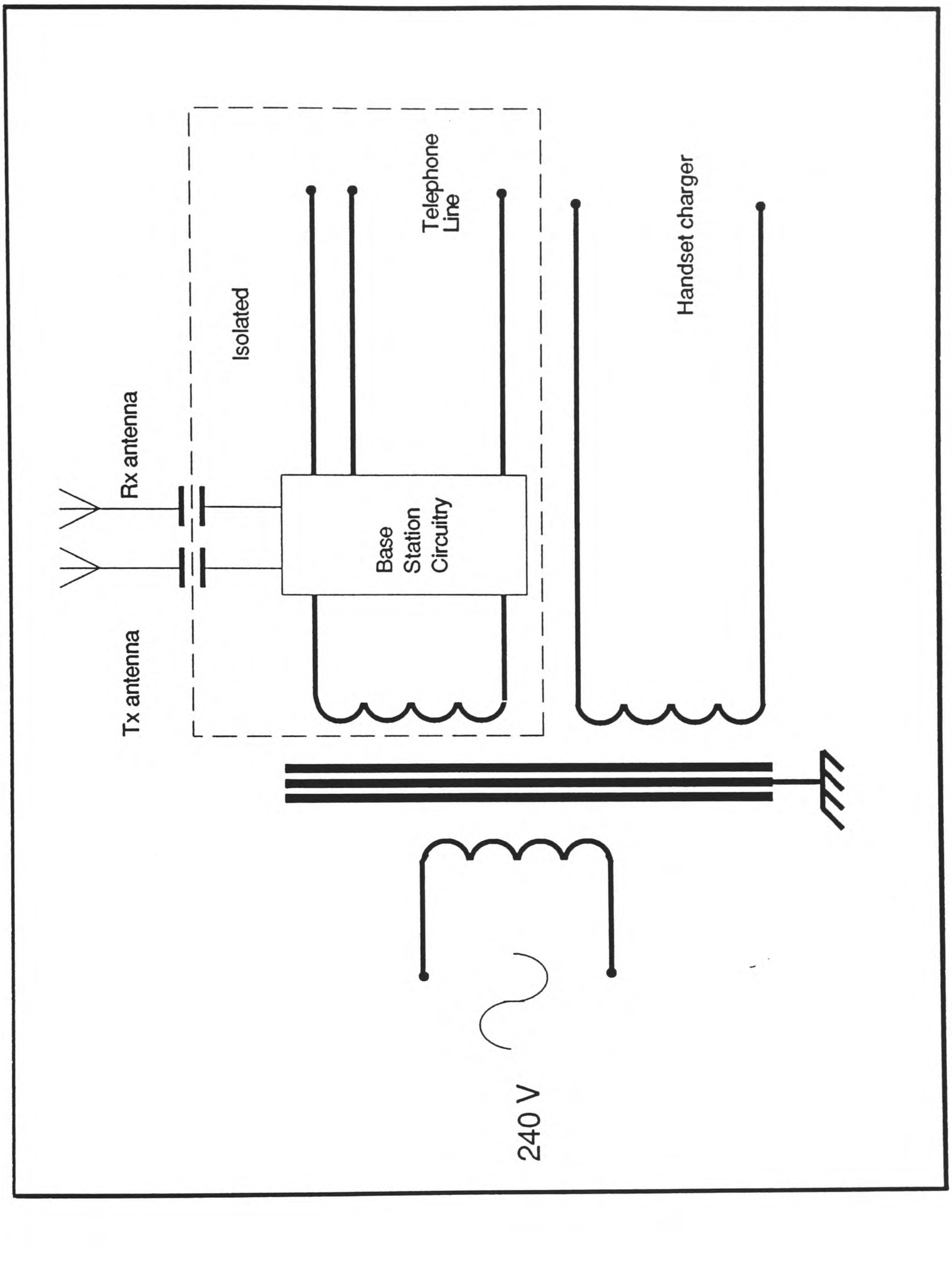


Figure 4-6 Isolation of the telephone line from external and mains voltage sources

4-4 Design Rule Application

Using the guide to designing with surface mounted devices, as included in appendix C, the fundamental project framework was defined. This required the answering of fundamental questions concerning the use of materials and SM facilities as following:

1. *PCB category.*

Mixed technology, using only one side of the circuit board, was seen as the most practical solution and most cost effective in the case of the test vehicle. This was so because a variety of components were not available in SM form, were several times more expensive, or had limited availability. This category was also chosen because of the soldering technique as discussed next.

2. *Method of soldering.*

The only automated technique available for soldering SMDs at the Autophon site was wave soldering. This suited the requirements of the SMD category and did not require investment and training in new practices. No cleaning requirements were defined, on advice of the Production Department who planned to use low activity fluxes during soldering, and so component selection did not have to include this feature.

3. *PCB material specifications.*

Cost comparisons identified paper based substrates (FR2) to be the cheapest solution (approximately 50% of the basic per unit cost of a fibre-glass base (FR4)). They were also practical in the product because there were no requirements for the increased strength, heat resistance or stability of fibre based types. Plated-through holes were to be avoided if possible to allow the material to be utilised. It would have been viable to include a ground plane on the second side of the board, but this was also to be avoided if possible to achieve minimum substrate weight and expense.

4. *Automatic placement*

At the outset of the project there was no high volume method of SMD placement available at the site. It was obvious that investment in such equipment was a necessity if this and future products containing high percentages of SMDs were to be produced internally. An onserter, suited to predicted demands was thus a high priority for capital investment. For the cordless telephone product it was assumed that an onserter would be available and leaded inserters, as detailed in the guidelines, could also be used.

5. *Product testing and rework strategy*

The company telephone manufacture strategy demanded confirmation of every testable component at the in-circuit level and then a functional test on the completed product. Cordless telephones also require a set-up stage before the functional test to tune radio circuitry. If possible, this strategy was to be adhered to but it was clear that with the high density of components and tracks on only one side of a PCB it may not have been possible to include the dedicated test pads required for SMDs. This suggested that a judicial selection of SMDs and leaded components was to provide the best compromise in order to make leaded component probe points available.

Due to the type of components to be used in the circuit of the **Piccolo** cordless telephone, no specific rework strategy was necessary. The removal of chip devices and small active components can be performed very simply with a hot air soldering iron. The removal of a faulty 52 pin microprocessor flat-pack would most easily be accomplished by cutting through its leads in preference to de-soldering.

The requirement for more than one PCB within the product in order to achieve the necessary PCB surface area resulted in the identification of an assembly topology to suit the mixed technology approach. Figure 4-7 illustrates the use of two substrates connected by conventional leaded connectors, which are used to set the distance between the two boards. The result was high packing density with good, robust connectivity. The PCB layout guide included in appendix C is suited to a product assembly of this type.

4-5 Summary

The initial set of design rules has been introduced with a discussion of a frame-work encompassing the control and selection of components and techniques.

The **Piccolo** cordless telephone is a real consumer orientated product requiring appropriate design and manufacturing constraints. This, and the circuitry necessary to achieve its function and subsequent approval, made it ideally suited to the study of RF circuit design with SMDs. Surface mounting was necessary because of the product's size constraints and the wave soldering of single sided, mixed technology PCBs had been identified as the basis for the assembly design.

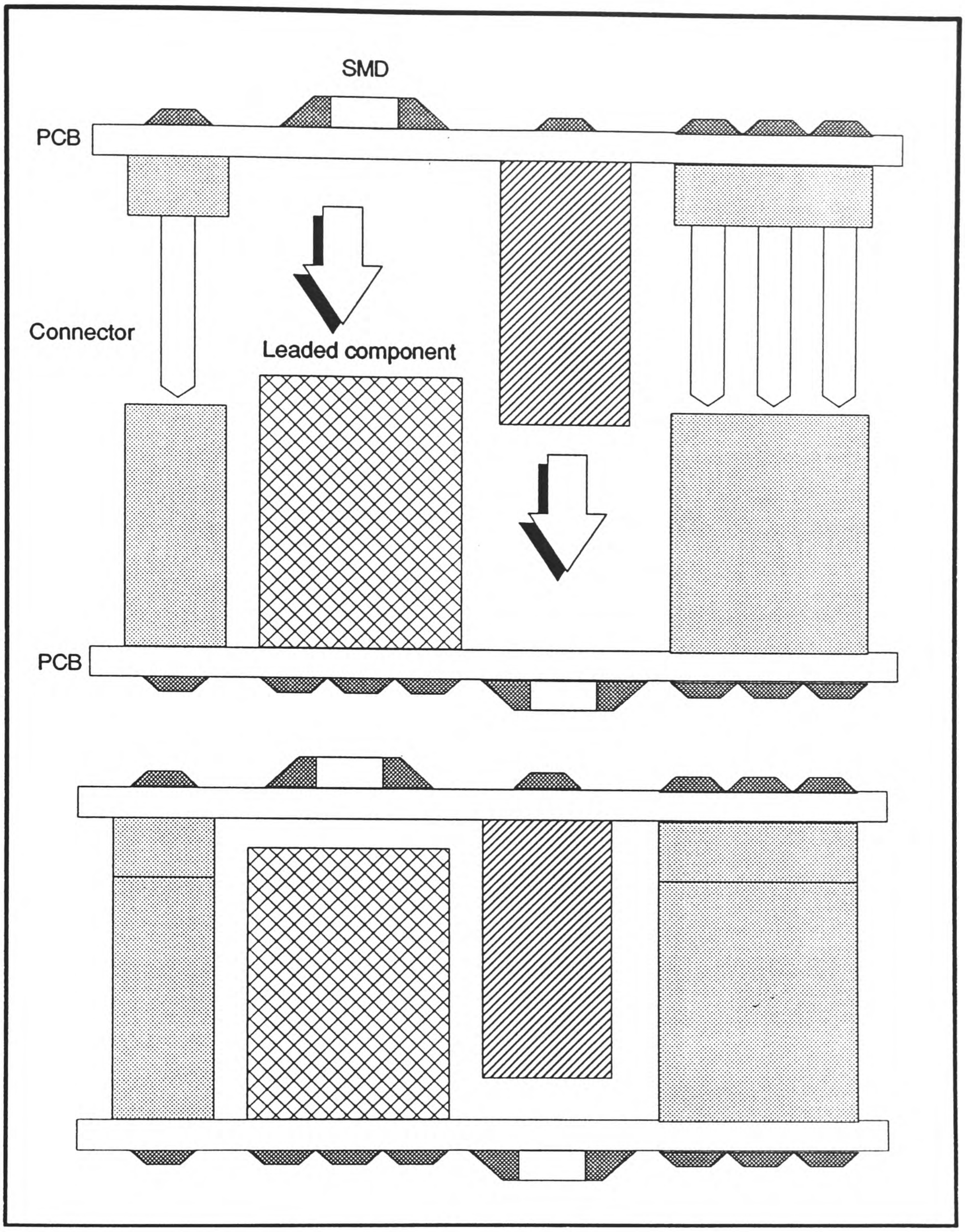


Figure 4-7 The topological assembly concept used to achieve high assembly density with mixed technology boards

Chapter 5

Test Vehicle Development Study

5-0 Introduction

In order to test and further advance the SMD design rules, the cordless telephone as introduced in the previous chapter was developed. The aim of the exercise was to end with an approved product which was commercially viable and which would be manufactured at the company premises with available facilities, including those to be introduced in the course of the program. Deficiencies in the initial set of design rules were to be identified and the guide to be updated through the practical experience obtained.

5-1 1.7 MHz Handset Receiver

The receiver circuit used within the Piccolo handset is reproduced in figure 5-1 and can be compared with that in the Solo in figure 5-2. It shows a ferrite loop-stick antenna from suitable grade material utilised for reception of the medium frequency signal. The high Q of the inductance (typically 240 in free-space) allows high frequency selectivity by tuning with a parallel capacitor. The reception signal is amplified to a level suitable for the following receiver integrated circuit, which requires 6 Vrms for effective limiting. Together with an amplifier collector load Q of 20, the front-end bandwidth is 15 kHz and tuning is simple due to negligible interaction between the two circuits.

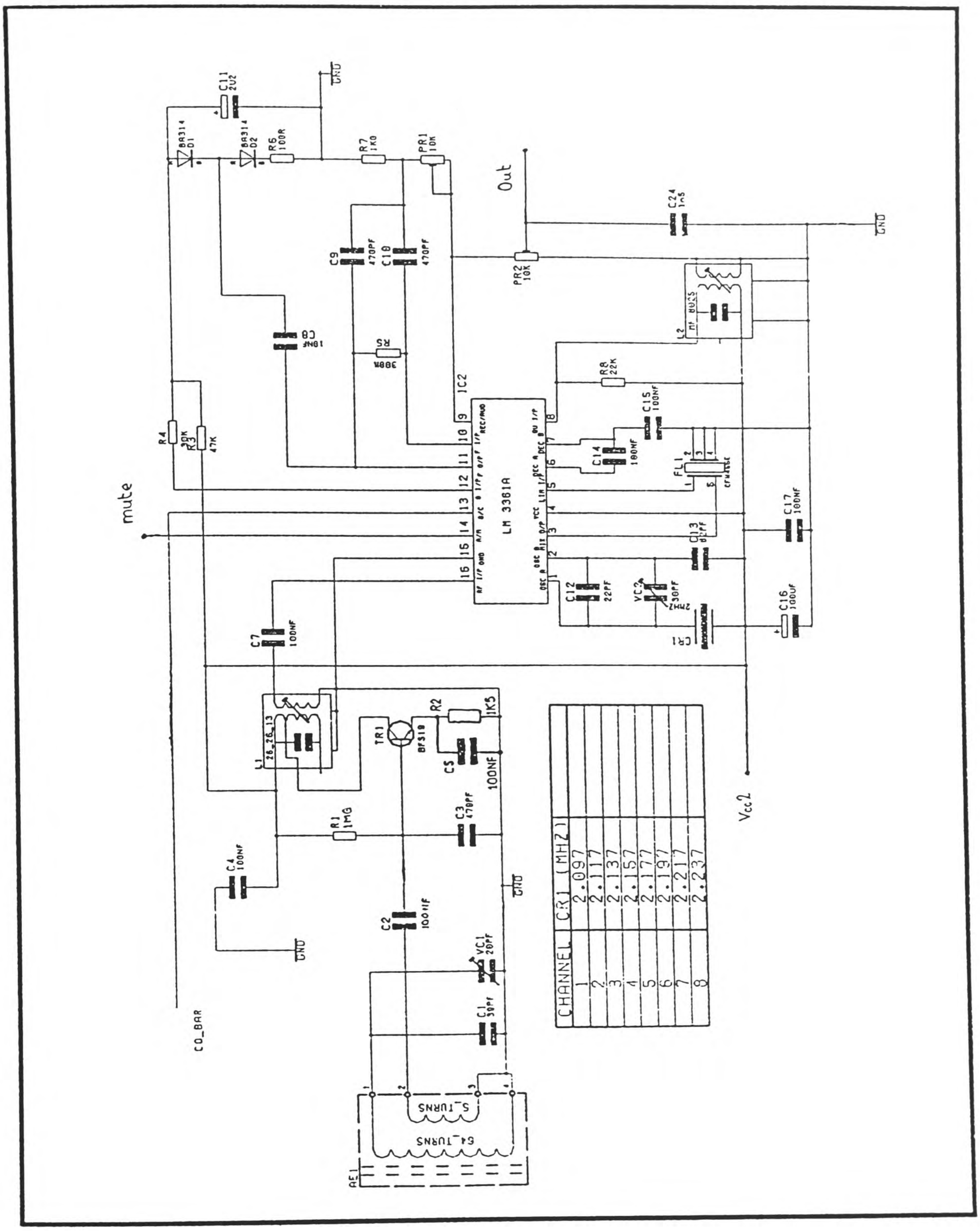


Figure 5-1 1.7 MHz handset receiver used in the Piccolo

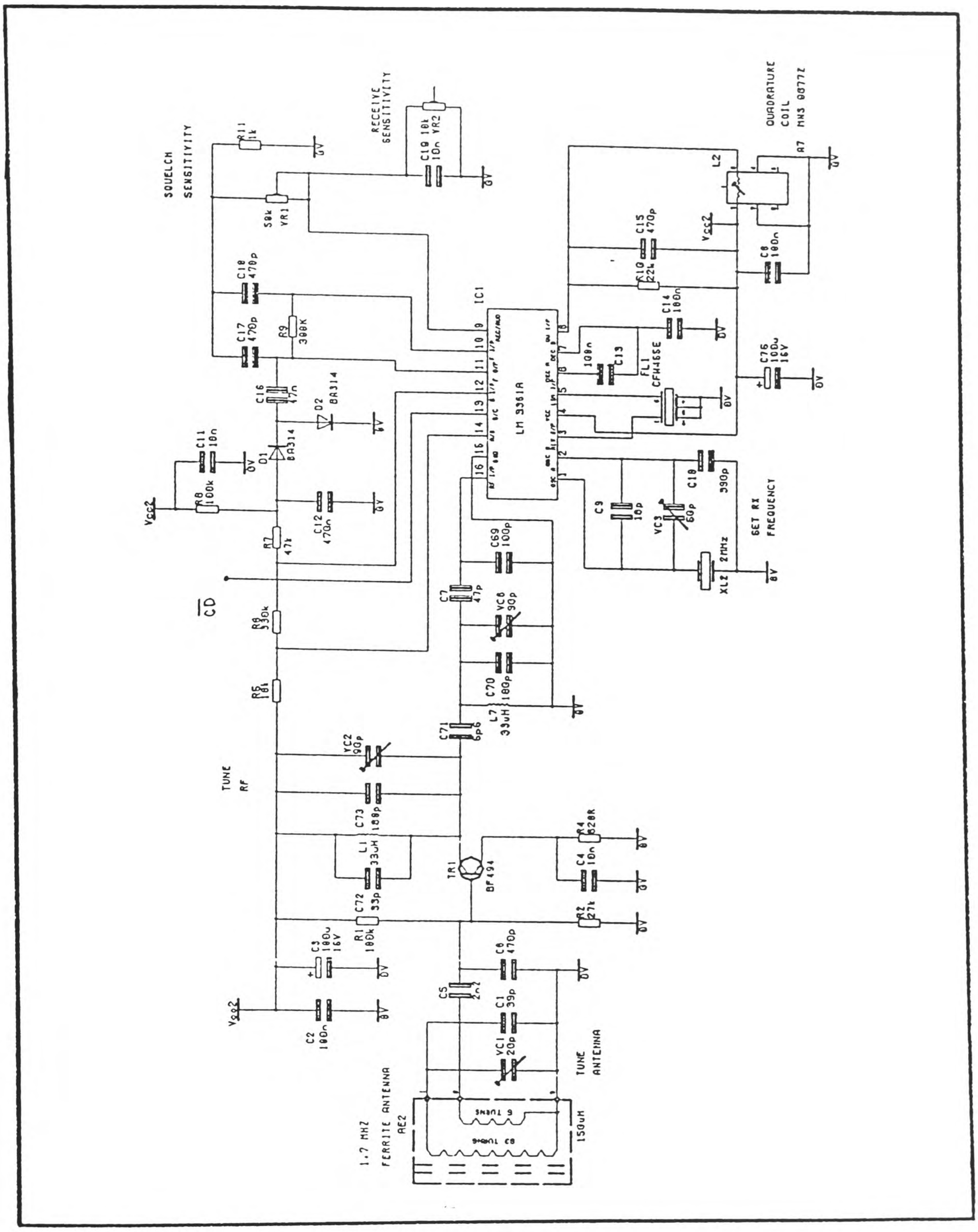


Figure 5-2 1.7 MHz handset receiver used in the Solo

The LM3361A contains the double-balanced mixer, limiter and quadrature detector necessary for demoduation as well as extra functions, configured for squelch detection and output muting (See appendix D). The operating channel is selected at manufacture by the local oscillator ceramic resonator frequency, tunable with a trimmer capacitor to account for component tolerances.

5-1-1 Circuit Topology

Figure 5-3 shows the handset receiver circuit board. The circuit was laid out in conjunction with the handset transmitter circuit board and the positioning of the larger devices were restricted very much to the locations seen. There were three major sources of receiver desensitisation which were resolved with the solution shown.

The microprocessor circuit included on the transmitter board (see figure 5-11) generated interference due to its key-pad matrix scan operation. The rise time of the drive scan signals was controlled by series resistances so that negligible interfering frequency components were present at the keypad. The internal operation of the processor itself did not effect reception due to its small physical size.

The ferrite antenna was positioned at the extreme of the board to distance itself from metallic components such as crystals and screened transformers which, if in close proximity, has a damping and de-tuning effect. To the side of the receiver circuit board was the transmitter telescopic

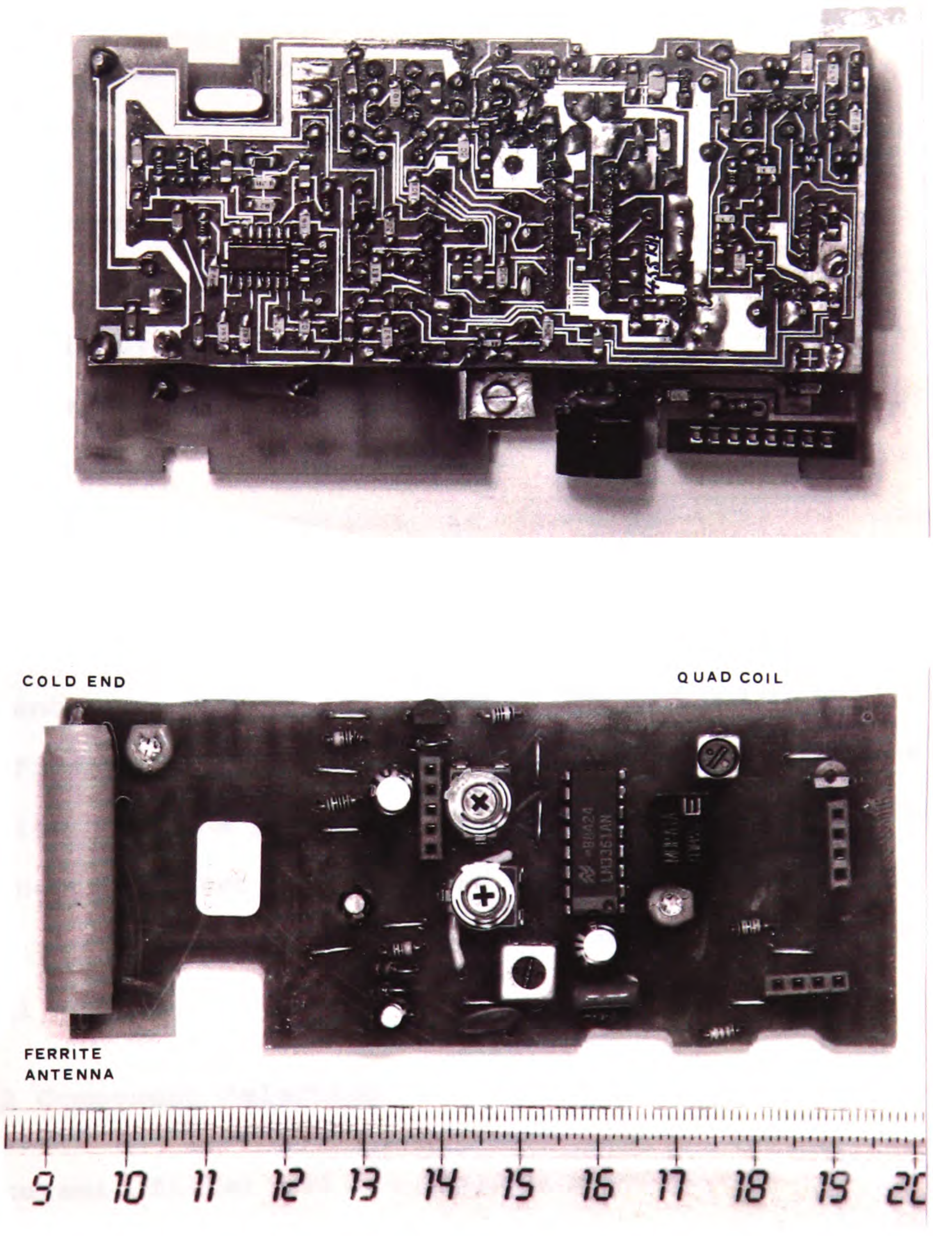


Figure 5-3 Piccolo handset receiver circuit board

antenna, which could not be distanced, but its proximity effect was minimised by positioning the ferrite's earthed (cold) end next to it.

It was also necessary to distance the ferrite antenna from the receiver integrated circuit due to the operation of the limiting amplifier. The de-sensitisation was originally noticeable by the SINAD curve as reproduced in figure 5-4. As the receive signal amplitude decreases there is an un-expected fall in the reception SINAD due to feedback of third harmonic components in the 455 kHz intermediate frequency bandwidth when the two are in close proximity. The deterioration is due to the third harmonic of intermediate frequency noise components around 565 kHz which only become significant as the wanted signal strength reduces. In addition to the physical separation, undesired frequency components present at the audio output were shunted by C24 so that they did not conduct around the board with the recovered signal.

5-1-2 Component Selection

The ceramic filter and the ferrite antenna were not supplied in SM form at the time of the study. All other components could have been surface mounted but several were not due to layout, cost and supply acquisition reasons. It was noted that high SMDs were not compatible with the assembly and generally caused an increase in circuit thickness in mixed technology circuits as illustrated in figure 5-5.

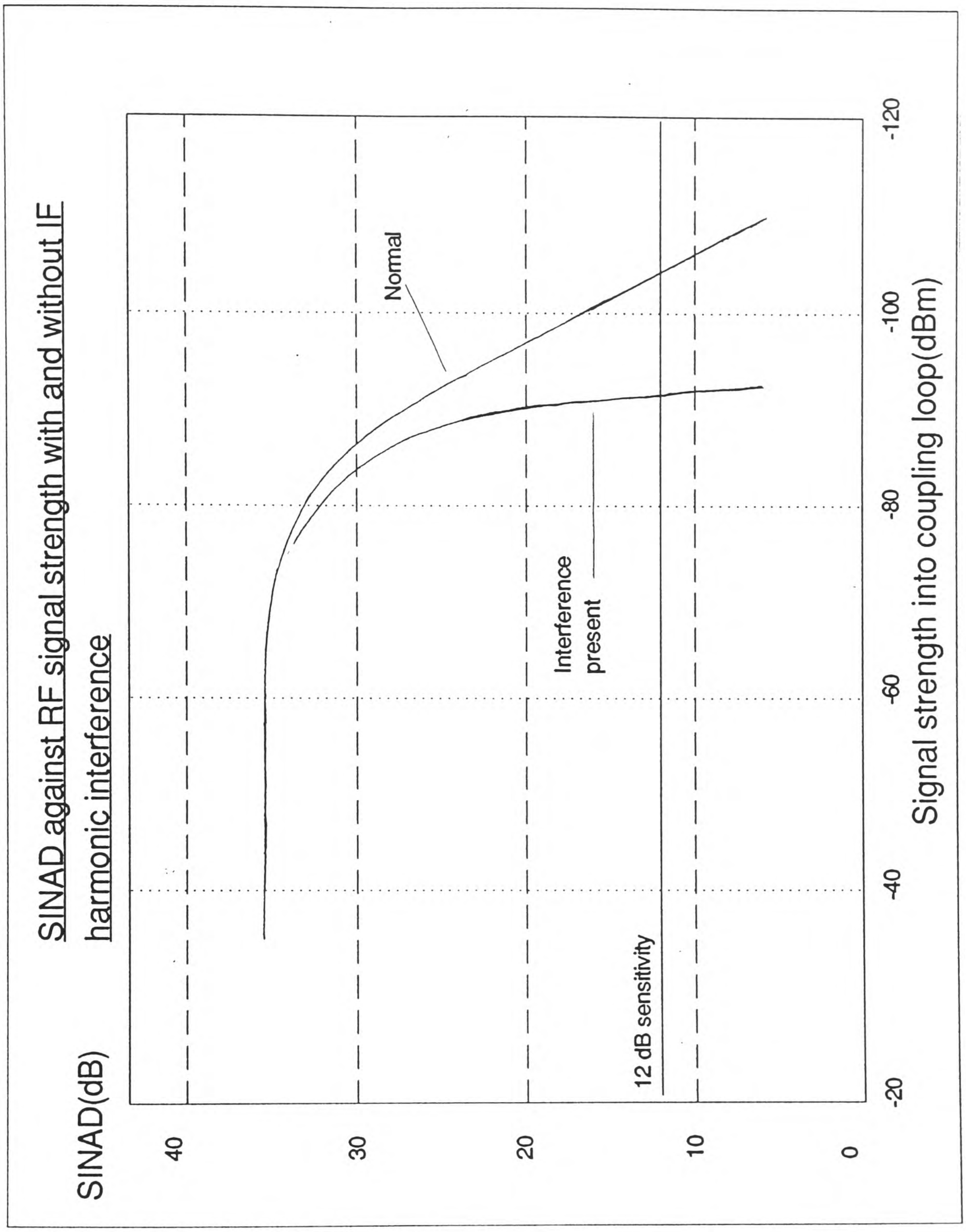


Figure 5-4 The effect of intermediate frequency harmonic interference on receiver SINAD

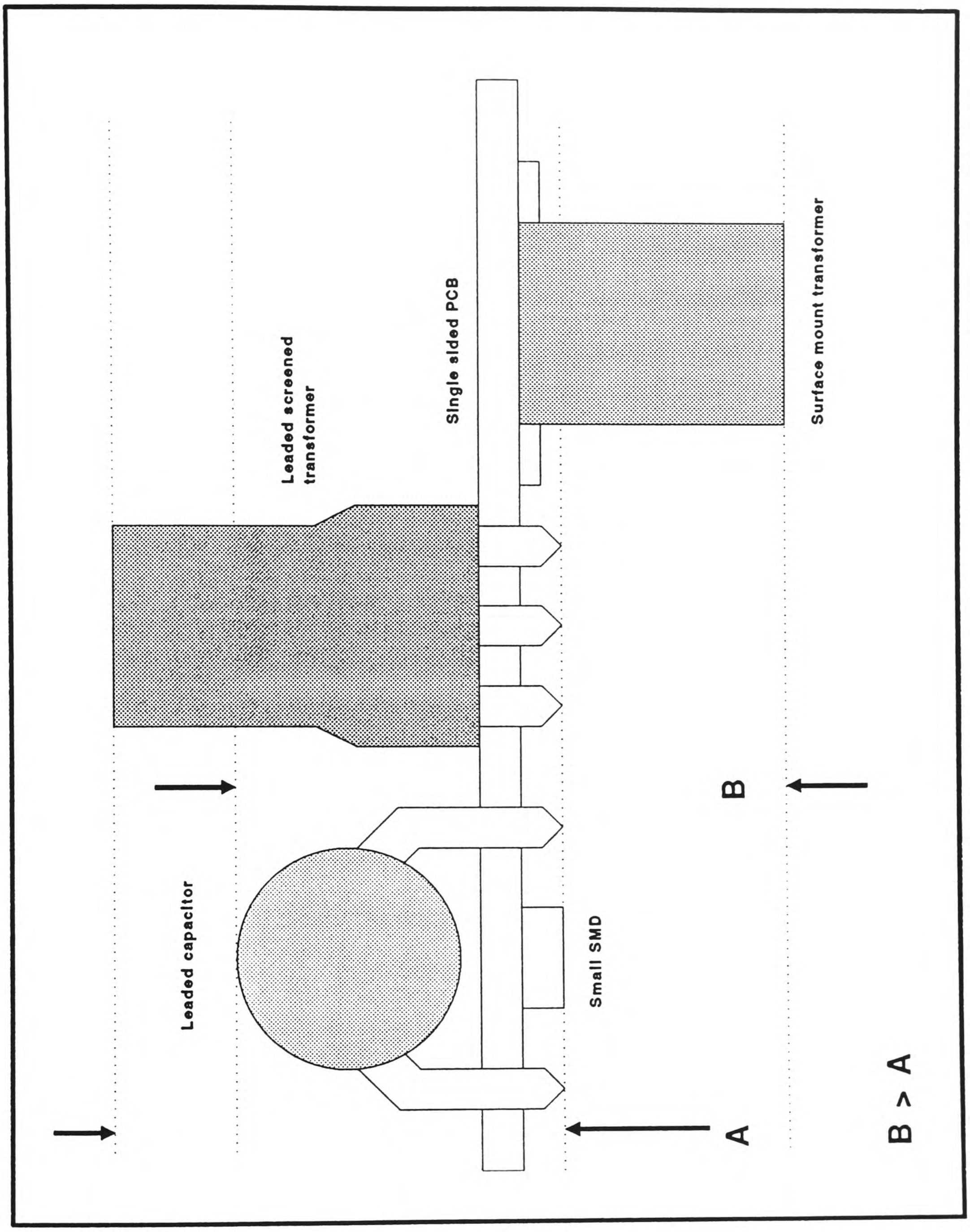


Figure 5-5 Illustration of how high SMDs used within mixed technology assemblies can add to circuit thickness

The receiver integrated circuit was readily available in SO-IC outline but layout with this component proved difficult. The difference resulted from the fact that the pin out of an integrated circuit is mirrored when mounted on the opposite side of a substrate. In this circumstance, the layout with the leaded part greatly simplified and minimised the length of connections to other circuit components. Having the choice between SM and leaded integrated circuits thus adds layout flexibility in such situations.

Two components used frequently within RF circuits are trimmer capacitors and tunable, screened inductors. A discussion of these two components follows in more detail due to their functional importance and their effect on the design philosophy.

Trimmer Capacitors

The trimmer capacitor is used to adjust a circuit at manufacture as in the case of VC1, figure 5-1, which tunes the ferrite circuit resonant frequency to the channel centre frequency. A typical surface mounted trimmer capacitor is illustrated in figure 5-6 next to a leaded type and shows a silicon membrane over the adjustor to allow vacuum pick up and to protect during wave soldering. The membrane is easily penetrated with a tuning instrument at adjustment and both component types are available in above or through board tuning versions. The SM version was much more expensive, £ 0.30 against £ 0.07 in quantity at the time of the study, and was not economical in the particular application. The device

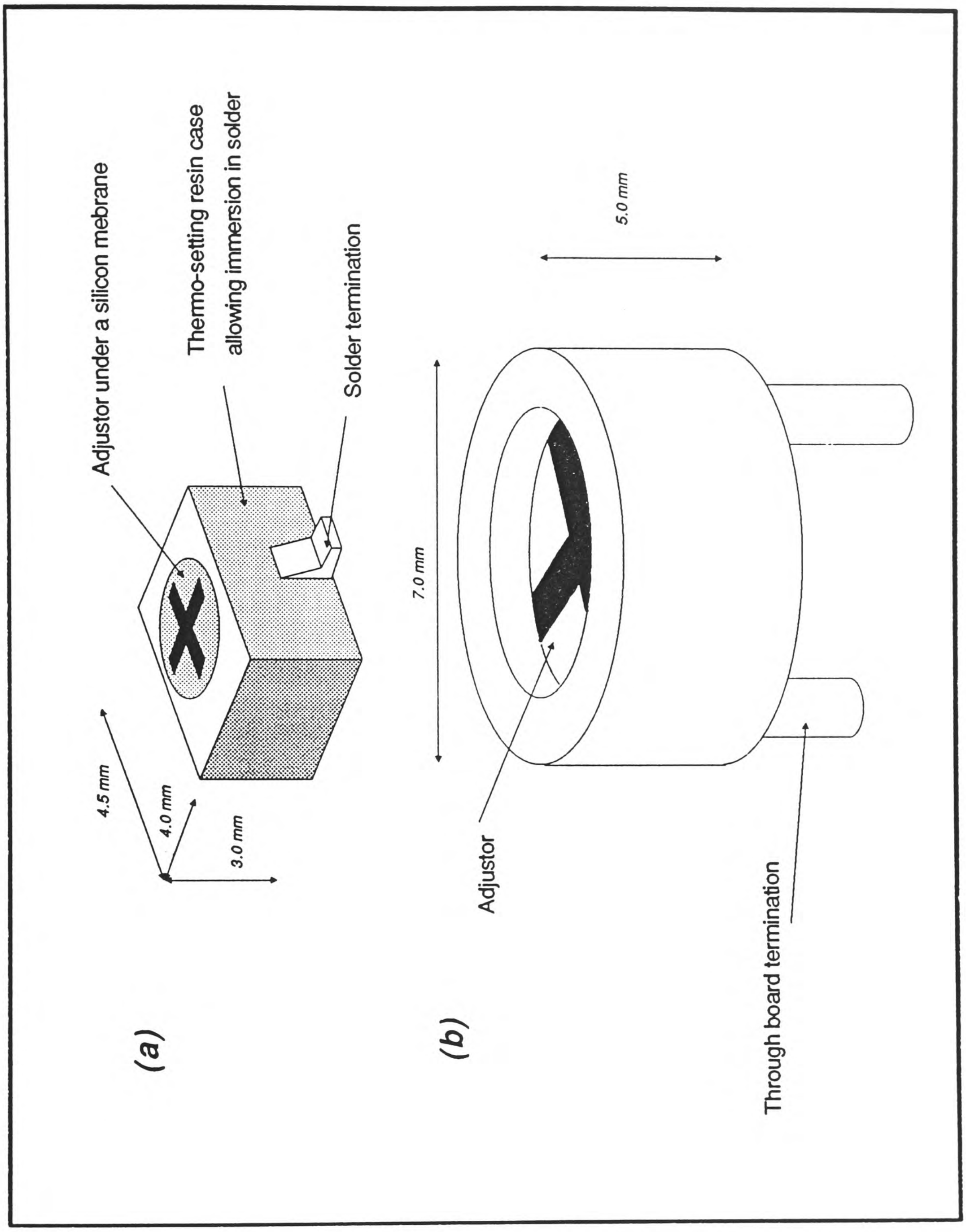


Figure 5-6 Comparison between typical surface mount and leaded trimmer capacitors

would only have brought an advantage through its ability to be automatically onserted but, due to the number of device placements that could not be automated in the particular product, this was considered as negligible. Practically it was found that tuning the SM trimmer device was more difficult due to a less robust construction: the capacitance would reduce slightly when the adjustor was removed due to flexing of the adjustment mechanism. This could necessitate several tuning attempts before establishing the desired setting.

Variable Inductors

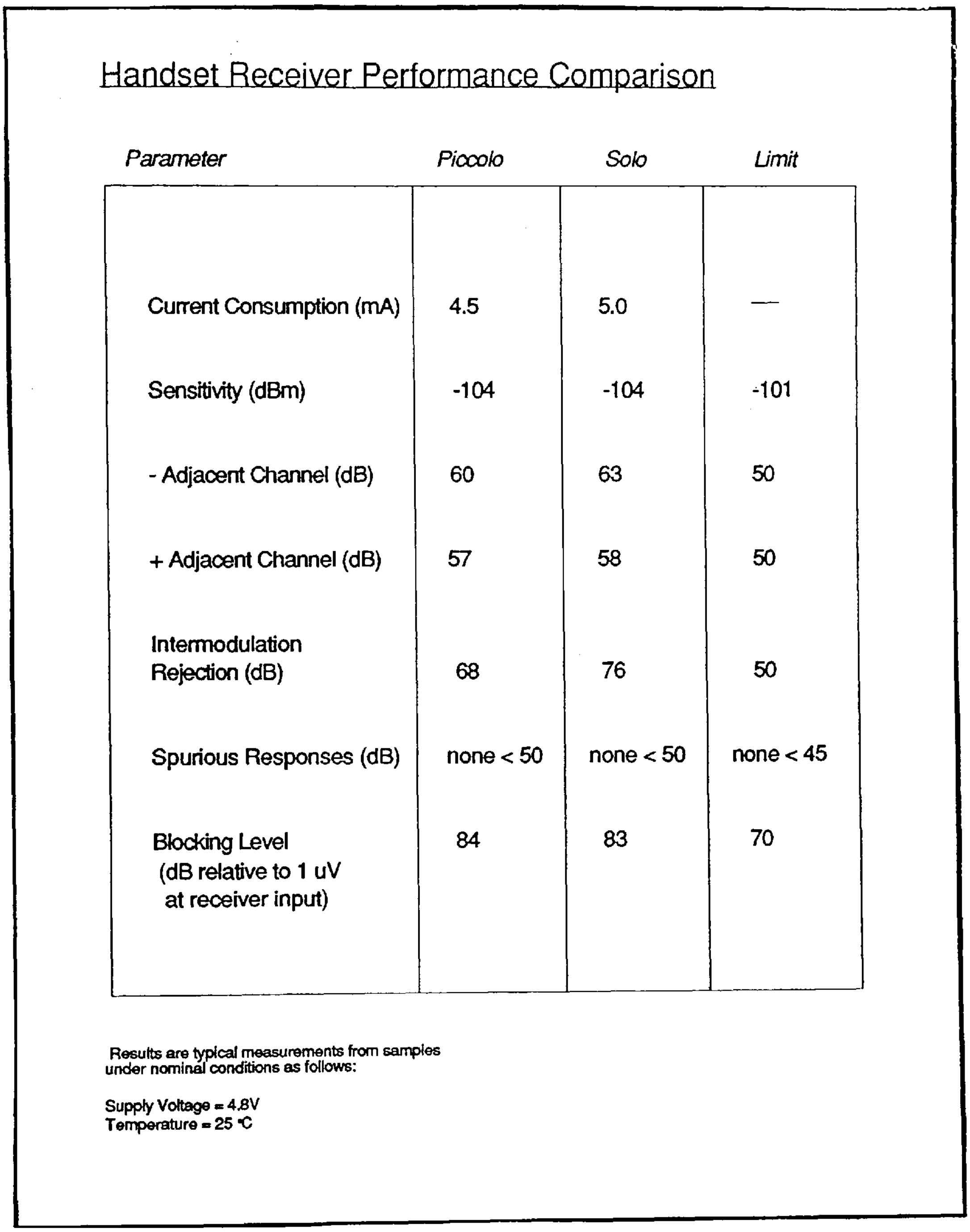
Using trimmer capacitors, it was possible to design many radio circuits without adjustable inductances. It was also possible to design without using transformers such as that used in the Piccolo RF amplifier collector load (L1). In the majority of circumstances it was, however, found that there was no disadvantage in choosing the screened transformer type solution with its flexibility at performing DC isolation, its impedance transformation capability and its tuning possibility. The cost of a conventional fixed inductor was comparable to that of a typical screened transformer. The actual cost depended on the device size, and smaller devices tended to be more expensive due to manufacturing difficulties. It was thus prudent to select the largest possible in keeping with the space allocation. The larger size also tended to offer an improved performance due to thicker winding wire and increased winding to screen separation. Thicker wire enables lower DC and skin effect resistance, and the greater screen separation reduces eddy current losses.

SM inductors were readily available, as well as a range of RF transformers. Predictably, their smaller size made them more expensive than their leaded counterparts (a typical quote in high quantity for a 7 mm square leaded quadrature coil against a 5 mm square SM verion was £0.12 /£0.30 pence respectively) and they typically had a slightly reduced Q. Many such parts were not capably of being wave soldered and hence were not practical for the test vehicle.

5-1-3 Surface Mount Device Advantages and Disadvantages

As shown by the measurements in figure 5-7, the Piccolo handset receiver circuit met the stipulated performance criteria. No performance advantages were apparent from the use of SMDs due to its relatively low operating frequency. The intermediate frequency feedback problem was fundamental to the circuit and further miniaturisation would be limited without the use of screening techniques or an alternative intermediate frequency selection.

The single sided mixed technology assembly was well suited to the circuit due to its requirement for relatively large wound and ceramic components. A particularly high board space utilisation efficiency was achieved when SMDs were positioned under large leaded components (Ferrite antenna and receiver IC are examples). Such area would often represent wasted



Handset Receiver Performance Comparison

Parameter	*Piccolo*	*Solo*	*Limit*
Current Consumption (mA)	4.5	5.0	—
Sensitivity (dBm)	-104	-104	-101
- Adjacent Channel (dB)	60	63	50
+ Adjacent Channel (dB)	57	58	50
Intermodulation Rejection (dB)	68	76	50
Spurious Responses (dB)	none < 50	none < 50	none < 45
Blocking Level (dB relative to 1 uV at receiver input)	84	83	70

Results are typical measurements from samples under nominal conditions as follows:

Supply Voltage = 4.8V
Temperature = 25 °C

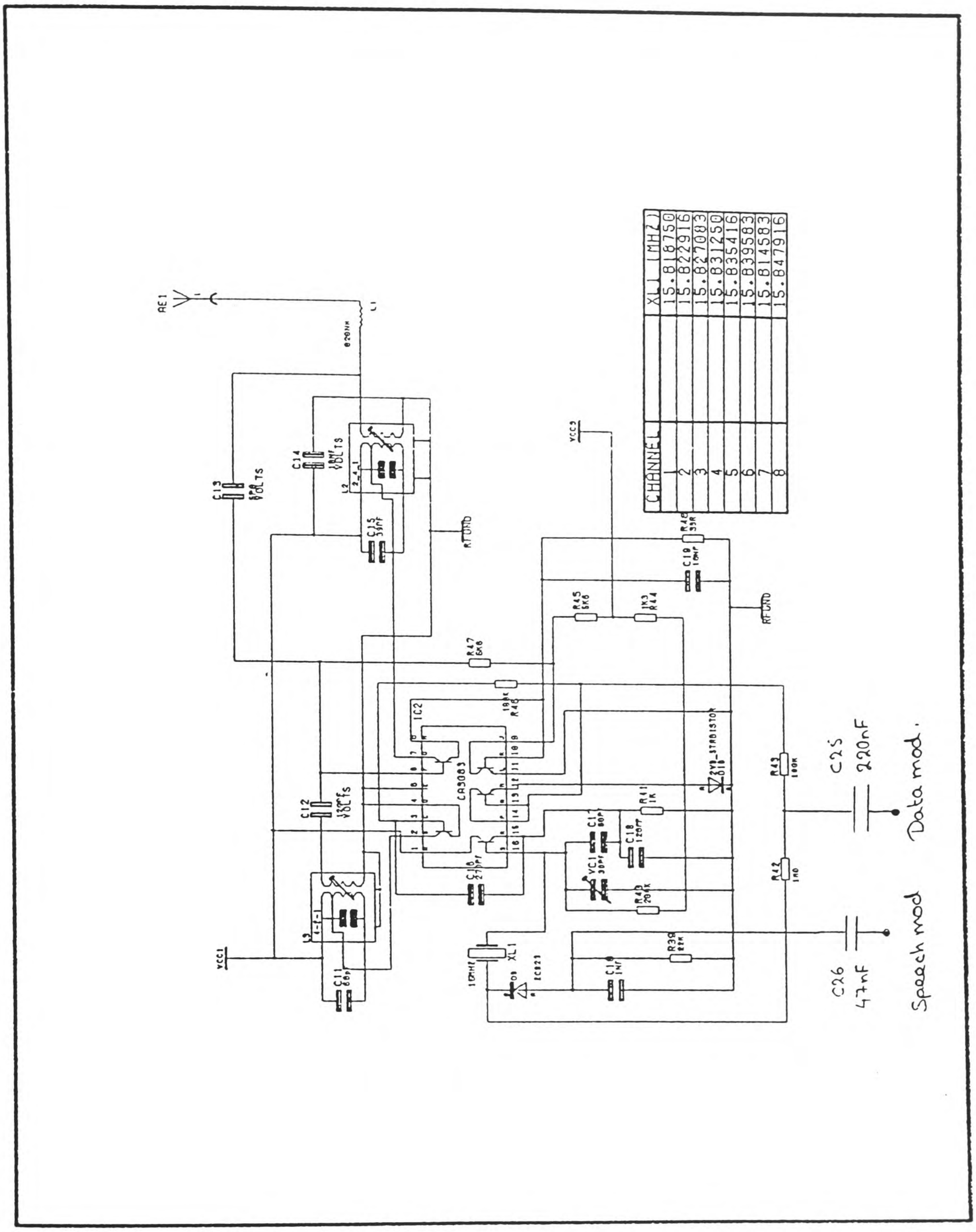
Figure 5-7 Handset 1.7 MHz receiver performance comparison board space in purely leaded component circuits.

It was noted that circuit density was very difficult to predict before layout was attempted. This was due to the use of a single side PCB where component footprints and inter-connections contended for the available space. A circuit with many common inter-connections across the complete board can demand a surprisingly large board area and considerations about reducing signal tracking distances can be important to retain high component density. A multi-layer circuit would not suffer from such limitations because SMDs cause no restrictions internal to the substrate.

5-2 47 MHz Handset Transmitter

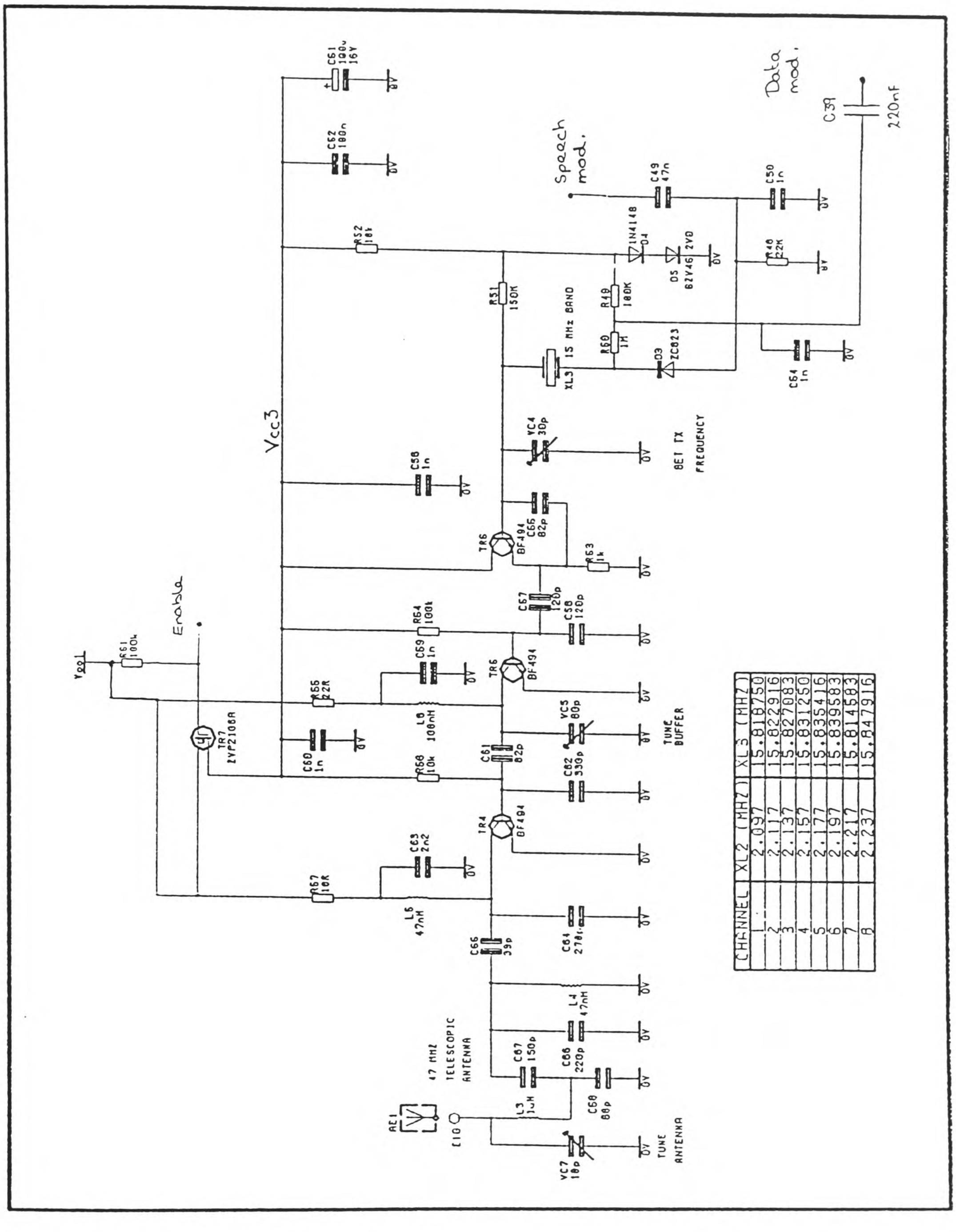
The transmitter circuit is shown in figure 5-8 and can be compared with that used in the Solo in figure 5-9. The circuit was designed with the object of high transmission efficiency and minimum component count, and made use of a five transistor array integrated circuit, the CA3083 (detailed in appendix D). Since only one component placement was required, assembly time was reduced while the device cost compared to that of as many discrete RF transistors (£0.142 was quoted for the SM version in high volume).

The carrier frequency was generated from a 15 MHz Colpitts configured voltage controlled oscillator tripled to 47 MHz. Trippling was necessary to achieve the maximum allowable frequency deviation of 2.5 kHz with a series hyperabrupt diode. Nominal oscillation frequency was stabilised by a



CHANNEL		XL1 (MHZ)
1		15.818750
2		15.822916
3		15.827083
4		15.831250
5		15.835416
6		15.839583
7		15.814583
8		15.847916

Figure 5-8 47 MHz handset transmitter used in the Piccolo



CHANNEL	XL2 (MHZ)	XL3 (MHZ)
1	2.097	15.818750
2	2.117	15.822916
3	2.137	15.827083
4	2.157	15.831250
5	2.177	15.835416
6	2.197	15.839583
7	2.217	15.814583
8	2.237	15.847916

Figure 5-9 47 MHz handset transmitter used in the Solo voltage reference consisting of a 2.0 V stabistor and a spare array transistor configured in series as a 0.6 V stabistor. The 2.6 V reference voltage allowed 900 Hz low distortion deviation at the oscillation frequency before non-linear modulation resulted from varactor forward bias due to the addition of oscillator signal and modulation drive.

The tripler transistor was biased lightly and operated in a mode approaching class B to generate a high content of third harmonic current at its tuned collector load. The current magnitude frequency spectrum is shown in figure 5-10a with the voltage at the collector with a load Q of 20 in 5-10b. The tuned load transformer was also used to impedance match between the tripler and the power amplifier transistor.

It was possible to achieve improved unwanted harmonic rejection by operating the output of the tripler into collector/emitter saturation. This was achieved by designing the collector load impedance to be high enough for the available current to cause a collector voltage swing to collector/emitter saturation. The output spends a time in this condition during each cycle, resulting in an effective decrease in the amplification to other frequency components. This operation caused a slight reduction in the output power of the wanted signal but effected high attenuation of unwanted frequency components as shown in the comparison in figure 5-10c. The tripler delivered typically 3 mW of carrier frequency power into a 3.3 KΩ collector load.

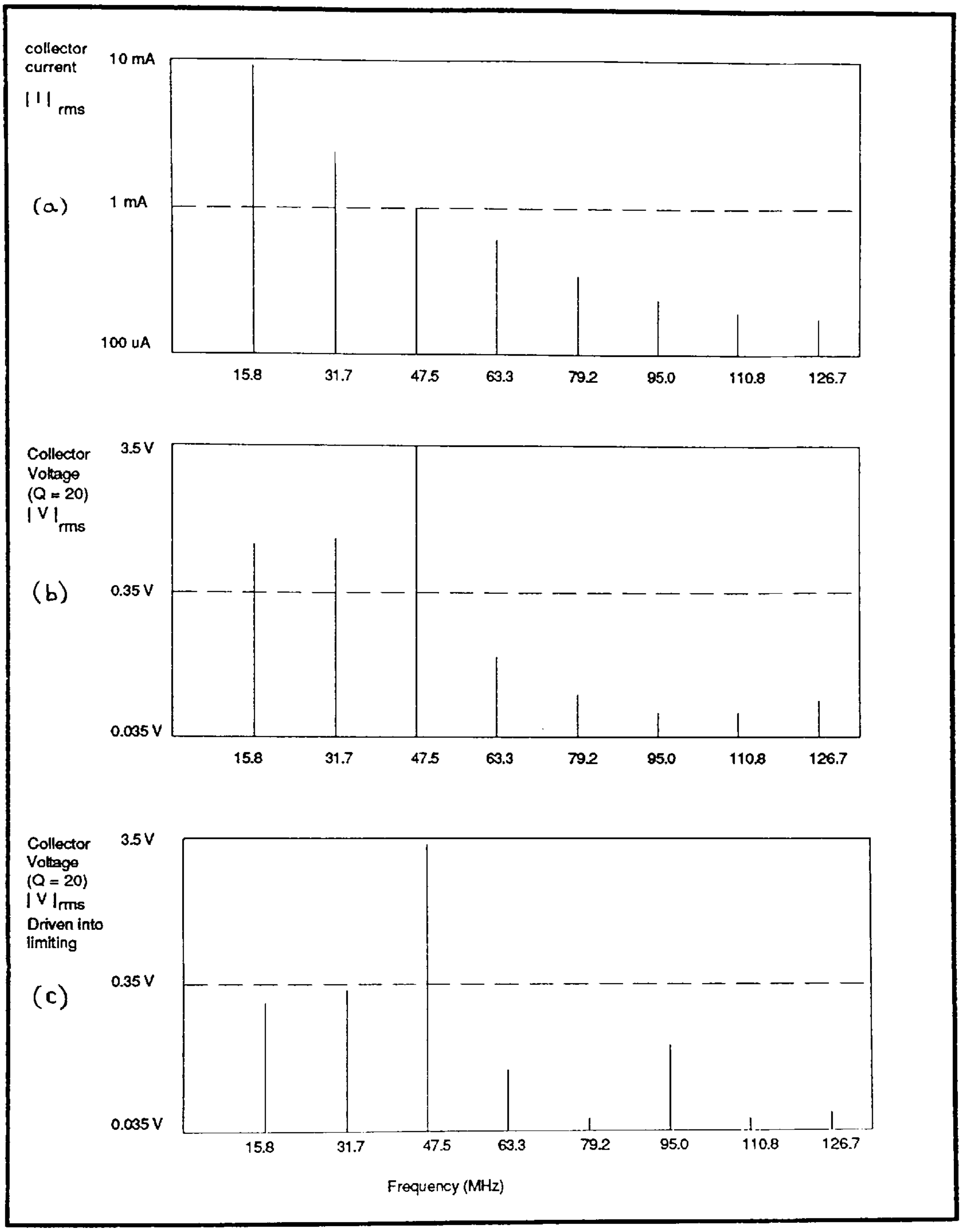


Figure 5-10 Harmonic components present at the trippler collector load

The power amplifier, operating in class A/B, was used to drive a 33 cm telescopic antenna. The amplifier supplied typically 30 mW into a 300 Ω tuned collector load. The transformer circuit was used to match the antenna load, which was series tuned with an inductance cancelling its capacitive reactance (equivalent to 5 pF at the carrier frequency). The tuned antenna load presented a resistance of typically 70 Ω, where 30 Ω was measured as loss resistance in the tuning coil (see appendix 2 of appendix C for discussion of component performance) at this frequency and the theoretical radiation resistance over an earth plane was 2.5 Ω (from equation four). This 3.5 % predicted efficiency corresponds well with the carrier power measured during approval testing.

The final array transistor was used to dc regulate the power amplifier's emitter current to 15 mA to guarantee current consumption and hence handset operating expectancy between charging.

5-2-1 Circuit Topology and Component Selection

Figure 5-11 shows the handset transmitter circuit board. The circuit occupies a small area of the board and uses leaded screened transformers, a trimmer and conventional crystal according to the selection criteria discussed in section 5-1-2. The standard sized 15 MHz crystal was too high for the assembly technique used, but rather than use an expensive miniaturised version, a cutout was left in the upper PCB for the component to fit through (this can be seen in figure 5-3). It would have been possible in many circumstances to lie

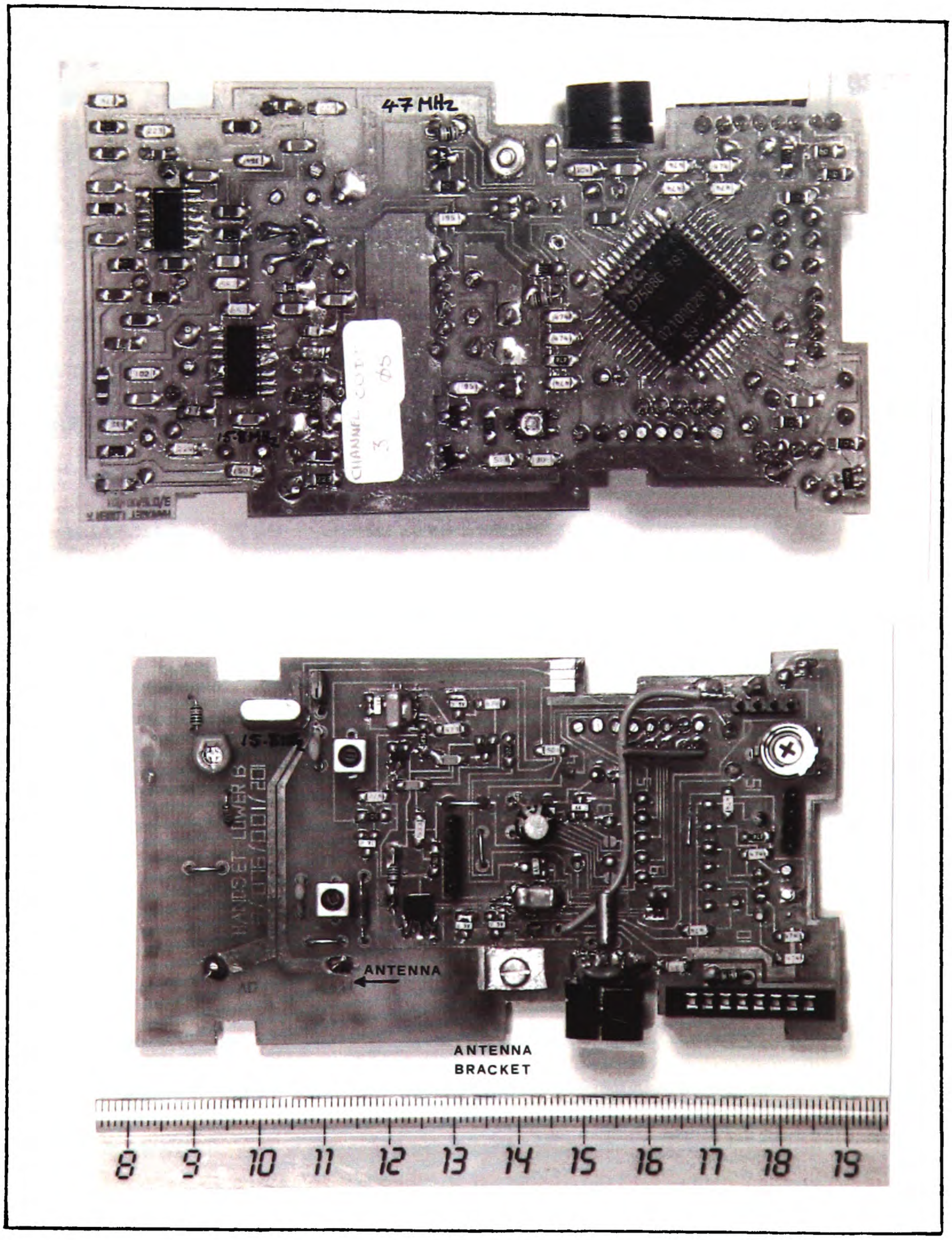


Figure 5-11 Piccolo handset 47 MHz transmitter circuit board

such a device on its side; because SMDs could be placed on the PCB beneath, no loss of board space would result in single sided designs.

5-2-2 Surface Mount Device Advantages and Disadvantages

The measurements in figure 5-12 show that the Piccolo transmitter met the radio regulation requirements. A single 10 nF SM capacitor, positioned at the supply point to the final stage transistor, was adequate to ensure stability of the circuit. The lower self-resonant frequency of leaded components (see appendix 2 of appendix C for discussion of component performance) would have made such a part less efficient.

The use of SMDs provided a circuit with greater repeatability of performance and improved stability. Component tolerances due to lead insertion variations were removed and, after placement, mechanical variations were eliminated. It was possible, for example, to cause de-tuning and even variations in the maximum output power possible from the Solo, which used an earth plane, by bending components within the output filter towards or away from each other. The Piccolo circuit proved repeatable without the use of an earth plane since stray circuit components were reproduced more accurately.

The development of the transmitter circuit highlighted also where a SMD can behave adversely different from the leaded part. Figure 5-13 illustrates the effect of utilising a SMD to 'jump' another track. The coupling between the track and

Handset Transmitter Performance Comparison

Parameter	*Piccolo*	*Solo*	*Limit*
Current Consumption (mA)	20	30	—
ERP (mW)	1.2	0.8	10
Spurious Emissions	pass	pass	50 nW in bands 87.5-118 MHz 135-136 MHz 174-230 MHz 470-862 MHz else 250 uW
Carrier Error (kHz) (over voltage and temperature range)	+0.66 - 0.65	—	+/- 2
Peak Frequency Deviation (kHz)	+/- 2.5	+/- 2.5	+/- 2.5
Modulation Frequency Response	pass	pass	see figure 2-4

Unless noted, results are typical measurements from samples under nominal conditions as follows:

Supply Voltage = 4.8V
Temperature = 25° C

Figure 5-12 Handset 47 MHz transmitter performance comparison

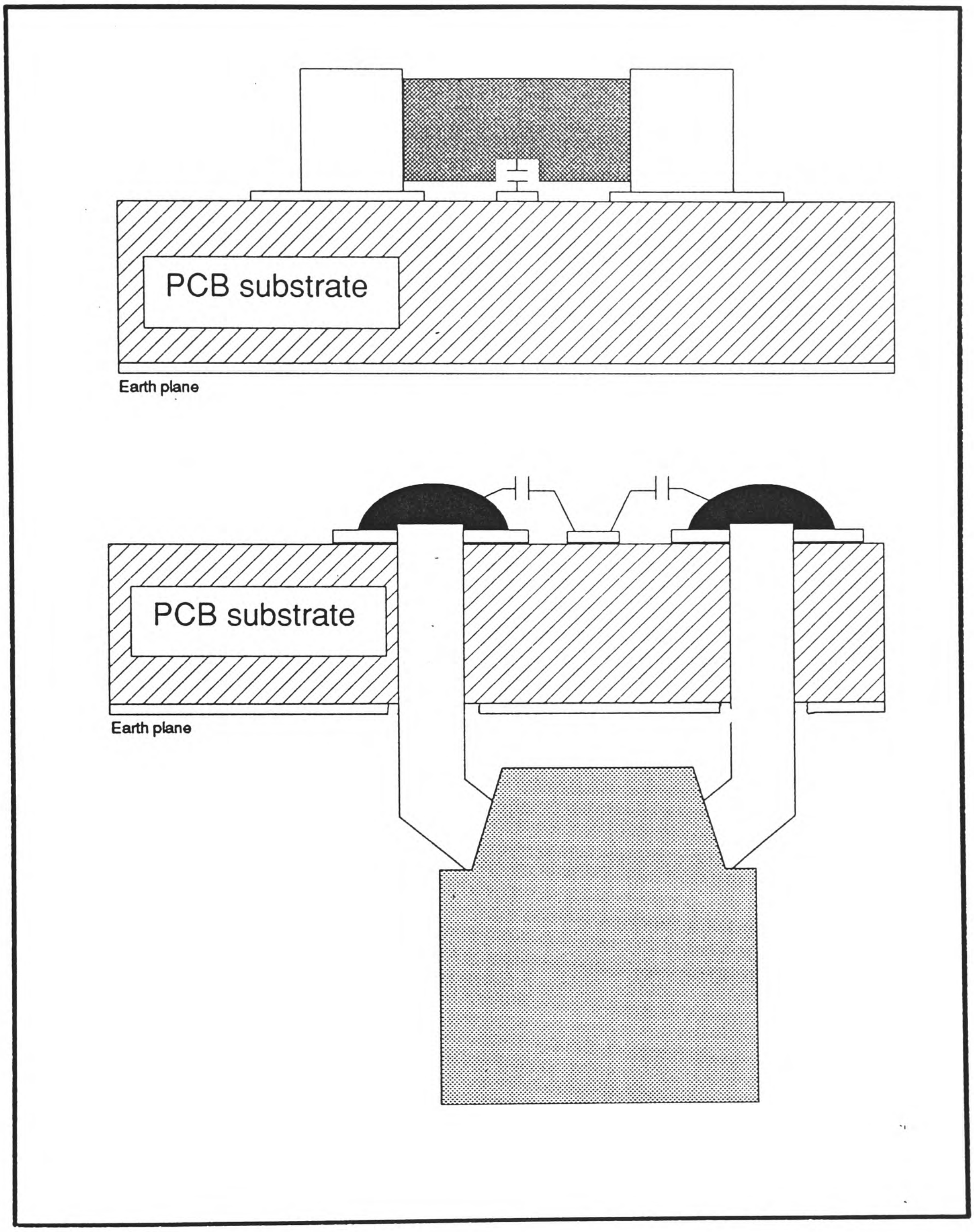


Figure 5-13 The increase in coupling experienced between SMDs and tracks routed between their end terminations

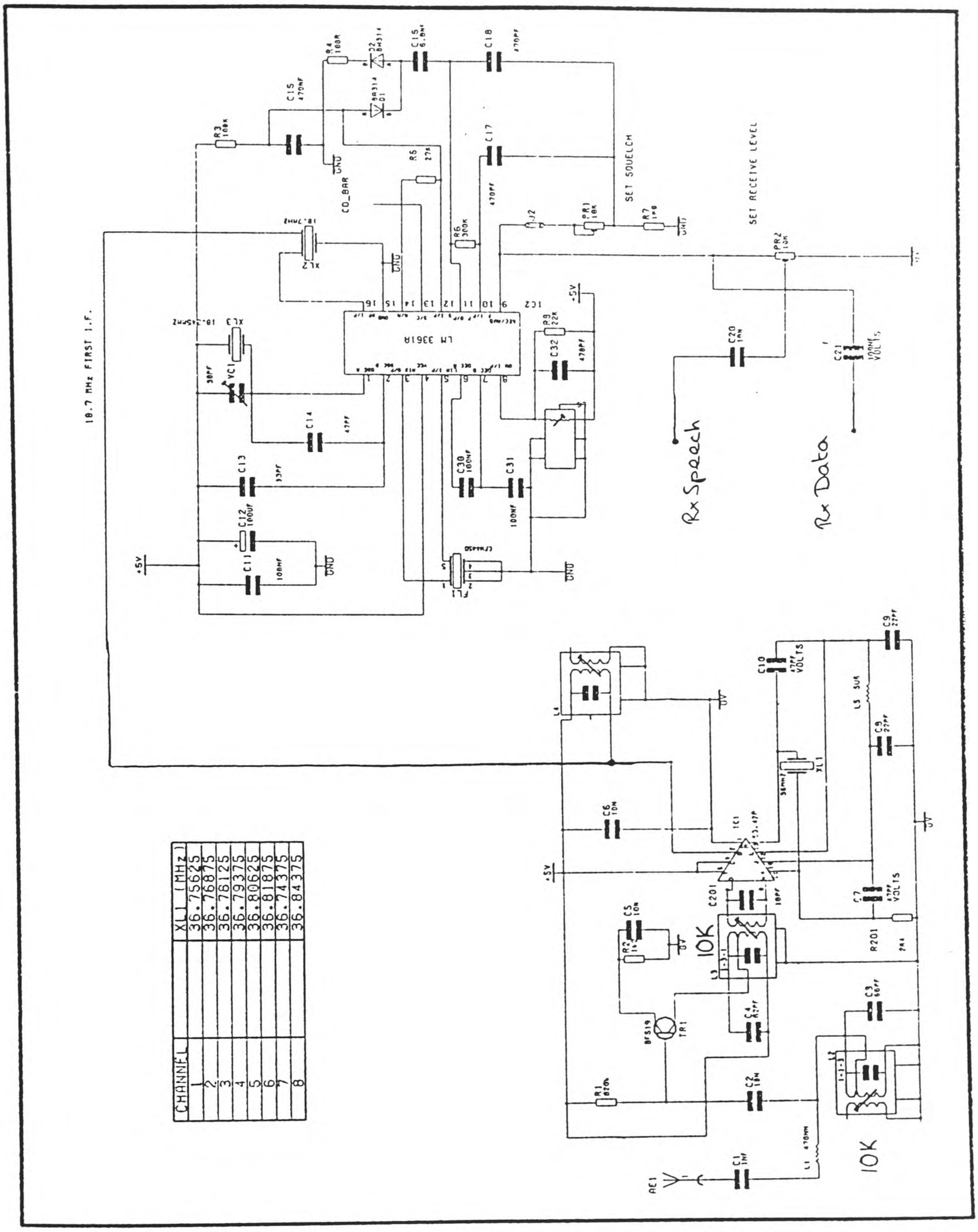
the component is clearly higher than between it and the leaded type. The inclusion of an earth plane to one side of the PCB also has considerably less effect in this case. In such a circumstance where reduced coupling is necessary, for stability or interference reasons, then either a leaded device will aid or a circuit re-layout will be necessary.

5-3 47 MHz Base Station Receiver

Figure 5-14 shows that the receiver circuitry used within the Piccolo was an adapted version of that used by the Solo, shown in figure 5-15. An RF amplifier was included within the front end to improve the noise figure but the remainder of the exercise involved assembly design.

After receiver telescopic antenna tuning with L1, the image frequency of the double conversion receiver at 24 MHz is rejected with a double tuned amplifier circuit. First conversion is achieved with the SO 42 double balanced mixer integrated circuit (detailed in appendix D), the local oscillator frequency being controlled by a third overtone 36 MHz band crystal.

A crystal filter was employed at the first IF frequency to meet high intermodulation requirements. Intermodulation testing involves applying two frequencies at ($f_o + 2f_s$) and (f_o and $4f_s$), where f_o is the receiver centre frequency and f_s is the channel spacing of 12.5 kHz. The second harmonic of the first frequency mixes with the second frequency to



CHANNEL		XL1 (MHz)
1		36.75625
2		36.76875
3		36.76125
4		36.79375
5		36.80625
6		36.81875
7		36.74375
8		36.84375

Figure 5-14 47 MHz base station receiver used in the Piccolo

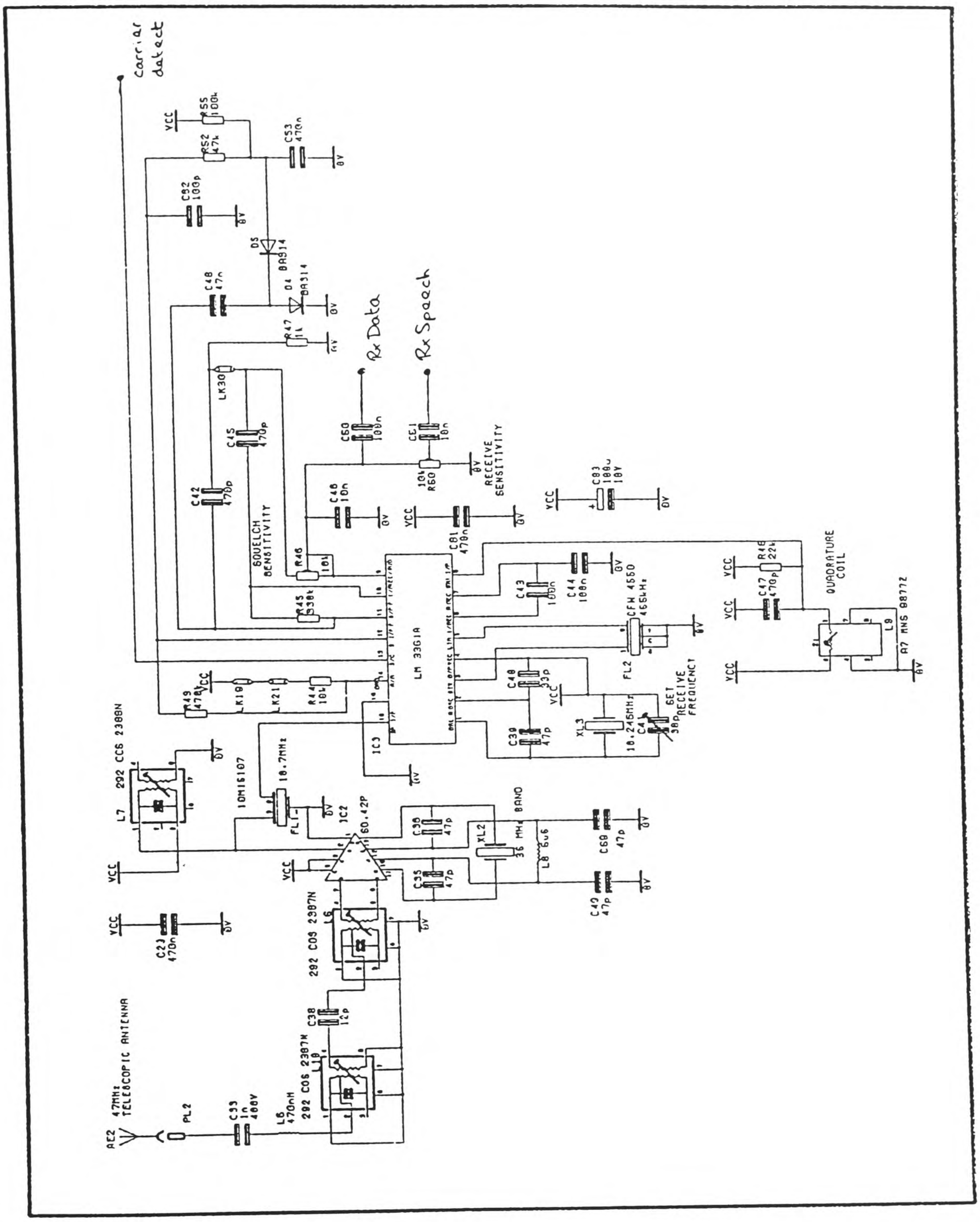


Figure 5-15 47 MHz base station receiver used in the Solo generate an interfering signal at f_o as shown by:

$$2(f_o + 2f_s) - (f_o + 4f_s) = f_o \text{ ...... } \textit{equation 6}$$

The intermodulation effect was worst at the second mixer because the signal at that point was 20 dB greater than at the first, where f_o was the first intermediate frequency value of 10.7 MHz. A crystal filter was necessary to adequately reject the signals due to the narrow bandwidth required.

The second conversion LO was crystal controlled at 10.245 MHz to give an intermediate frequency of 455 kHz. Tuning at this point also offset frequency error in the first intermediate frequency which, due to the 36 MHz crystal specification, would not be great enough to cause distortion through the 10.7 MHz crystal filter.

5-3-1 Circuit Topology and Component Selection

Figure 5-16 shows the base station RF circuit board. The philosophy of using large leaded components was continued as can be seen from the inclusion of 10K size screened transformers. These have the dimensions, 10 mm by 10 mm square and 17 mm high. The receiver was positioned to the extreme of the PCB due to the internal transformer's field that could induce hum into the detection circuit when in proximity. The high components were positioned to match the height available at the side of the case. The 1nF antenna isolation capacitor, C1, was not found in SM form approved to withstand the voltages required.

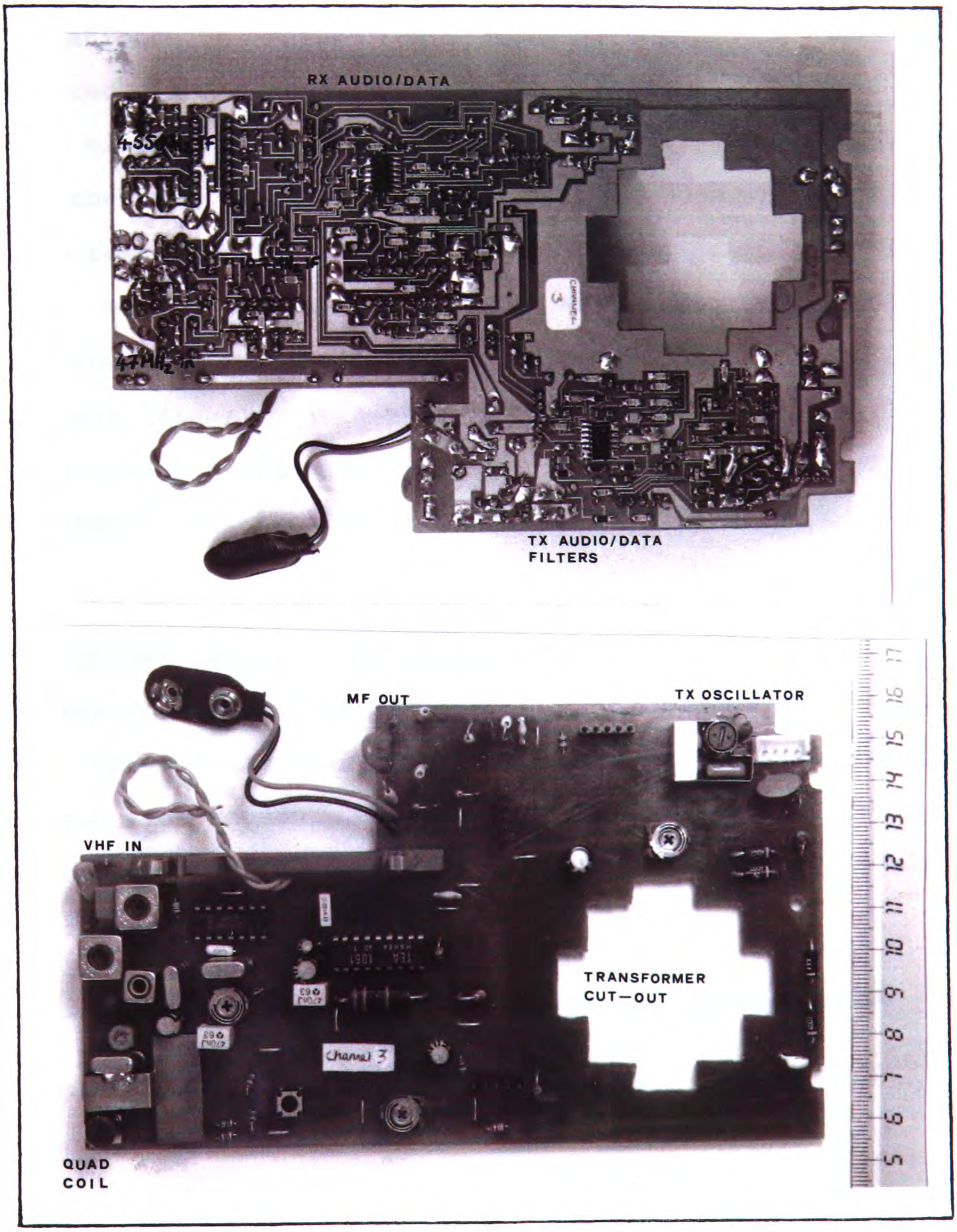


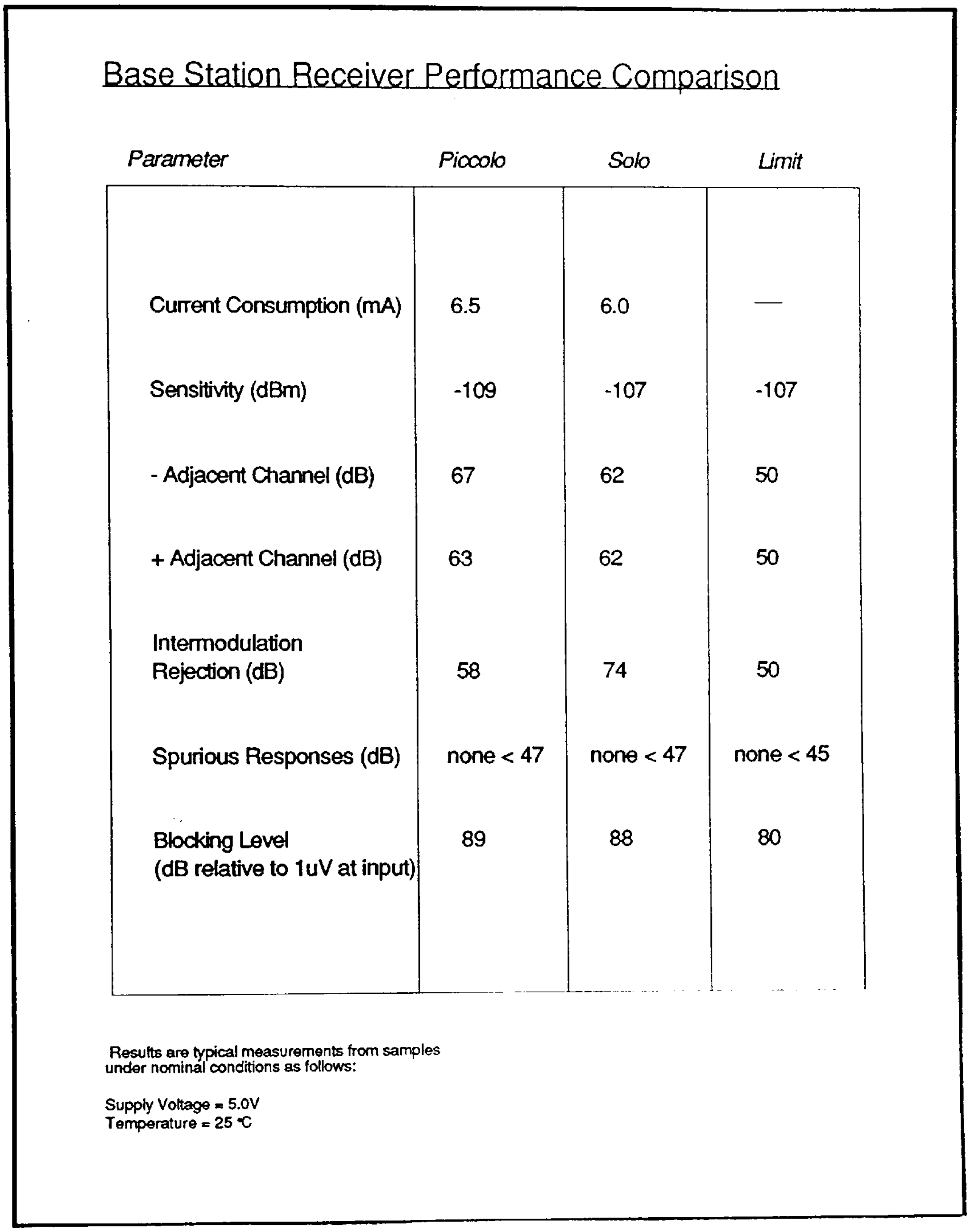
Figure 5-16 Piccolo base station radio circuit board

Limitations on where the components could be positioned resulted in an undesirably close positioning of the first mixer circuit to the antenna. Spurious UHF signals coupling past the front end filter circuitry caused responses that had to be removed by rejection at the coupling point. C4, figure 5-14, was positioned to shunt such frequencies at the differential input of the SO 42 mixer. An example of a spurious signal that needed to be attenuated was 121.1 MHz which caused a response by mixing with the third harmonic of the first local oscillator (121.1 MHz - (3 x 36.8 MHz) = 10.7 MHz).

The screen over the LM3361A receiver integrated circuit and 455 kHz ceramic filter was positioned to reduce the coupling from the 1.7 MHz transmitter contained in the same housing. Without the screen, the detected level was great enough to capture the intermediate frequency amplifier as low levels of wanted reception frequency.

5-3-2 Surface Mount Device Advantages and Disadvantages

Figure 5-17 summarises the receiver performance. No performance advantage was noted due to the use of SMDs. The reduced isolation between the antenna and first mixer to UHF signals was due to layout constraints, but the solution illustrated how the addition of extra components could achieve the desired performance. Similarly, although reduced circuit sizes achieved with SMT could increase inter-circuit coupling, such shunting techniques could often be used to counteract performance degradations.



Base Station Receiver Performance Comparison

Parameter	*Piccolo*	*Solo*	*Limit*
Current Consumption (mA)	6.5	6.0	—
Sensitivity (dBm)	-109	-107	-107
- Adjacent Channel (dB)	67	62	50
+ Adjacent Channel (dB)	63	62	50
Intermodulation Rejection (dB)	58	74	50
Spurious Responses (dB)	none < 47	none < 47	none < 45
Blocking Level (dB relative to 1uV at input)	89	88	80

Results are typical measurements from samples under nominal conditions as follows:

Supply Voltage = 5.0V
Temperature = 25 °C

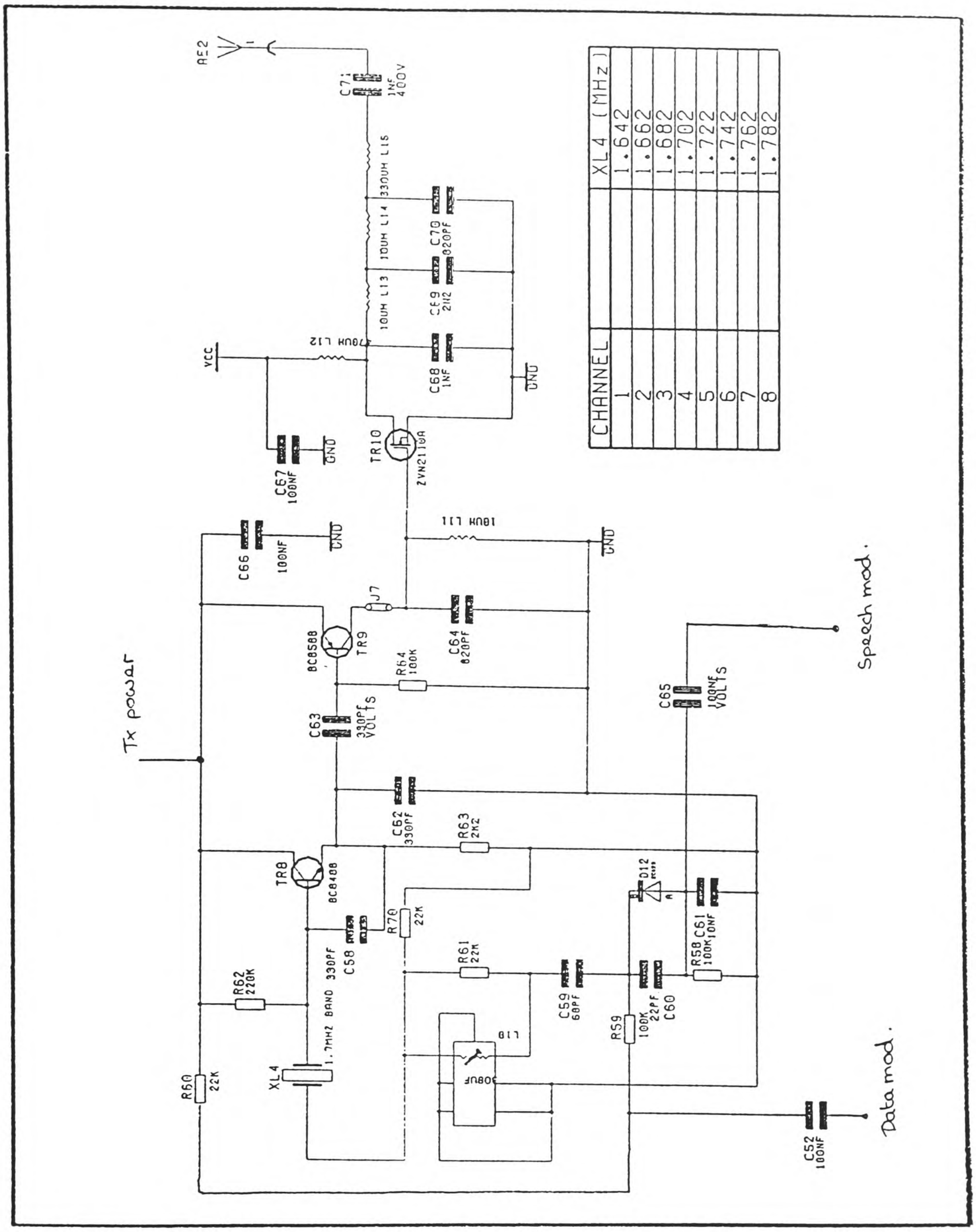
Figure 5-17 Base station 47 MHz receiver performance comparison

5-4 1.7 MHz Base Station Transmitter

The fundamental difference between the Piccolo transmitter circuit, illustrated in figure 5-18 and that of the Solo in figure 5-19, is that it was required to be operational from a primary backup battery. A PP3 9V battery was chosen because of its small size and ease of integration into the base station moulding but had to ensure eight hours operation in the case of a mains failure, including one hour of continuous use.

The Colpitts configured voltage control oscillator is tuned with a series inductor and modulated by the same varactor diode as used in the handset. The modulation sensitivity was greater than required due to the use of a ceramic resonator (lower Q than crystal) and was reduced by C60 in parallel with the varactor capacitance. The sensitivity reduction made it no longer necessary to include a precision voltage reference as used in the Solo.

The signal is fed to a buffer transistor with tuned collector load to amplify the carrier frequency to a level great enough to cause the final stage MOSFET to act as a switch. Because the input impedance of the MOSFET is high, power gain is not a criteria at this stage. A PNP transistor was chosen so that the MOSFET gate potential would be zero when no power was supplied to the oscillator circuit, ensuring that the FET is held off.



CHANNEL	XL4 (MHz)
1	1.642
2	1.662
3	1.682
4	1.702
5	1.722
6	1.742
7	1.762
8	1.782

Figure 5-18 1.7 MHz base station transmitter used in the Piccolo

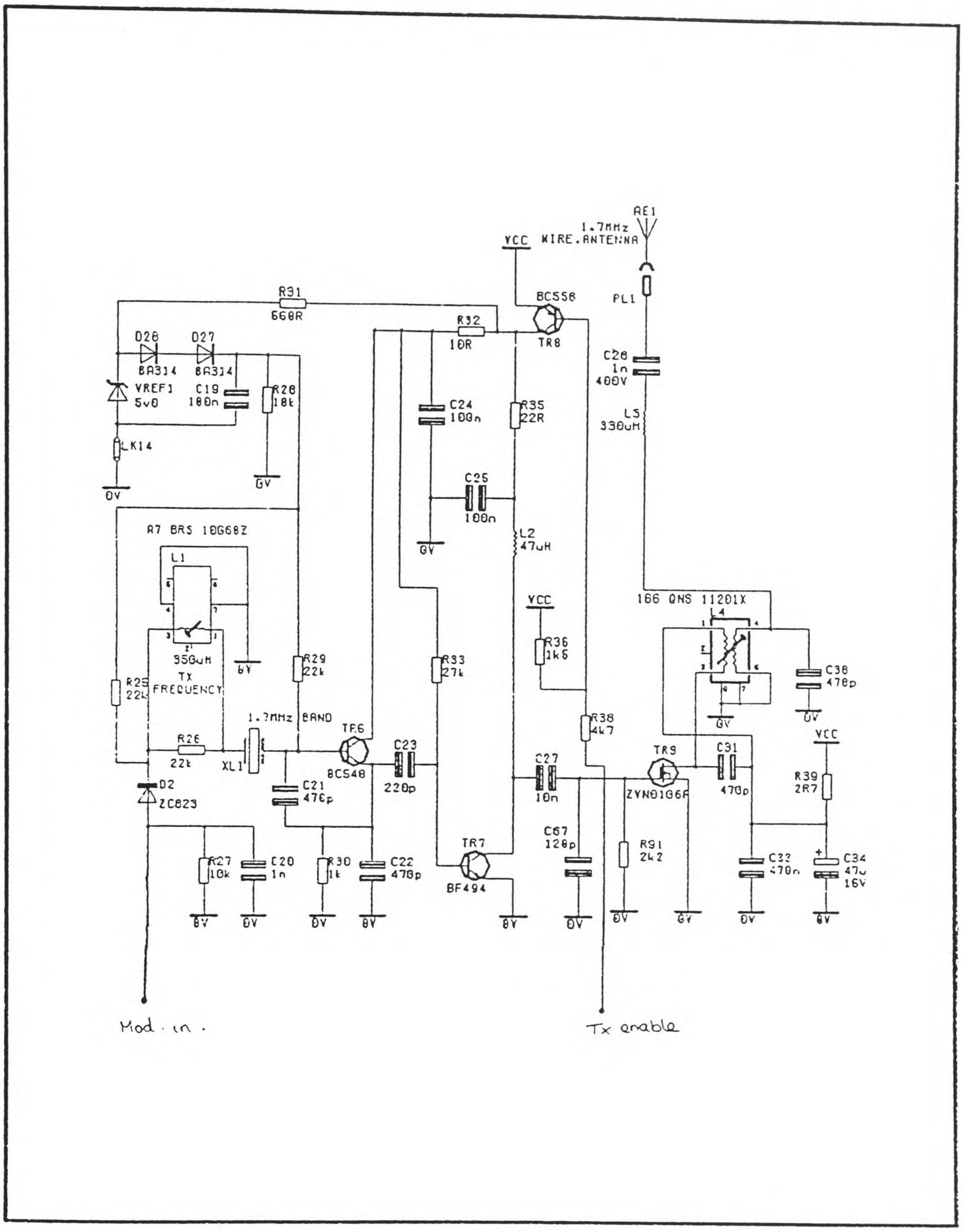


Figure 5-19 1.7 MHz base station transmitter used in the Solo

The MOSFET switched current directly from the power rail rather than a regulated supply. This allowed 1W of DC power to be supplied to the power amplifier stage, taking 75 mA from the 13 V transformer supply. The Solo circuit, using a 6.8 V regulated supply, demanded 150 mA for the same power level. Mains ripple caused 4% depth amplitude modulation but this caused no noticeable degradation to the FM link performance. Transformer operating temperature was thus reduced and the requirement for a high power voltage regulator removed.

In times of mains failure, the 9V battery was used to power the transmitter and the base station would reset at 5.9 V before illegal frequencies could be transmitted due to regulation loss. Powered from the battery, the transmitter circuit would operate at reduced output power levels of -3 dB down to -7 dB when the battery finally failed, but allowed operation for the specified time interval.

The antenna filter design was fundamental to the efficient operation of the base unit. It served to reject harmonics of the carrier frequency from being radiated and also to match the antenna to the power amplifier. It was required to regulate the level of power drain to the antenna circuit and to supply maximum power to the antenna when it was correctly positioned.

The 1.5 m wire antenna used by the base unit had to be positioned straight and away from walls in order to obtain a repeatable radiation performance. When positioned straight upwards from the base station to a ceiling it could be tuned with a 330 uH inductance and the resistance of this network was typically 100 Ω.

Figure 5-20 shows a simulation of the frequency response of the Piccolo's output filter (Inductor Q = 60, Capacitor Q = 500) when fed by a current source. At the transmit frequency of 1.7 MHz, the network presented an input impedance of 110 Ω. The broken line represents the input impedance of the circuit with the antenna removed. The low pass filter required no tuning as did the bandpass used in the Solo. A normal Butterworth or Chebychev design was not chosen because the power consumed by the transmitter could increase when the antenna was badly positioned. This was due to the series resonance of the LC paths to ground being un-damped and offering a very low impedance path to the carrier frequency. Such an effect was avoided by designing the filter in two stages, one with a cut off frequency of 2.8 MHz.

5-4-1 Circuit Topology and Component Selection

The 75 mA supplied to the transmitter contained mains frequency fluctuations which could be detected as voltage fluctuations along its conduction path. In order to ensure that this did not cause FM fluctuations at the transmitter the earth return was routed separately and the 5V regulator's reference was positioned at the same point as the modulation circuit's ground. (This circuit is shown in figure 5-16).

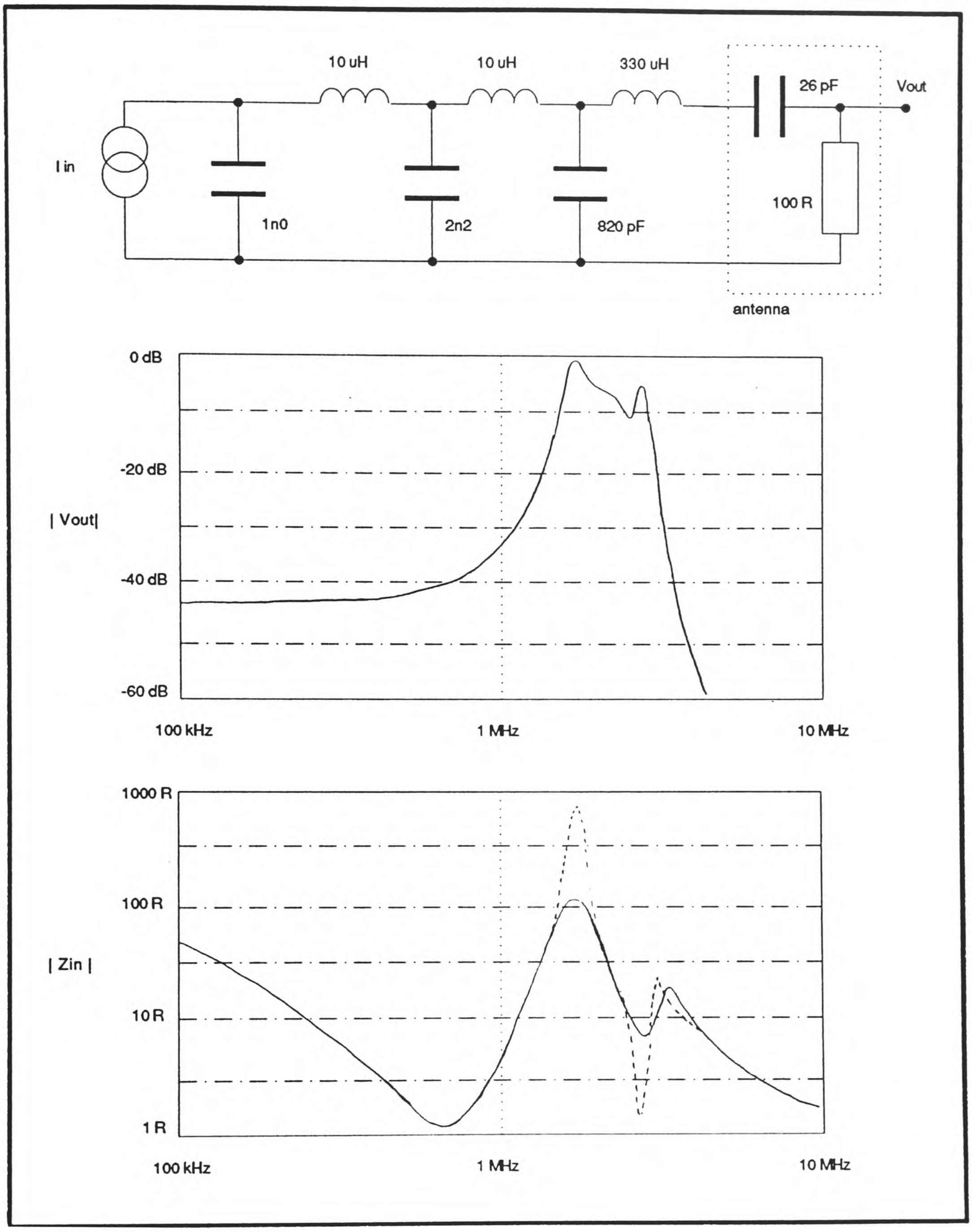


Figure 5-20 Simulation of the frequency response of the base station transmitter antenna matching network

A screen was placed around the VCO to reduce effects of transmitter potential coupling back and effecting a change in transmitter frequency. Due to voltage amplification at the antenna, the terminal voltage could be as high as 250 Vrms and transmit frequency varied initially by up to 2 kHz with antenna position. With the screen, and R70 to reduce coupling to the most sensitive circuit point, susceptibility was less than 200 Hz.

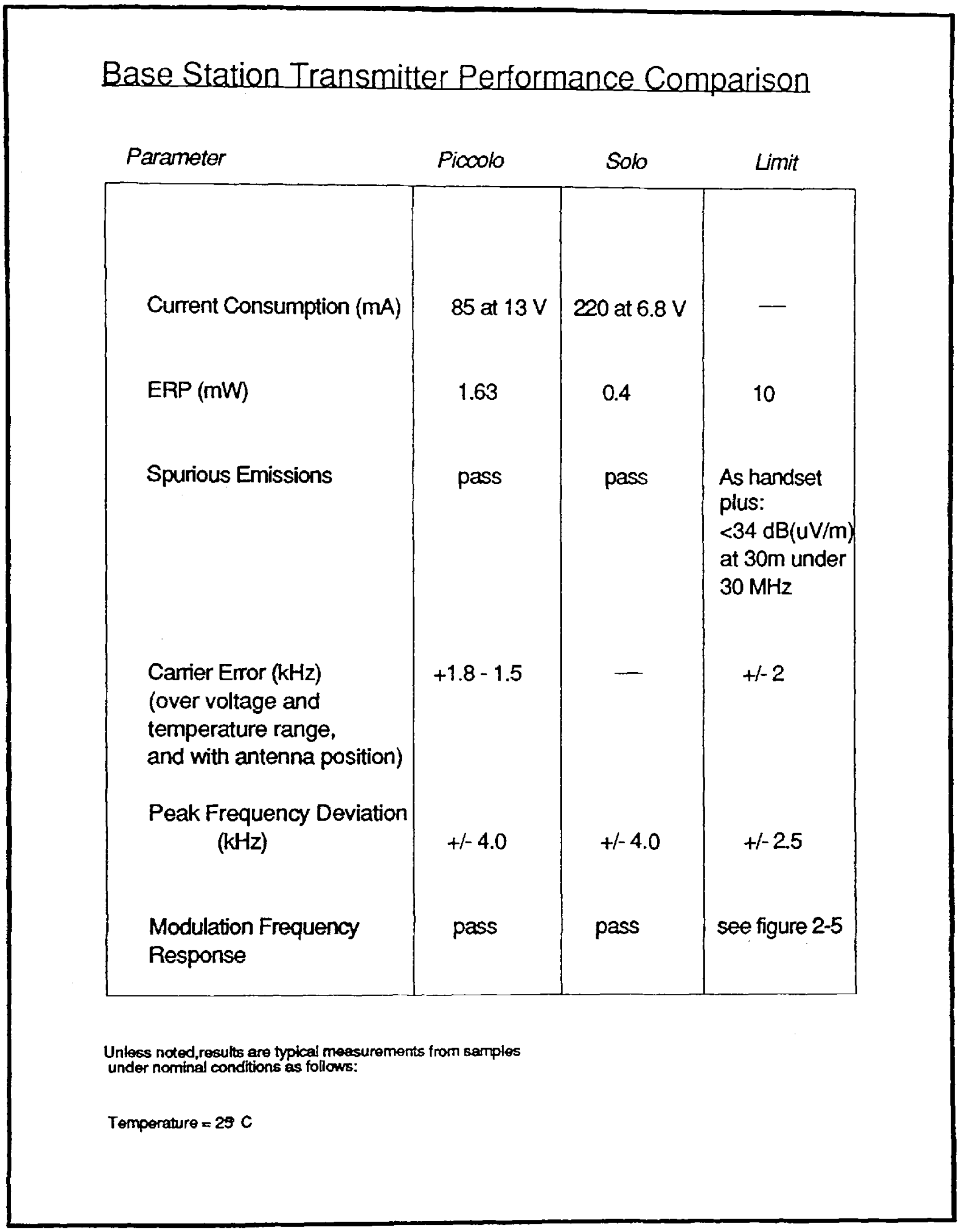
5-5-2 Advantages and Disadvantages of SMDs

The use of SMDs within the 1.7 MHz transmitter circuit showed no performance improvements because of the low operating frequency and the selection of components was governed by the same criteria as in the 47 MHz receiver circuit. The circuit performance is compared against that of the transmitter used in the Solo cordless telephone in figure 5-21.

5-5 Summary

The Piccolo cordless telephone successfully satisfied the many requirements of the approvals mechanism and obtained full authority for use within the UK in July 1988.

From the RF circuit development experiences it was possible to compile a guide as to what had been recognised in terms of good design practice in RF SMD work. This is contained in appendix E as an update to the initial set of SM design rules.



Base Station Transmitter Performance Comparison

Parameter	*Piccolo*	*Solo*	*Limit*
Current Consumption (mA)	85 at 13 V	220 at 6.8 V	—
ERP (mW)	1.63	0.4	10
Spurious Emissions	pass	pass	As handset plus: <34 dB(uV/m) at 30m under 30 MHz
Carrier Error (kHz) (over voltage and temperature range, and with antenna position)	+1.8 - 1.5	—	+/- 2
Peak Frequency Deviation (kHz)	+/- 4.0	+/- 4.0	+/- 2.5
Modulation Frequency Response	pass	pass	see figure 2-5

Unless noted,results are typical measurements from samples under nominal conditions as follows:

Temperature = 25° C

Figure 5-21 Base station 1.7 MHz transmitter performance comparison

The chapter has discussed the telephone radio circuitry and the use of SMDs within, but has not discussed manufacturing and testability concerns. This deficiency is due to circumstances detailed in the following conclusion.

Although various specific costings were mentioned, an overall cost comparison was not presented. This is due in part to reasons discussed in the next chapter concerning the project circumstances but was also complicated by the nature of the two products. The specifications were not identical because of updates occuring during the course of the project and the circuit design was different in various areas due to an improved power consumption design and the need to be suited to the **Piccolo** enclosure. An overall cost comparison would have best been made with a conversion of the existing circuit using the original case but was not performed due to the test vehicle being a commercial product rather that a conversion excercise.

Chapter 6

Conclusion

6-0 Objectives of the Study

The objectives of the study, introduced initially in chapter one, section five, can be summarised as follows:

1. To critically review the relevant radio frequency techniques and circuit designs at cordless telephone frequencies.

2. To form an appraisal of SM components and manufacturing methods.

3. Based on objectives one and two, to lay out an initial set of design guidelines for the development of an RF product utilising SMT.

4. To identify and justify a suitable test vehicle.

5. To undergo a major design project to prove and further develop the design rules.

6. To produce a definitive document for the guidance of RF designs for SMAs.

7. To review the study and identify further relevant issues.

6-1 Achievement of the Objectives

1. RF techniques and circuits at cordless telephone frequencies were reviewed in chapter two. It was seen that the utilised FM technique was suited to the application and had advantages over AM solutions due to a signal to noise improvement and the constant receive signal amplitude without

AGC. Optimum transmission efficiency would have been achieved with suppressed carrier amplitude modulation, but the complexity of both the transmitter and receiver would have greatly increased.

It was possible to transform existing leaded circuits directly to surface mount types without changing circuit designs. Other miniaturisation means, such as integration onto silicon, often require a change in design philosophy because specific techniques are more suited. SMDs did not demonstrate a suitability to any particular circuit type within the application studied. As a result of circuit miniaturisation, further transmission optimisation could be considered because of space availability and the companding solution, discussed in section 2-4-2, was identified as an applicable technique.

2. Surface mount devices and surface mount assembly methods were appraised in chapter three. From the discussion it was clear that the success of the technology relies heavily on effective communication between the various design, development and production departments. The areas of concern were as follows:

a. Suitable manufacturing compatibility, especially soldering and onsertion requirements.
b. Component selection, availability and cost.
c. PCB design rules.
d. Personnel training.
e. Testing of assemblies at in-circuit and functional levels.

f. Rework of faulty assemblies.

The majority of components were available in a surface mountable form. When selecting less common types it was found necessary to be aware of their production compatibility, expense in comparison with the leaded part and the availability of compatible second sources.

As shown from the measurements of surface mount capacitors in section 3-4, they offer a marked in-circuit advantage because of their low value of lead inductance. Their higher value of self resonant frequency offers performance improvements and can extend their operating frequency range.

3. From the studies recorded in chapters two and three, the set of design rules included in appendix C was formulated. Chapter four discussed the structure of this document and it was noted that it was not possible to make it RF specific because of the scope of the information to be conveyed.

4. Chapter four also introduced and justified the **Piccolo** cordless telephone as a test vehicle for the proving and updating of the design rules. The product was suitable because of the following points:

a. It was a commercial product and had to be developed under the normal constraints of time, cost and manufacturing compatibility.

b. The design required the inclusion of radio frequency circuits in the form of 1.7 MHz and 47 MHz transmitters and receivers.

c. There existed an equivalent leaded product, the **Solo**, that functioned as a bench-mark for the study.

In addition, the project required the circuit to be designed into an existing enclosure. The internal volume of this new case was too small for a leaded assembly, thus making miniaturisation a necessity.

5. The **Piccolo** cordless telephone was successfully approved for operation and sale in the United Kingdom in August 1988. Chapter five discussed the development of the RF circuits in light of the use of SMDs. From the development experience, a section was added to the design rules (appendix E) to act as a guide to good design practice when developing RF circuits using SMDs.

6. The study did not result in the foreseen definitive document for Autophon because the planned production of the telephone did not take place. This deficiency is explained in the following section.

7. Recommendations resulting from the study are included in section 6-3.

6-1-1 Deficiencies in the Work Performed

The original objective was to design and approve a production compatible cordless telephone using SMT. However, due to company reasons beyond the control of the author, the **Piccolo** was not taken into production, although it was still essential that it became approved. The decision to abandon production planning and a change to the TG-47 type approvals altered the course of the final stage of the project. Without a production run, no feedback was available to assess solderability and assembly manufacturability.

Even though the production restrictions were removed, the telephone complied with the majority of the initial design objectives. The deviations were in two areas: firstly, there was no need for in-circuit testing and, because the successful approval was of highest priority, no test points were designed into the PCB; secondly, the second side of one handset PCB was also used for mounting SMDs (See figure 5-11). This was due to a late specification change requiring that the handset ringer volume build up in a crescendo fashion. It could have been possible to achieve this by pulse modulating the ringer drive signal but, since no software modifications were possible, extra hardware had to fulfil the function. To avoid the need for a major hardware modification and the associated layout and testing time, a second board side was used for this extra circuitry.

Although the Piccolo was not manufactured, it had aided in the introduction of SMT to the company. At the end of the project period, SMDs had also been introduced into other products and the company had committed financially to SMT. Major purchases included an Omega Wave solder bath and a Dynapert onsertion machine. Notes concerning the onserter are included in the additions to the design rules in appendix E.

Due to lack of feedback concerning the suitability of the design rules in the manufacturing environment, it was not possible to complete a definitive guide rule document. The guide rules have been adopted for subsequent products and may be upgraded as necessary as manufacturing statistics become known.

6-2 Review of the Assembly Topology

The basic assembly philosophy identified and adopted during the project was the construction of electronic circuitry on single sided, paper-based substrates for ease of manufacture and cheapness of material.

The connection technique, using two parallel circuit boards, as illustrated in figure 4-7, with the solder sides facing away from each other was very suited to mixed technology surface mount boards. Conventional leaded connectors could be positioned strategically around the PCB so as to achieve good board to board connectivity and a self supporting assembly structure, while the board to board spacing could be set with the connector pin length. Although possible with leaded assemblies, this approach is not so suited because of the high density of leaded components contending for space. The leaded parts used in this structure were chosen due to their availability, price or performance advantages. Large leaded components that require a large area of board space but only a small number of connection holes could be combined with surface mounted circuitry on the opposite side of the PCB to result in a high efficiency of board area utilisation.

The principle used by the **Piccolo** can be extended to double sided, mixed technology assemblies resulting in a still greater component density. An example of such an assembly is shown in figure 1-4 (A later prototype of an advanced cordless telephone). This solution required double-sided plated through circuit boards that had to be wave soldering on one side to handle the leaded terminations. The second side could be soldered by any of the reflow methods available and the two board sides were, therefore, designed using separate layout rules. Taking this concept further results in a double sided circuit board with only SMDs on both faces. All devices could be onserted (due to the basic SMD property), resulting in optimum assembly automation, although the extra price or supply difficulties of less common SMDs could offset this advantage in many circumstances.

When large volumes of substrates are required, paper based FR2 boards can become very economical by manufacturing with a punch tool. This method is not suitable for the tougher fibre-glass based FR4 materials which must be drilled and rauted. It was noted that the use of FR2 bars the inclusion of plated through holes and is not suited to high infra-red soldering temperatures.

6-2-1 Earth Planes within Surface Mount Assemblies

The use of an earth plane is often necessary within circuit assemblies operating at high frequencies. The earth plane acts as a sink to electrostatic flux and reduces capacitive coupling between components and circuit sections. In general, the use of an earth plane helps to reduced circuit interactions, giving a more predictable operation and an improved repeatability of production assemblies.

In many situations a radio circuit may be designed without an earth plane but will suffer functionally when the layout is slightly modified or when components are inaccurately inserted. The higher placement repeatability of SMDs and the fact that they cannot be bent after positioning, makes surface mount designs without earth planes more feasible. The removal of the earth plane from single sided radio frequency assemblies results in a cheaper circuit board and reduced assembly weight.

6-3 Review of the Study and Further Recommendations

The choice of a single-side, mixed technology design observed compatibility with the available manufacturing facilities and offered component cost advantages as discussed in chapter five. Although the test vehicle did not give feedback concerning the suitability of the PCB layout rule set, subsequent products have begun to use them with good success.

Notably, the soldering of flat-pack integrated circuits at 45° to the wave has become common practice at the company. The footprint, with solder thieves positioned at each corner can be seen in figure A-4, in appendix 1 of appendix C.

The **Piccolo** cordless telephone is compared against the benchmark, the **Solo**, in figure 6-1. The comparison illustrates how the design enabled a reduction of size, weight and electronic

Handset

PICCOLO	SOLO
Two single sided printed circuit boards mounted parallel to another and connected by three connector/socket pairs	Two double sided printed circuit boards mounted parallel to another and connected by an 8 way ribbon cable
Printed circuit board area = 11250 mm^2 paper based construction	Printed circuit board area = 10640 mm^2 fibre-glass construction with plated through holes
Receiver circuit electronic component count = 37	Receiver circuit electronic component count = 51
Transmitter circuit electronic component count = 30	Transmitter circuit electronic component count = 44

Base Station

PICCOLO	SOLO
Two single sided printed circuit boards mounted parallel to another and connected by three connector/socket pairs	Two boards mounted parallel to another, connected with a 14 way ribbon cable. Single sided radio frequency board and double sided microprocessor board
Printed circuit board area = 25810 mm^2 paper based construction and 4516 mm^2 lost due to transformer cut-out	Printed circuit board area = 28120 mm^2 1225 mm2 lost due to transformer cut-out 3168 mm2 used by double sided board of fibre glass base with plated through holes
Receiver circuit electronic component count = 51	Receiver circuit electronic component count = 46
Transmitter circuit electronic component count = 34	Transmitter circuit electronic component count = 40

Figure 6-1 Comparison of the assembly requirements of the Piccolo and Solo cordless telephones

component cost, while complying with the necessary operational performance.

6-3-1 Surface Mount Capacitors

Surface mounted capacitors offer advantages in medium frequency circuits because of their low series inductance. In ultra high frequency circuits, this property is more relevant because it will extend the range of component operation before other circuit techniques, such a strip-line design, must be adopted. Further work is necessary to identify the limitations of general purpose chip capacitors in these applications. Low-loss dielectric, thin-film chip types are supplied specifically for use at ultra high frequencies and it is necessary to determine when these should be used in preference and whether it is possible to successfully manufacture such circuits on cheap, paper-based PCB substrates.

6-3-2 Prototyping Issues

SMDs can complicated prototyping because it is more difficult to breadboard with them. The problem has been addressed by some accessory manufacturers who supply prototyping sockets for multi-leaded integrated circuits[58]. These allow them to be used with conventional wire-wrapping techniques. In general, it is feasible to prototype with leaded equivalents since the improved performance of SMDs will only be realisable in PCB based test circuits.

The use of circuit simulation as a replacement to initial prototyping, and ideally all prototyping, would eliminate this issue. This is discussed more in section 6-3-5.

6-3-3 Rework Issues

Rework of assemblies in a development environment was not found to be more difficult than reworking leaded circuits although optical aids were found useful by some people because of the small size of chip components.

Multi-leaded parts, such as flat packs, caused some difficulty because many leads had to be de-soldered at once. Removal was, however, possible with a hot air soldering iron when it was used with a circular motion.

In the production environment, wave soldered assemblies use glue to hold the components to the substrate. Extra force is required to break this bond when components are being removed. An accessment of the extra difficulty and possibility of board damage is required to fully gauge the rework issue.

6-3-4 Thermal Considerations

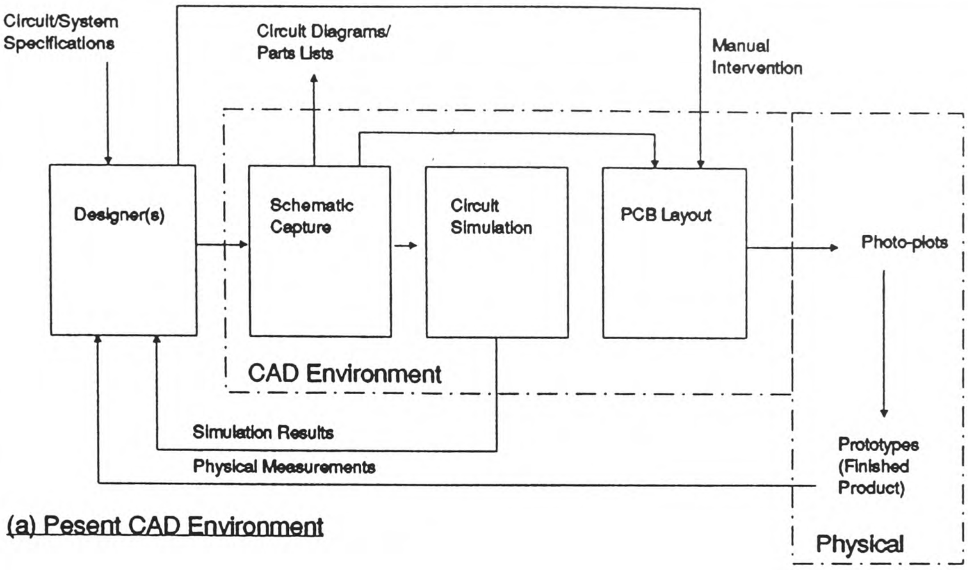
It was noted that miniaturised assemblies containing power dissipating components have greater problems with the dissipation of heat due to higher packing density and less surface area[53]. Heat dissipation may become an important factor in the design of a surface mounted assembly but no such problems were experienced during the design project because of the low powers involved.

6-3-5 Computer Aided Design

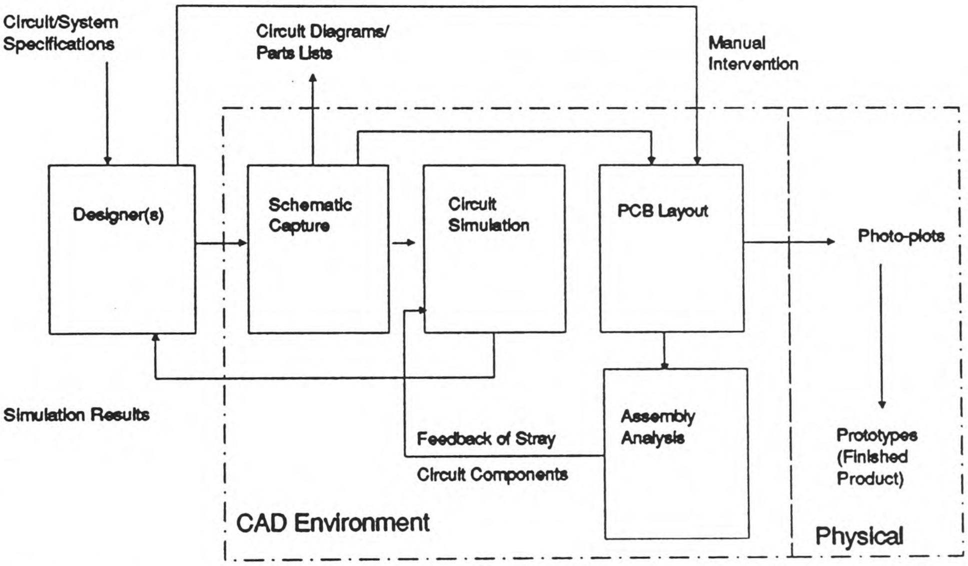
Computer aids are commonly used for schematic capture, circuit simulation and PCB layout. The majority of such aids are suited to the use of SMD parts. The distinction between a SMD or leaded component is made at the schematic capture stage, where the correct footprint and layout rules are attached in preparation for PCB layout.

Simulation of radio frequency circuits gives a performance bench-mark with which to gauge a physical prototype. An exact correlation between a circuit diagram and physical construction is only possible when there are no stray circuit components, and becomes less likely as frequency increases. Design of high frequency radio circuits often involves the need to prototype in order to evaluate the effect caused by circuit components that are not depicted on the circuit diagram and then to minimise detrimental effects.

To remove this stage of development, it would be necessary to have feedback in the CAD process as illustrated in figure 6-2. No such tool was found suited to such a stage and the analysis of the possibility of such a development is necessary if a complete CAD development environment is to be achieved.



(a) Pesent CAD Environment



(b) Proposed CAD Environment

Figure 6-2 Electronic computer aided design environments

6-3-6 Test Point Minimisation

SMAs require in-circuit test points to be designed into the PCB because SMDs terminals can not be probed directly. This requires the involvement of PCB test engineers early on in the project to achieve correct testability. The need for the test points also reduces the packing density of PCBs, thus offsetting a major advantage of the components, and is most acute in single sided circuit designs.

A judicial selection of leaded components and SMDs can increase component density because leaded components' terminations can be probed. Alternatively, the use of functional testing of circuit sections could reduce in-circuit probe pads. It is thus necessary to examine functional test strategies which confirm individual component correctness while minimising the number of probe points necessary.

Appendix A

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Appendix B

Piccolo Cordless Telephone Users' Guide

PICCOLO 'A'

USER GUIDE

CONTENTS

1. GENERAL

The PICCOLO Cordless Telephone is approved for use as an extension telephone on :

Direct Exchange Line (DEL) using Loop Disconnect signalling.

IMPORTANT NOTES :

1. The PICCOLO telephone is **NOT** suitable for connection to the following types of installation :
    1. Shared service.
    2. DC ´Code C´ switchboard.
    3. British Telecom cordless switchboards in the range 2 exchange lines, 6 extension capacity up to 5 exchange lines 25 extension capacity.
    4. As an extension to a payphone.
    5. 1+1 carrier systems.
    6. PABX´s.
    7. Direct Exchange Lines with MF signalling.
2. The PICCOLO is suitable for making emergency calls to the BT emergency (999) service. It is advisable to keep a record of this number.

APPROVED for connection
to telecommunication systems
specified in the instructions for use
subject to the conditions set out
in them

3. If the batteries within the handset become discharged to the extent that the Low Battery light comes on and subsequently goes out (the light would be on for a few hours at least), then the PICCOLO can neither make or receive calls until the battery is recharged. It takes 24 hours to fully recharge the battery.

The handset battery will normally provide for 30 hours use in Standby mode or 6 hours of continuous In Use mode operation.

4. Only the baseunit charging facility supplied with the PICCOLO can be used to charge the handset batteries.

5. If other cordless telephones operating on the same radio channel are in close proximity, co-channel interference may occur. If this happens, the PICCOLO telephone will detect the interference and close down the operation after 16 seconds. Any further usage of the PICCOLO whilst the interference is present will be terminated after 16 seconds.

This interference is more likely to occur as the general use of cordless telephones increases. Should you experience this difficulty, please contact the supplier of your PICCOLO telephone.

6. It may prove impossible to make calls, including 999 emergency calls due to :

(a) radio channel interference

(b) a discharged handset battery (See Note 3)

(c) a fully discharged baseunit battery when the mains supply has failed (See Note 7)

7. The base unit of the PICCOLO contains a battery intended to provide back-up power in the event of a mains power failure. The battery will provide enough power to keep the PICCOLO operational for 10 hours in Standby. Making or receiving calls, ie with the switch in the ´Use´ position, with the ´In Use´ light on, the battery life is a minimum of 6 hours in standby plus 1 hour in ´In Use´.

Should the base battery become completely discharged, it should be replaced with a new battery of the same type. The base battery is a Duracell PP3 type which is accessible for purposes of changing by removing the two screws thus releasing the battery box cover. The battery may then be lifted out and disconnected. Replace the battery with a new one and re-assemble the cover.

8. Users are advised that the received conversation during a call may be overheard by some domestic radio broadcast receivers since it is transmitted from the base unit to the handset in the same band of frequencies.

9. This cordless telephone has been designed to operate on radio frequencies which have been assigned to the exclusive use of cordless telephones. As the use of cordless telephones becomes more widespread, users may experience a reduction in the quality of service obtainable from this apparatus.

CONNECTION :

The PICCOLO is connected to the PBX or Public Network via the new standard Line Jack Unit (LJU) and is fitted with a compatible BS6312 plug and cord. If your installation is already wired with the new style socket, you may connect the telephone to the network by simply plugging the line cord into the socket.

If your installation has not yet been wired with the new sockets you should contact your local British Telecom Area Sales Office who will be pleased to arrange for a socket to be fitted. Please use the enclosed card to request the fitting of a socket.

FACILITIES:

Your PICCOLO telephone is fully tested and approved for use of the following facilities :

- * LD Dialling
- * Simple telephone
- * Automatic storage of last number dialled
- * Push button dialling
- * Storage of telephone numbers
- * Abbreviated dialling of stored telephone numbers

Any other usage will invalidate the approval of the instrument, if, as a result, it then ceases to conform to the standard against which approval was granted.

NOTE: There is NO recall facility provided on the Piccolo.

RINGING:

Standard exchange lines provide only a small current to make telephones connected to them ring. Although it is possible to connect any number of sockets to a line, it is important to limit the number of telephones connected to those sockets to ensure that each telephone will receive enough current to ring. In most cases, a standard line will provide enough current for any number of telephones to ring provided that the "Ringer Equivalence Number" or REN add up to no more than 4.

The PICCOLO has a REN of 1. Any other instrument may be assumed to have a REN of 1 unless otherwise stated.

2. INITIAL CHECK

When the cordless telephone is first unpacked confirm that the package contains the following items :

(a) The Cordless Handset

(b) The Baseunit

(c) Application for connection to BT Lines.

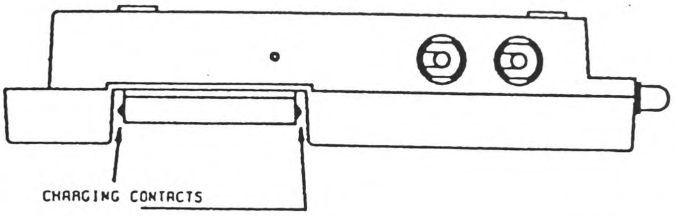
3. KEY TO COMPONENTS

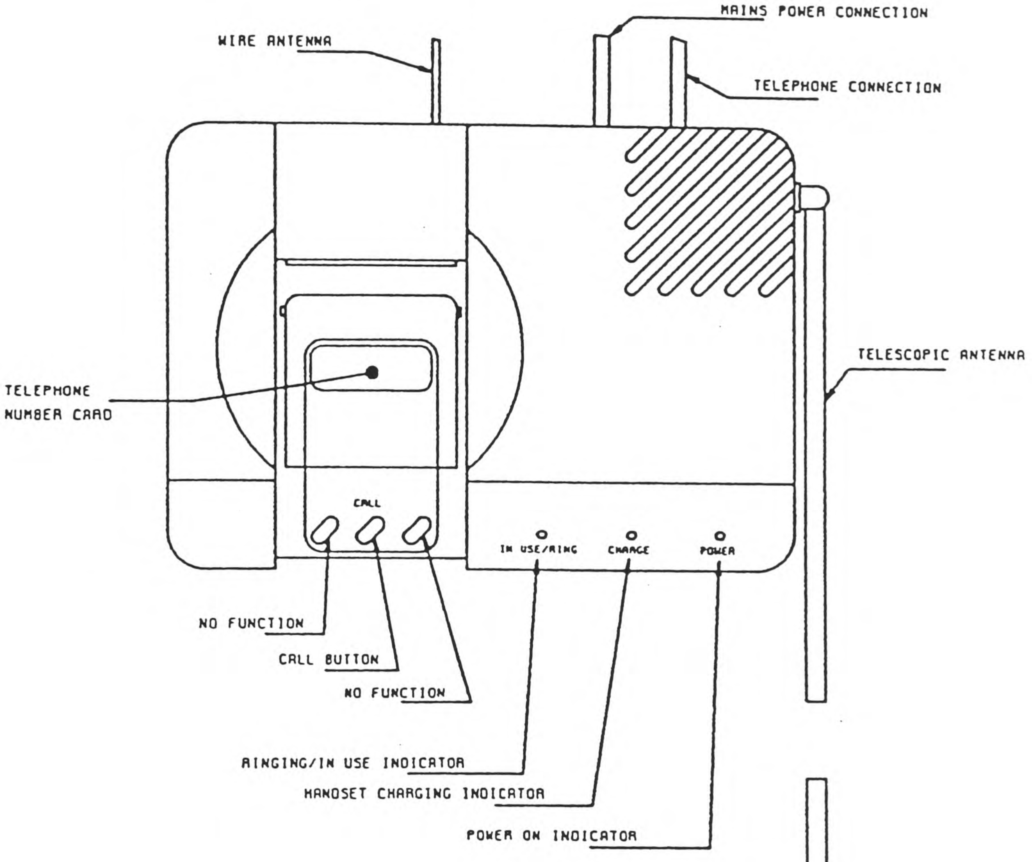
The baseunit is shown on page 8. There are two connections at the back of the instrument. These are the telephone line connection, and the mains supply cable. In addition there is a wire aerial situated at the back.

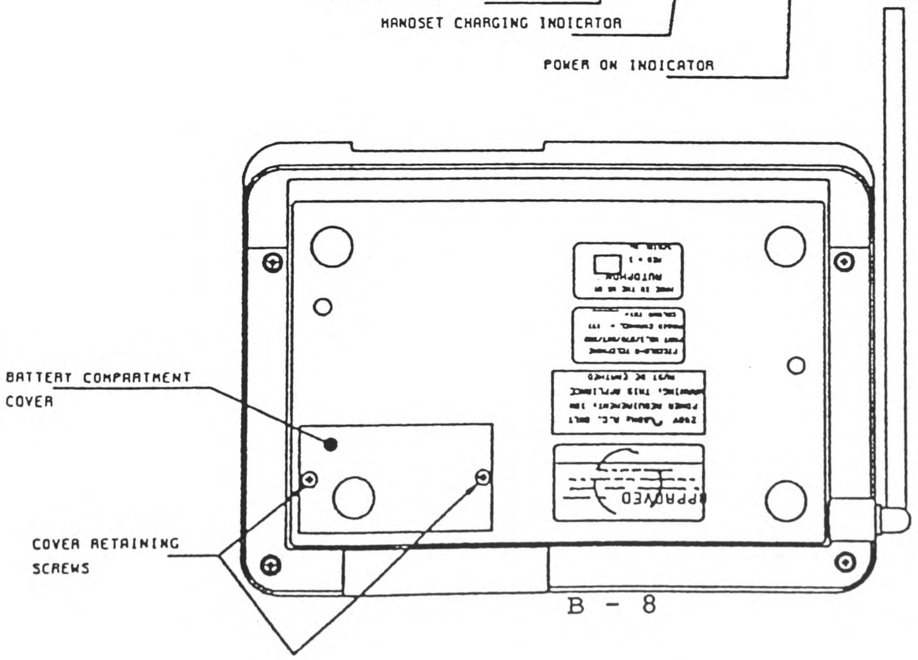
To the right of the instrument is a telescopic antenna which is used for receiving the signal from the handset. This antenna has a swivel joint allowing it to be moved to any position in the vertical or horizontal planes.

The baseunit has three indicators which are ´CHARGE´, ´IN-USE´ and ´POWER´.

A call button is provided which allows paging of the handset.


CHARGING CONTACTS


WIRE ANTENNA
MAINS POWER CONNECTION
TELEPHONE CONNECTION
TELESCOPIC ANTENNA
TELEPHONE NUMBER CARD
CALL
IN USE/RING
CHARGE
POWER
NO FUNCTION
CALL BUTTON
NO FUNCTION
RINGING/IN USE INDICATOR
HANDSET CHARGING INDICATOR
POWER ON INDICATOR


BATTERY COMPARTMENT COVER
COVER RETAINING SCREWS

The handset is similar to a normal telephone handset with the addition of a telescopic antenna and further indicators and buttons. The telescopic antenna is used for transmission to the baseunit.

A transparent window retains the telephone number card.

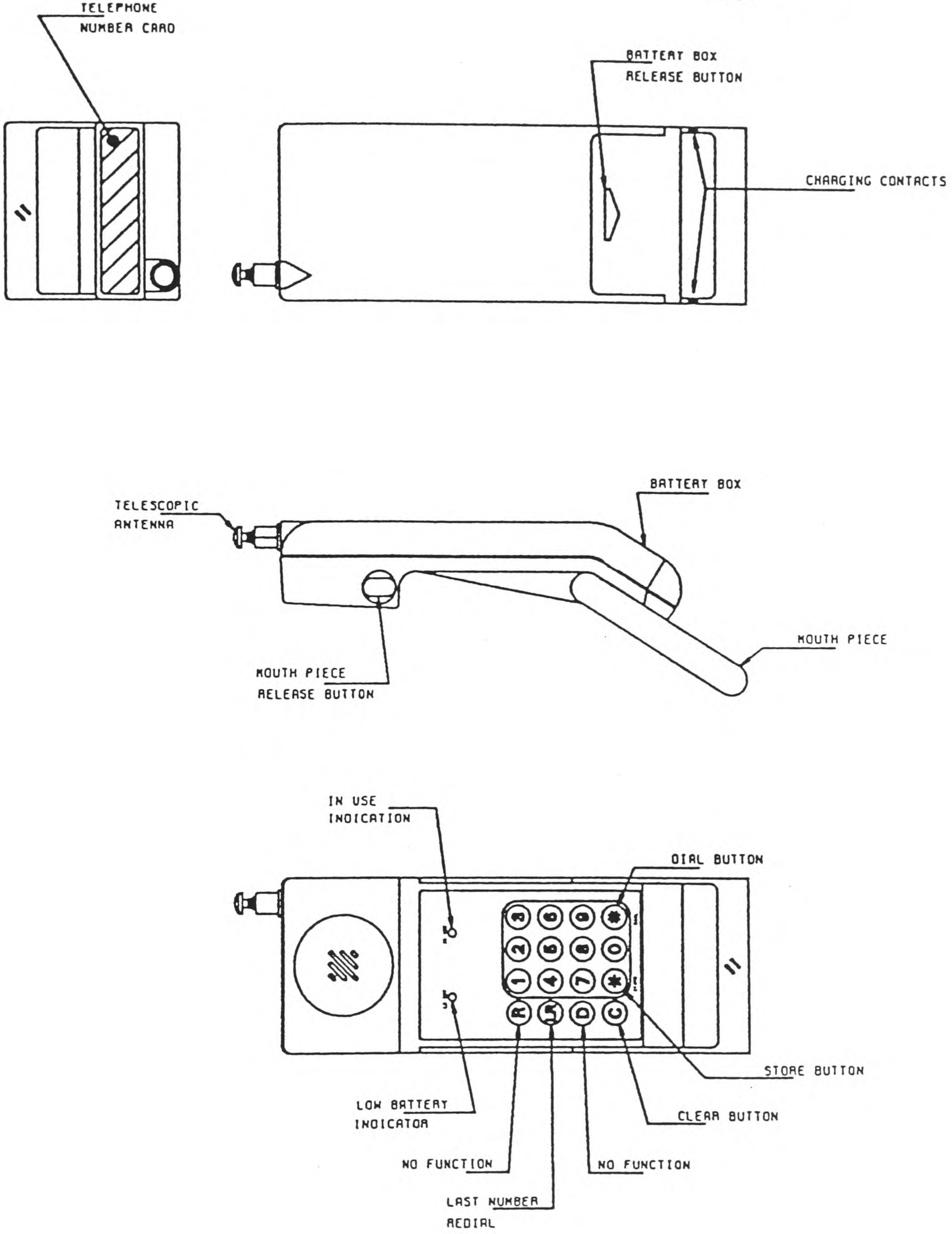
In addition to the usual ´0´ to ´9´, ´*´ and ´=´ buttons, two further buttons are provided, these being ´C´ (Clear) and ´LR´ (Last Number Redial).

NOTE: The buttons labelled ´R´ and ´D´ perform no function in this version of the PICCOLO.

Two indications are provided and these are ´LOW BATTERY´ and ´USE´.

A ringer is mounted in the handset to indicate incoming calls.

The handset charging contacts are placed in the microphone arm of the handset.



PICCOLO 'A' CORDLESS TELEPHONE
HANDSET FEATURES

4. CONNECTION

The baseunit should be fitted with a mains plug taking care to connect the Brown wire to the ´live´ pin, the Blue wire to the ´neutral´ pin and Green/Yellow wire to the ´earth´ pin. A one amp fuse should be installed into the plug.

The telephone number card window may be removed by levering in the centre of the window using a pointed object and the subscribers number then written on the number card.

A position should be chosen for the baseunit that is convenient for both a mains socket and a BT line socket.

Plug the telephone line connection into the BT socket and connect the mains supply. The ´POWER´ indication should be illuminated showing that the baseunit is on.

NOTE: For connection to the telephone line, see Connection section of General instructions.

Now place the handset onto the baseunit and note that the charging indicator on the base unit is illuminated. LEAVE THE HANDSET ON CHARGE FOR 24 HOURS BEFORE USING THE TELEPHONE.

When the batteries are fully charged and the telephone is ready for use extend the telescopic antenna on the baseunit to its full length and position vertically. Unwind the flexible wire antenna and extend it to its full length away from the baseunit. The antenna should preferably be placed as high as possible and away from any metal surfaces.

5. OPERATION

In order to make or receive a call on the cordless handset two actions are required :

(1) Extend the handset telescopic antenna.

(2) Release the microphone arm by pressing the release button by the side of the earpiece.

Calls may then be made in the normal way by dialling the required number.

At the end of a call, close the microphone arm by pivotting it back to the earpiece end. A clip will hold it in place.

When incoming calls are received, the call will be accepted with the antenna retracted, but it is necessary to extend the antenna in order to take the call and talk to the caller.

STORING TELEPHONE NUMBERS

The PICCOLO telephone can store up to 9 telephone numbers each up to 16 digits long. These are stored under each keypad digit 1 to 9. To store a telephone number :

* Ensure microphone arm is closed.
  (The ´USE´ light will be extinguished)

* Press the ´STORE´ button

* Press the digit (1 to 9) that you require the number to be stored under
  Enter the telephone number

* Press ´STORE´ button

NOTE 1: The Maximum number of digits allowed in each store is 16. If further buttons are pressed, no confidence tone will be heard and the extra digits will not be stored.

2: If a mistake is made in entering numbers, press the ´C´ (CLEAR) key. All numbers pressed after the first number following pressing of the ´STORE´ button will be cleared - the number can then be re-entered from the beginning.

MAKING CALLS

In-Use Light

When making calls, ensure that the ´In-Use´ light is on by releasing the microphone arm.

Having ensured the ´In-Use´ light is on, there are then several possible ways of making calls -

DIALLING FROM THE KEYPAD

Simply key the digits of the telephone number on the keypad. A confidence tone will be heard for each button press. If the button is not recognised, no confidence tone will be heard. In this case, press the ´C´ button, wait for dial tone and then re-dial.

DIALLING FROM STORE

To dial a previously stored number (see "Storing Telephone Numbers" section), use the following procedure :

- Ensure the ´In-Use´ light is on. (See ´In-Use Light´ section)
- Press the ´DIAL´ button.
- Press the digit under which the required number is stored. The complete number stored will then be dialled.
- If necessary, digits may be entered on the keypad after the stored number has been completely dialled.
- If required, digits may also be entered from the keypad and then the ´DIAL´ button followed by a digit for a stored number pressed.

NOTE 1: If a mistake is made, eg pressing the ´*´ or ´0´ buttons after the ´DIAL´ button, no tone will be heard when the ´*´ or ´0´ button is pressed. In this case, the incorrect press will be ignored and you can proceed by pressing the correct button.

LAST NUMBER REDIAL

The last number dialled from the keypad may be redialled by simply pressing the ´LR´ (REDIAL) key. Remember to ensure that the ´In-Use´ light is on before pressing the ´LR´ key. (See ´In-Use Light´ section).

If ´Unobtainable´ tone or no tone at all is heard after dialling from the keypad, it is not recommended that ´LR´ is used - you may have mis-dialled. It is better to re-dial using the keypad.

NOTE: If the last number dialled contained more than 21 digits, the ´LR´ key will be ignored, no confidence tone will be heard when it is pressed and no dialling will take place.

FOLLOW-ON CALLS

When wanting to make another call immediately after finishing a call, simply press the ´C´ button, wait for a dial tone and proceed with the next call.

PAGING

The baseunit ´CALL´ button can be used to ring the handset. In this case the tone caller will continue to ring as long as the base unit ´CALL´ button is depressed.

NOTE: The paging facility will not operate when either a call is in progress or the handset is ringing.

INCOMING CALLS

When in the ´STANDBY´ mode the handset indicates incoming calls via the tone caller. The tone will be sounded with the same ON/OFF period as normal ringing tone.

LOW BATTERY

The ´LOW BATTERY´ lamp will light if the battery voltage is lower than required. If this happens, the handset should be placed on the baseunit until the ´Low Battery´ lamp no longer lights. If the handset is not placed on charge within a few hours, the ´Low Battery´ lamp will extinguish, and further use of the telephone will not be possible until the batteries are recharged.

ERROR

If the user makes a keypad entry which the telephone cannot interpret, no confidence will be sounded when buttons are pressed.

POWER ON INDICATOR

The 'POWER ON' indicator is used to show that mains power is being supplied to the baseunit.

IN USE INDICATOR

This indicates that the handset is either in the 'USE' mode, or an incoming call is being received, or that the handset is being paged from the baseunit.

SECURITY CODING

The handset is uniquely identified with its own baseunit by a security code that is transmitted between the handset and the baseunit while a call is in progress.

There are more than 65,000 codes in use and the possibility of a handset being able to access a baseunit other than its own is virtually eliminated.

Microprocessors in both the handset and the baseunit maintain continuous signalling and in the event of an unidentifiable code being received prevent the users telephone line being accessed.

6. INSTRUMENT CARE

The telephone should not be exposed to rain or moisture. Clean the telephone with a damp cloth without the use of abrasive cleaners.

Should the telephone fail to operate properly carry out the procedures detailed under 'Fault Procedure'.

7. FAULT PROCEDURE

Your PICCOLO telephone is built to the highest standards and should give you many years of trouble-free operation. If, however, you are unable to make a call when first installing the telephone a few simple items can be checked :

1. The telephone cord is properly plugged in.
2. The power indicator on the baseunit is lit. If it is not check that the mains power supply is plugged in and switched on.
3. The ´CHARGE´ indicator is ON when the handset is replaced.
4. The handset and baseunit antennas are fully extended.
5. The handsets on other telephones connected to the line are properly in place.
6. The ´BATTERY LOW´ indicator is not lit.

If after making these checks the cordless telephone does not work a few basic checks can be made :

1. Disconnect the telephone from the socket and, if possible, plug into another socket. If the telephone now works, the original socket was faulty.
2. If possible, plug another telephone into the socket and try to make a call. If you succeed in making a call, the PICCOLO must be faulty.

NOTE 1: If it is not possible to identify a fault by any of these means, the PICCOLO should be returned to the supplier, stating the nature of the fault.

8. GUARANTEE

Following the purchase of your PICCOLO Cordless Telephone the attached Guarantee Card should be completed and returned within seven days to Autophon.

GUARANTEE

Your PICCOLO telephone is fully guaranteed for a period of one year provided that :

(a) The telephone has only been used for its intended purposes and has not been subjected to misuse or accidentally damaged.

(b) The telephone has not been tampered with or repaired by anyone other than Autophon (UK) Limited, its staff or Agents.

If a fault does occur in the instrument, it should be returned to the place you bought it and, provided you produce your receipt, it will (within the guarantee period) either be repaired or replaced free of charge.

The terms of this guarantee do not affect your statutory rights.

TO BE RETAINED BY PURCHASER

PICCOLO TELEPHONE

Purchased from ....

Address ....

....

....

Date of Purchase .... Date of Guarantee Card Sent ....

Tear off along this line

GUARANTEE REGISTRATION CARD

PICCOLO TELEPHONE

Purchaser's Name ....

Address ....

....

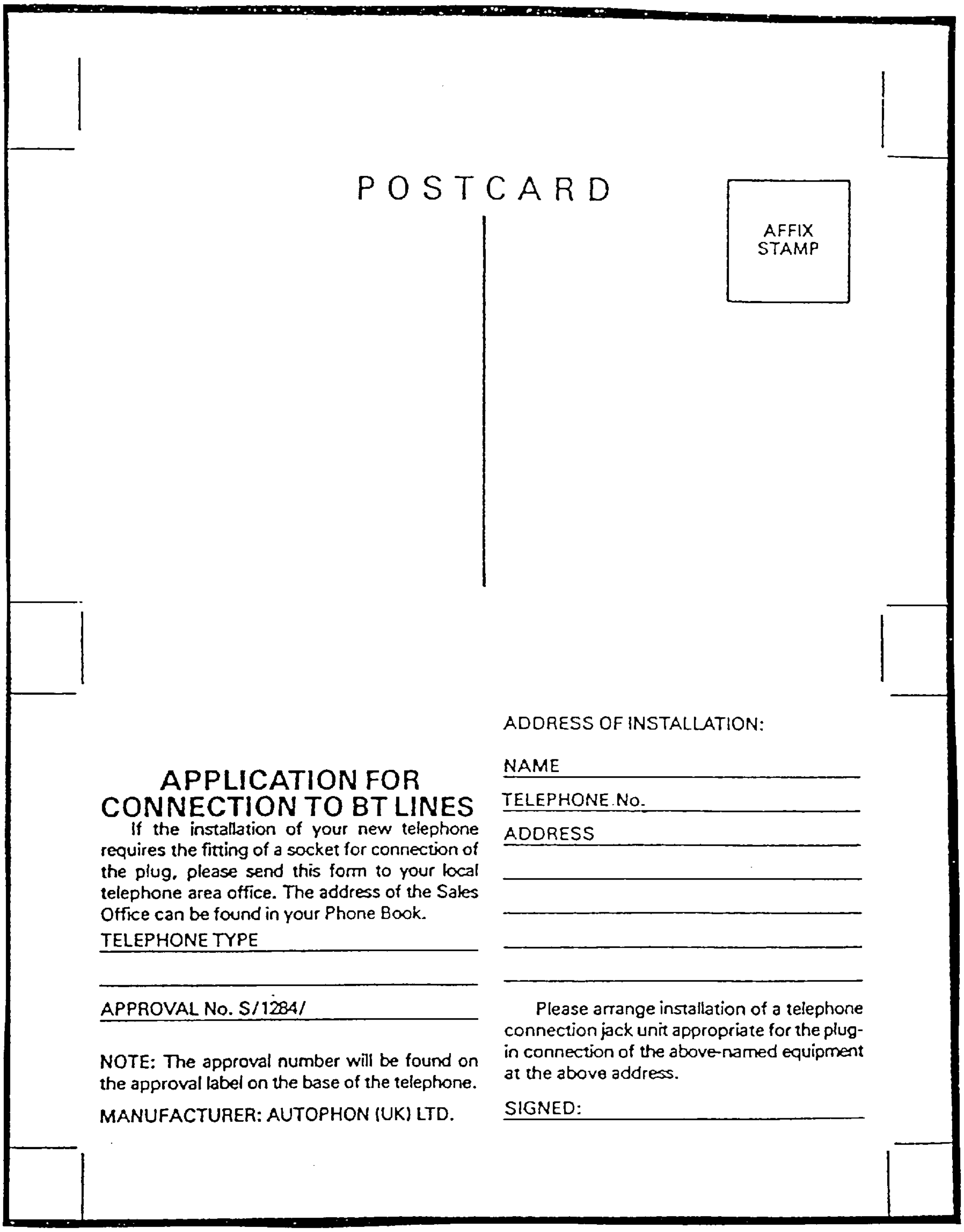
Purchase From .... Date ....

Address ....

....

I accept the Terms and Conditions to this Guarantee.

SIGNATURE: .... DATE: ....



POSTCARD

AFFIX
STAMP

APPLICATION FOR CONNECTION TO BT LINES

If the installation of your new telephone requires the fitting of a socket for connection of the plug, please send this form to your local telephone area office. The address of the Sales Office can be found in your Phone Book.

TELEPHONE TYPE

APPROVAL No. S/1284/

NOTE: The approval number will be found on the approval label on the base of the telephone.

MANUFACTURER: AUTOPHON (UK) LTD.

ADDRESS OF INSTALLATION:

NAME

TELEPHONE No.

ADDRESS

Please arrange installation of a telephone connection jack unit appropriate for the plug-in connection of the above-named equipment at the above address.

SIGNED:

Appendix C

Surface Mount Design Guidelines for the
Development of the Cordless Telephone

1-0 Introduction

This document is aimed as a guide to the choice and use of various surface mount assembly possibilities. Along with overviews of possible techniques and difficulties, various sets of detailed design rules are included. Such techniques and rules are applicable to the facilities available at Autophon (UK) Ltd. and are intended to be continuously updated as new methods become established, new equipment becomes introduced and as feedback statistics become available as to production reliability, etc.

The document also contains a section concerned with developing and prototyping circuitry using surface mounted components and contains notes about Surface Mount Device (SMD) application in high frequency circuits.

Several techniques and terms introduced may be unfamiliar to the reader. When a deeper understanding is required, specific information can be obtained from the Industrial Engineering Department. This interaction and exchange of interests throughout all stages of the planning and development of products is encouraged due to the inter-related nature of the surface mount processes.

2-0 Guide to Selecting Surface Mount Solutions

Surface Mount Technology (SMT) offers various assembly options. Four categories exist for the manufacture of a PCB incorporating SMDs. These are shown in table 1. As indicated, there are two basic soldering processes that are in common use although there are a number of others available in special circumstances (laser reflow, hand soldering, hot shoe for flat packs, etc.).

CATEGORY	Soldering Process
1. SMDs on one side of PCB	Reflow or wave soldering
2. Mixed technology. SMDs on one side of the PCB only	Wave soldering only
3. SMDs on both sides of the PCB	Reflow and/or wave
4. Mixed technology. SMDs on both sides of the PCB	Reflow and wave

Table 1

Before commencing with PCB layout or component acquisition for a project it is necessary to establish the basic surface mount solution assembly category. The answers to the following set of questions are essential to the selection of techniques to be used for design and manufacture and also for component selection criteria. Most important to the complete assessment is the consultation with all Autophon departments as to their exact requirements (ie. Computer Aided Design, Industrial Engineering, Purchasing, Production, etc.). It can not be over-stressed how much more interdependent the needs of Surface Mounted Assemblies (SMAs) are and how the effective use of them relies on well-organised communication between all sections concerned.

Fundamental Surface Mount Solution Category Definition

1. Category of Printed Circuit Board (PCB) or PCBs to be used. The categories are those found in table 1.

2. Method of soldering to be employed and any PCB cleaning necessities.

3. Detailed PCB requirements. (Is copper required on both sides of the PCB ? Are plated through holes to be used ? Is an earth plane necessary ? Are ground planes to be used ?)

4. Automatic placement equipment demands.

5. Product testing and rework strategy.

Production Process

In order to introduce the basic manufacturing processes involved with surface mount technology, the steps required for a category 4 assembly will be described. Other assembly categories tend to be a sub-set of these.

```
                         Bare Board
                              |
[1]                 Screen Print Solder Paste
                              |
[2]                   Place SMDs on side 1
                              |
[3]                   Reflow solder side 1
                              |
[4]              Auto-Insertion of leaded devices
                              |
                         Board Invert
                              |
[5]                     Glue Placement
                              |
                      Place SMDs on side 2
                              |
[6]                        Cure Glue
                              |
                         Board Invert
                              |
                Hand Insert special components
                              |
[7]                    Wave Solder side 2
                              |
[8]                       Clean Board
                              |
                              |<-------------------\
                              |                    |
[9]                     In-circuit Test  -->    Rework
                              |                    |
                 Assembly and Functional Test -->-/
                              |
                           Packing
```

[no.] Notes are included over-leaf.

[1] A PCB to be reflow soldered uses a solder paste which is screen printed onto the flat surface of the bare PCB. Its viscosity is used to hold the components in place before they are securely soldered.

[2] SMDs are sometimes placed by hand, often with a computer guidance system for the operator but for high volumes an automatic placement machine is essential.

[3] Reflow soldering forms bonds by heating the solder paste to a temperature at which it becomes molten. The heating is often achieved by infra-red radiation or by the condensation of a vapour from a boiled liquid. Laser soldering is also possible where each solder joint is attended to individually.

[4] Leaded components are inserted as normal.

[5] When SMDs are to be wave soldered they must be held in place by a glue. The glue is applied normally by a glue dotting process. The automatic SMD placement machine often offers such a facility although dedicated equipment is also available. It is possible to screen print glue but this has some drawbacks, one being that the surface must be flat and so it is excluded from this production category.

[6] Glue curing is performed by infra-red or ultra violet light.

[7] Wave soldering of assemblies with SMDs requires modified wave soldering machines. Often the machine uses a specially turbulent wave before the main laminar wave to ensure good wetting across the PCB.

[8] Board cleaning may be defined by a customer or be necessitated by the fluxes used in the solder bath but can often be avoided.

[9] Board testing and rework may require alternative techniques. High density can make test points more difficult to supply. Double sided boards may require test points on both sides of the PCB and test fixtures to suit. Rework of SMDs may be complicated by the glue used to hold them in position for wave soldering and also due to their smallness.

Not all facilities mentioned are available at Autophon. At the time of writing, the following were available and design rules are based on their use:

DEK 245 Screen Printer.
Computer based manual SMD placement system.
Glue Curer.
Panasert Axial and Radial leaded component inserter.
Universal Axial and Leaded component inserter.
Dual wave solderer.
Huges hot shoe flat pack solderer.
2 x Marconi in-circuit testers.
Hot air soldering and de-soldering work station for re-work.

Adhesive placement

Glue can be placed only on a flat board by screen printing. This method is quick but can suffer from screen clogging and offers no control over glue dot height. An SMD component onsertion machine will offer a glue dotting facility or a dedicated glue dotter could be purchased.

The glue placement process should aim at positioning a quantity of glue with a profile sufficient to reach the underside of all SMDs. The quantity should not be such that the adhesive spreads onto pads as components are positioned. To avoid problems of variable glue profile across a PCB it is beneficial to place "dummy" tracks beneath SMDs when none already exist. Such a "dummy" track consists simply of an unused copper track with the usual copper thickness to raise and standardise the glue height. Such a track is described in the PCB design section.

Glue Requirements and Curing

Glues used within the SMA process should have the following properties:

1. The viscosity and drop profile should be such that it enables the glue to reach the under side of all SMDs but does not spread greatly when components are placed.

2. It must be electrically non-conductive.

3. It must be non-corrosive when placed and also as it ages.

4. It is required to be tacky before curing in order to hold the components in place.

5. It must be chemically un-reactive with fluxes or solvents used within the production process.

6. It is beneficial if it has a distinctive colour to aid quality inspection.

7. Glue curing is performed normally by heat or with ultra violet light and depends on the glue type chosen. When heat is required it is important that the cure temperature at the surface of the PCB does not exceed the maximum permitted for the type of PCB material used. FR2, Paper phenolic - 80 °C. FR4, Epoxy glass - 150 °C.

8. The glue must be able to withstand the wave soldering temperature. At a glue's glass transition temperature it becomes brittle and the bond is easy to break. Components must not fall off into the solder bath.

9. The bond made by the glue should not be excessively strong such that components become impossible to be removed in the case of rework.

10. Any toxicity associated with the adhesive must be taken into account before handling.

Prior to adhesive curing, the PCB should be inspected to ensure correct component placement and to ensure no glue fouling of the component footprints.

Component Placement

Component placement rate is limited by the speed of the manual operator and can only be expected to be between 300 and 600 components per hour. Typical automated onserters are able to place 4000 components per hour.

Automatic Component Insertion

A number of parameters are affected by the type of equipment used in production. For example the possible component pitches placed by the two types of insert machines are as follows:

Panasert: Radial 0.2"
Axial 0.2", 0.4", 0.5"

Universal: Radial 0.2"
Axial 0.2" to 1.3" in 0.05" increments

Only in exceptional circumstances should a layout be tailored for a particular automatic insertion machine, eg. when the flexible placement of the Universal machine would allow production of a PCB which would not otherwise be possible. All other non-critical PCBs should be laid out for worst case insert conditions allowing optimum use of the auto-inserters.

SMDs may be placed in between the legs of leaded components as long as this is done in accordance with the constraints imposed in the PCB design section of the document. Such a placement is illustrated in figure 1.

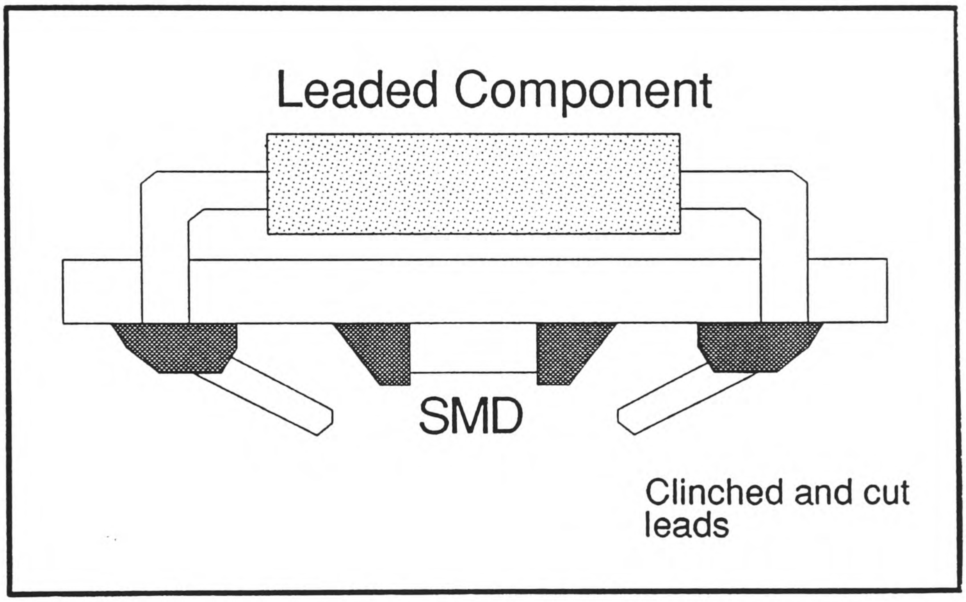


Figure 1 Example of a SMD positioned under a leaded component

<u>Wave Soldering</u>

The dual wave machine used for soldering SMDs differs from ordinary wave soldering machines in that it incorporates two wave sections. The first is a turbulent wave which drives away trapped gases and flux residues. The second section is a smooth wave which completes the solder fillet formation and eliminates bridges. Difficulty will always be experienced if the use of normal wave soldering equipment is attempted.

The quality of wave soldering is very dependant on the layout of the PCB which is detailed in the PCB design section of this document. Component footprints are designed so that they attract sufficient solder from the solder bath and components are positioned to avoid shadowing others.

For correct wave soldering it is necessary to take a number of other parameters into consideration. The standardisation of them should be established by the production section.

1. Flux type and specific gravity.
2. Conveyor speed (usually ft/min).
3. Pre-heat temperature.
4. Solder bath temperature.
5. Solder alloy (eg. 63/37 tin lead).

Within a wave soldering bath the flux is applied initially by brushing, foaming or spraying. Its purpose is to remove oxide from the soldering surface and then to ensure that no re-formation of the oxide occurs prior to soldering. As the board is pre-heated, the flux is activated and its viscosity increases as solvent is boiled off. Pre-heating usually achieves a board top side temperature between 80 and 100 °C. Optimum soldering tends to be accomplished by passing the board at a slight angle of 5-7 degrees to the horizontal.

Solder bath temperature is around 250 °C and the board is in contact with it for between two and three seconds. Oil is sometimes added to the solder bath to help eliminate solder bridges or "icicle" formation.

All boards should be as clean as possible prior to the wave soldering process. Contact with the PCBs should therefore be avoided and handling should be only by the edges.

Solder Fluxes

Fluxes may be divided into two broad categories; organic and water soluble. Most organic fluxes consist of a rosin dissolved in a thinning agent such as alcohol. Activators are sometimes added which increase the flux activity. Table two compares various rosin based fluxes with varying strengths.

Due to legislation on the use of organic solvents, the cleaning of such fluxes may be limited in the future. Other organic fluxes which are not rosin based are termed synthetic. They tend to be weak and have a low solids content: eg. Multicore X32. Cleaning is not normally necessary with synthetic fluxes.

Water soluble fluxes are very active and will always require PCB cleaning following the soldering process. The residues of these fluxes can either corrode the PCB or create conductive substances which provoke current leakage. As the name implies, the residue of these fluxes are cleaned using aqueous cleaning equipment.

Flux type	**Comments**
R (Rosin) Flux	Contains no added activators and flux action is weak. No PCB cleaning is necessary.
RMA (Rosin Mildly Activated)	Contains small amounts of added activators but not sufficient to warrant cleaning. Residues may clog up test points for in circuit testing.
RA (Rosin Activated)	Contains a higher percentage of activators than RMA. Cleaning will depend on the working environment of the finished product.
RSA (Rosin Strongly Activated)	Fluxes of this activity should not be required in surface mount soldering due to the high solderability inherent of SMDs. Cleaning would probably be necessary.

Table 2

Cleaning

The issue of SMA cleaning is very debatable and depends on a number of factors with the solder bath flux influencing it greatly. Some fluxes, such as water soluble types leave what are termed ionic contaminants which will freely conduct current and react with metals to give corrosive products

Some fluxes leave corrosive residues which may damage the PCB as they break down with time. Other residues solidify and are not corrosive. The cleaning process itself can, however, also cause problems. Apart from the difficulty of cleaning assemblies with non-solvent proof components, such as telephone hook switches, it is possible for flux resides to become trapped under SMDs. This is due to the cleaning process forcing them under these devices which are very close to the board surface. If cleaning is to be performed it must thus be done thoroughly.

It should be ensured that if cleaning is necessary, all components used are solvent proof. Some solvents may only be used with SMDs as they attack leaded components. It is generally accepted that solvents such as Geneklene and Arklone-AM are suitable for both types of components although suitability should be confirmed by the Industrial Engineering Department. Some products may require cleaning due to customer specifications (eg. Military or British Telecom). In general is is best to avoid cleaning unless it is absolutely necessary. The use of ultra-sonic cleaning may be prohibited by some customer requirements.

Reflow Soldering

Although no facilities exist for reflow soldering at Autophon at the time of writing, this method will almost certainly be necessary for double sided assemblies. The soldering of devices such as plastic leaded chip carriers is also not practical by any other method. The most common forms of reflow soldering are infra-red and vapour phase. Since the latter uses the vapour of a boiling liquid to flow the solder it has the advantage that all of the substrate attains this temperature (215 °C) and no hot spots are created.

Infra-red is more applicable to a pass through system and normally contains a number of heating zones so that the temperature profile can be altered for every type of PCB. Problems may be encountered with colour selectivity using infra-red, although the systems based on 6-10 micron wavelength radiation claim greater immunity.

If reflow soldering is to be used on cheap board materials such as FR2 then the vapour phase solution will probably give the best results and avoid board damage possibility. Newer infra-red machines, using a high percentage of heat supplied by convection rather than radiation, claim to be better suited to paper based boards.

Hot Collet Machine

A hot collet machine is available although is considered rather more a rework tool. Flat pack devices may be soldered without glue paste when the footprint is tinned to over 50 microns thickness. A small amount of solder paste in addition can aid as a supplement but the method's reliability has not yet been confirmed. Flat packs can also be wave soldered as detailed in the section concerning PCB design and this method is preferred, although again its reliability has not yet been fully assessed.

PCB Constraints and Materials

The size of a PCB is limited by the processes that it must pass through. The limitations of the available equipment are as follows:

DEK 245 Screen Printer	225 x 280 mm
Panasert Axial and Radial	334 x 250 mm
Universal Axial and Radial	457 x 457 mm
Wave soldering machine	400 mm width

It is important from a financial point of view to ensure that the optimum panel size is adopted for a particular PCB. This should be done in conjunction with the PCB layout and purchasing departments where the possible areas to consider are the manufacturers' standard panel sizes, the PCB dimensions and materials, and the method of production or assembly (eg. the use of carriers to solder panels at an angle in the solder bath).

Materials in the consumer electronics industry usually vary between the cheap FR2 to the quality FR4 materials. The following table gives some properties of these types of materials. The cost indications are based on Mullard estimates where FR2 is the baseline and the other materials are quoted as a percentage increase on FR2.

Material	**Properties**
FR2 Paper Phenolic	No solder levelling, cheap, bad stability in terms of warpage etc., questionable whether plated through holes allowed, can be punch tooled.
FR3 Paper Epoxy	Approx. 35% more expensive than FR2, solder levelling not advisable, plated through holes allowed when board not punch tooled.
CEM1 Composite Epoxy Glass with Epoxy Paper Core	Approx. 35% more expensive than FR2, solder levelling allowed.
FR4 Epoxy Glass	Good stability, approx. 80% more expensive than FR2, solder levelling and plated through holes allowed but no punch tool.

Table 3

Solder levelling should be specified on tin plated boards to ensure that the components, once placed, do not slip from their pads. This is especially important for SOT-23 components and flat packs.

Thermal mismatch between SMDs and the boards listed above will not present a problem unless leadless ceramic chip carriers are used. Due to the size of such components, the thermal expansion mismatch can be great enough for the devices or footprints to be destroyed unless a matched ceramic substrate is used. Leadless ceramic chip carriers should be avoided due to the expense of ceramic substrates although such devices could be socketed.

Non-tinned PCBs may be used for SMD applications provided that the copper is covered with a protective coating to prevent tarnishing. Sourcing of this type of PCB may prove difficult although this technique is available from Mullard.

A single sided FR2 PCB is the cheapest substrate that can be used. It does not, however, display as good a stability with temperature as FR4 and may give added manufacturing complications such as re-work difficulty and lack of heat resistance during glue curing. FR2 is not suited to plated through holes. Plating through also adds greatly to the cost of a PCB and if it can be avoided will make for much cheaper substrates.

To avoid problems with bleeding of solder resist onto SMD footprints, solder resist is best applied using a phot-imaging process.

Component Selection

Due to the lack of reflow soldering facility, devices that require reflow soldering, such as plastic leaded chip carriers, some wire wound components and connectors may be restricted. All components selected must be compatible with the intended production process.

Chip components of the 1206 variety should be used as standard unless larger sizes are absolutely necessary (eg. high capacitance chip capacitors). Smaller sizes are available such as the 0805 package, which would offer space savings and tend to be marginally cheaper than larger outlines. Although more difficult to handle, they could be considered for future use when more experience with SMDs has been gained.

Mini-melf cylindrical components may be inter-changed with 1206 chip devices because they use the same footprint. Such devices do have a cost advantage but may prove more awkward to handle due to their shape requiring special pick-up heads and their tendency to roll from the footprint pads.

A good many components are available or are becoming available in a surface mountable form. The following factors should be taken into account when selecting such devices.

1. Are they suited to the soldering and/or cleaning process to be used?
2. Does the SM version offer advantages of miniaturisation, automation or performance?
3. Does the SM part have a cost/supply disadvantage that must be gauged against the advantages noted under 2?

In high frequency circuits, SMDs offer an advantage over leaded parts due to less lead length. Signal pick-up at and radiation from leads can be expected to be reduced along with circuit delays due to diminished lead/pin inductance. Capacitors used for coupling and decoupling tasks exhibit improved efficiency due to a higher self resonant frequency. For more guidance to the behaviour of practical inductor and capacitors in high frequency circuits see appendix 2.

3-0 PCB Design

The following section includes guide rules for the design of PCBs to be wave soldered at Autophon (UK) Ltd. The component footprints, component spacing and orientation will need to follow different rules should a PCB be reflow soldered. Such a guide should be added when necessary.

The precision of a PCB layout, track thickness tolerance and etch accuracy will be dependant on the PCB manufacturing process. Generally higher precision is achieved by the dry film photographic process as opposed to a wet film technique used mainly on paper based boards.

General rules for the thickness of tracking and etch accuracy obtainable are covered in the relevant Autophon document and these details are relevant also for PCBs using SMDs. Illustrations are found in the attached appendix 1.

Wave Solder SMD Footprints

Footprints to be used for SMDs are illustrated in figures A-1 to A-10. The guide includes the following components which have been taken from component manufacturers recommendations and should be updated as necessary to suit the Autophon soldering process as and when quality feedback statistics become available.

Figure A-1 SO-8 small outline integrated circuit.
Figure A-2 SO-14 small outline integrated circuit.
Figure A-3 SO-16 small outline integrated circuit.
Figure A-4 52 pin quad flat pack.
Figure A-5 0805 chip component.
Figure A-6 1206 chip component.
Figure A-7 1210 chip component.
Figure A-8 1808 chip component.
Figure A-9 1812 chip component.
Figure A-10 SOT-23.

Component Spacing

Rules for the spacing of chip components to be wave soldered are given in figures B-1 to B-2, as follows.

Figure B-1 Chip components.
Figure B-2 SOT-23 packages.

Conductor Routing Between SMD Footprints

Rules for the routing of tracks under SMD bodies are included in figures C-1 to C-4 as follows.

Figure C-1 Chip components. Assuming a minimum conductor width of 0.012", a maximum of two tracks may be routed in between the pads of a 1206 component.

Figure C-2 SOT-23 packages. The maximum number of tracks that may be placed under an SOT-23 is one.

Figure C-3 SOIC Packages. No tracks may be routed between the device legs but a number of tracks may be laid along the centre of the device where the exact number will depend on the body width.

Figure C-4 Dummy tracks for component gluing reliability. When small SMDs to be glued for the wave soldering process have no conductors running under their bodies then dummy tracks should be laid. These will help to ensure a uniform glue dot height across the board.

Component Orientation

The footprint diagrams, A-1 to A-10 show also the optimum component orientation to the solder wave. Generally the longer axis of a component should be perpendicular to the travel of the PCB during the soldering process for small devices and integrated circuits should "ski" through the wave.

Quad flat packs present difficulties to the wave soldering process due to potential shadowing and bridging. It will be possible to solder flat packs if the following rules are followed.

1. The component should enter the soldering bath at an angle of 45 degrees. This may be achieved by PCB layout or else the whole PCB should be entered at an angle. The entry of a PCB at 45 degrees should not have adverse effects on other SMDs.

2. Solder thieves must be added as illustrated in the footprint diagram for such devices (Figure A-4). Solder thieves attract solder due to their large surface area and reduce the possibility of solder bridges forming along a flat-pack's pins. Solder thieves must not be covered with solder resist because this will cancel their effectiveness.

SMD footprint/Solder land Relationships.

When connecting an SMD footprint to other parts of circuitry, such as component lands, it is desirable to make their connection as narrow as possible. This avoids solder migration from the footprint along the track. It is also beneficial to cover the track with solder resist as close to the footprint as possible for the same reason.

To avoid bridging effects, the minimum distance between adjacent solder lands and SMD footprints should be 0.035".

4-0 Test and Rework

Because SMDs can not be probed directly by a test bed of nails it is necessary to supply test points. Such test points can be the legs of leaded components that are common to this point. All test points should be made available unless the testing can be satisfied by functional test means. In situations of severe space limitations it may be impossible to supply all necessary test pads and the omissions must be approved by the Product Responsible Engineer.

The following serves as a guide to SMD test points.

1. The end terminals of SMDs are under no account to be used as test points for probing.

2. All test points should be tinned to ensure good probe contacts.

3. Via's on double sided PCBs may be used as test points under the condition that they are filled with solder to prevent the sticking of test probes.

4. There must be no solder resist on points used as test pads.

5. If possible, test pads should be marked on a PCB.

6. Numerous power and ground points should be supplied.

Figures governing test pad design rules are shown as figure D-1 to D-2, as follows.

Figure D-1 Test pad diameter and pitch.
Figure D-2 IC test pad preferred arrangements.

Rework or repair of SMAs is more difficult than leaded assemblies, especially when a device has many legs or has been glued to the substrate. Rework should be minimised and preferably avoided when low enough process defects can be achieved. If rework is essential then the following should act as a guide.

Removal

Chip devices, SOT-23s and small ICs should be removed with a hot air soldering iron. If adhesive has been used then the remnants should also carefully be removed with a scalpel ensuring that conductors running under the SMD are not damaged. Larger SMDs such as flat-packs will require special rework tools that heat all legs simultaneously. Faulty flat packs can also be removed by cutting their pins and then simply removing the individual legs from their pads.

If devices have been glued then additional heat may be required to aid in breaking the glue bond with the aid of some leverage. Ensure that the board does not become excessively heated which can cause damage to the components footprints as tracks come away from the board.

Replacement

Replacement components may be hand soldered with a hot gas soldering iron and tweezers, or alternatively a fine tipped iron. Table four serves as a guide to the suitability of soldering irons for the task.

It is important that SMDs are handled gently so that they do not crack and that heat from a soldering iron tip does not come into contact with the component body. When a hot gas iron is used a small amount of solder paste can be placed on the footprint before replacing the component. Normal soldering irons should heat mainly the component footprint and solder then be applied at the footprint to flow to the component termination.

Soldering iron type	Nicrome heating	Temperature: 280 °C max Wattage : 30 W max
	Ceramic heating	Temperature: 250 °C max Wattage : 18 W max
Tip diameter		3 mm max

Note: No pre-heating required under these conditions but iron should not touch device bodies.

Table 4

5-0 Automatic Component Placement Requirements.

Leaded Component Placement

When SMDs are used along with leaded components the requirements of the leaded component inserter must be taken into account. Two insertion machines exist at Autophon and each has its own guidelines dependant on its operation. A design should not, however, be tailored to the benefits of one unless absolutely necessary.

The decision as to whether a component may be placed should be based on the requirement for 1mm (0.0393") clearance from the SMD and any component lead.

The figures E-1 to E-3 illustrate the guide rules for positioning SMDs near to leaded components.

Figure E-1 Axial component placed by Universal machine.
Figure E-2 Axial component placed by Panasert machine.
Figure E-3 Radial components for both machines.

6-0 Additional PCB Artwork Considerations

Solder Resist

Solder resist should be used on bare copper or copper that has had plating selectively removed. This will act as a barrier to prevent solder migration from SMD footprints. The adoption of this technique is particularly suitable for the reflow soldering process but should also be used for wave soldering.

There should be a border of 0.010" between SMD footprints and the solder resist as shown in figure F-1.

Component Legend

Due to the high packing density of PCBs using SMDs the application of a component legend may prove difficult. It is thus important that an assembly drawing accompanies every PCB artwork.

7-0 Prototyping of SMAs

SMDs can not be so readily breadboarded as leaded designs often are without using a PCB. During prototyping it is therefore acceptable to use leaded component equivalents when the performance benefits of SMDs are not critical, but the aim should be to move as rapidly as possible to PCB based prototypes. In fact, the increased repeatability and predictability of circuit stray components in SMAs favours their use within a design philosophy which goes from concept through circuit simulation to PCB models.

SMDs are more difficult to handle due to their small size and some people require vision aids to work with them. Handling with tweezers is acceptable as long as it is done so carefully. It may also be achieved with a suction pickup bit. Storage in a laboratory environment, where very low volumes of circuits are constructed, is best using containers for each component type with numerous compartments for each specific value. It is recommended that the containers have a common lid for all compartments rather than having to open a separate one each time a new value is selected, but the lid must close well so as to avoid devices moving into false sections.

Soldering of chip devices can be achieved with fine tipped soldering irons when the following points are observed

1. The soldering iron specification must conform to that in table 4.

2. It helps to first tin the footprint pads with the solder needed for the joint.

3. Avoid contact with the device body and apply heat mainly to the solder at the pad. Extra solder can be added by flowing it into the molten solder at the bond point.

4. It is best to solder both ends of a chip component simultaneously by applying heat alternatively to both pads until the component is in its correct position. The correct position is usually achieved by the surface tension of the solder. When both ends are soldered separately, the surface tension of the second bond point tend to exert a force against a fixed pivot and there is a greater possibility that the component may be damaged.

Soldering may also be performed with a hot air soldering iron after a small amount of solder paste has been put onto the footprints. The component is best held in position during the heating with a pair of tweezers.

Removal of devices can also be performed with a soldering iron or by hot air. Hot air is generally the easiest removal method because both, or all contacts points, can be heated simultaneously. (This may involve a circular motion around all sides of larger devices). Devices with many leads can only effectively be removed with a hot air soldering instrument and when such is not available it is advisable to cut the component body away from the legs and then remove the stubs from the pads. The component will in this case be destroyed but this is generally better than risking damage to the device footprint.

When it is necessary to build several prototypes and a production run is not merited, the use of a small infra-red oven is advisable. The SMDs are positioned after solder paste has been applied to their footprints. Although the PCB may have been designed for wave soldering, the joint success rate is acceptable due to the low number of models and the high level of inspection that they will receive. Several ovens are commercially available for this purpose and have time and temperature controls for consistent soldering.

Appendix 1

PCB Design Illustrations

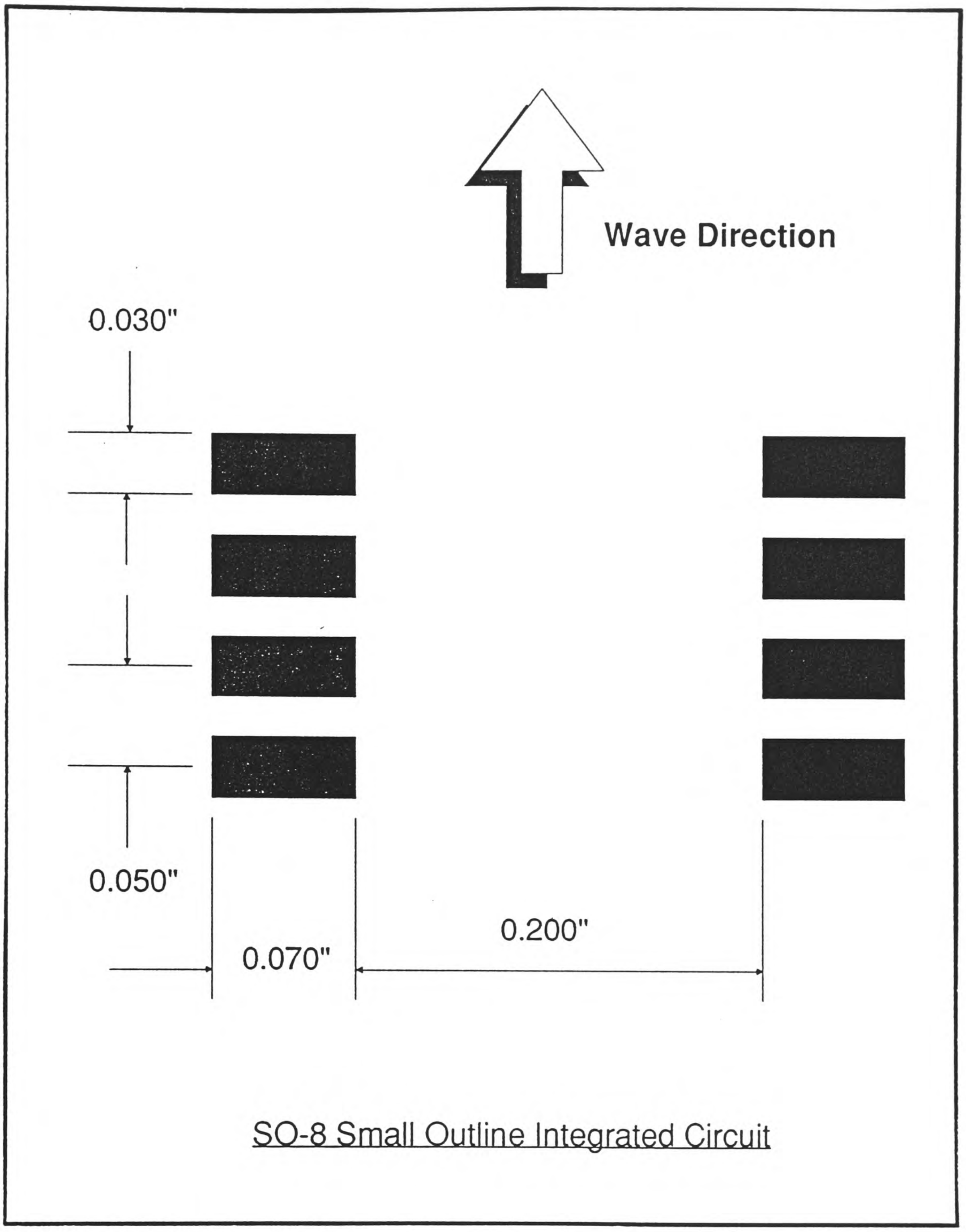

Wave Direction
0.030"
0.050"
0.070"
0.200"
SO-8 Small Outline Integrated Circuit

Figure A-1

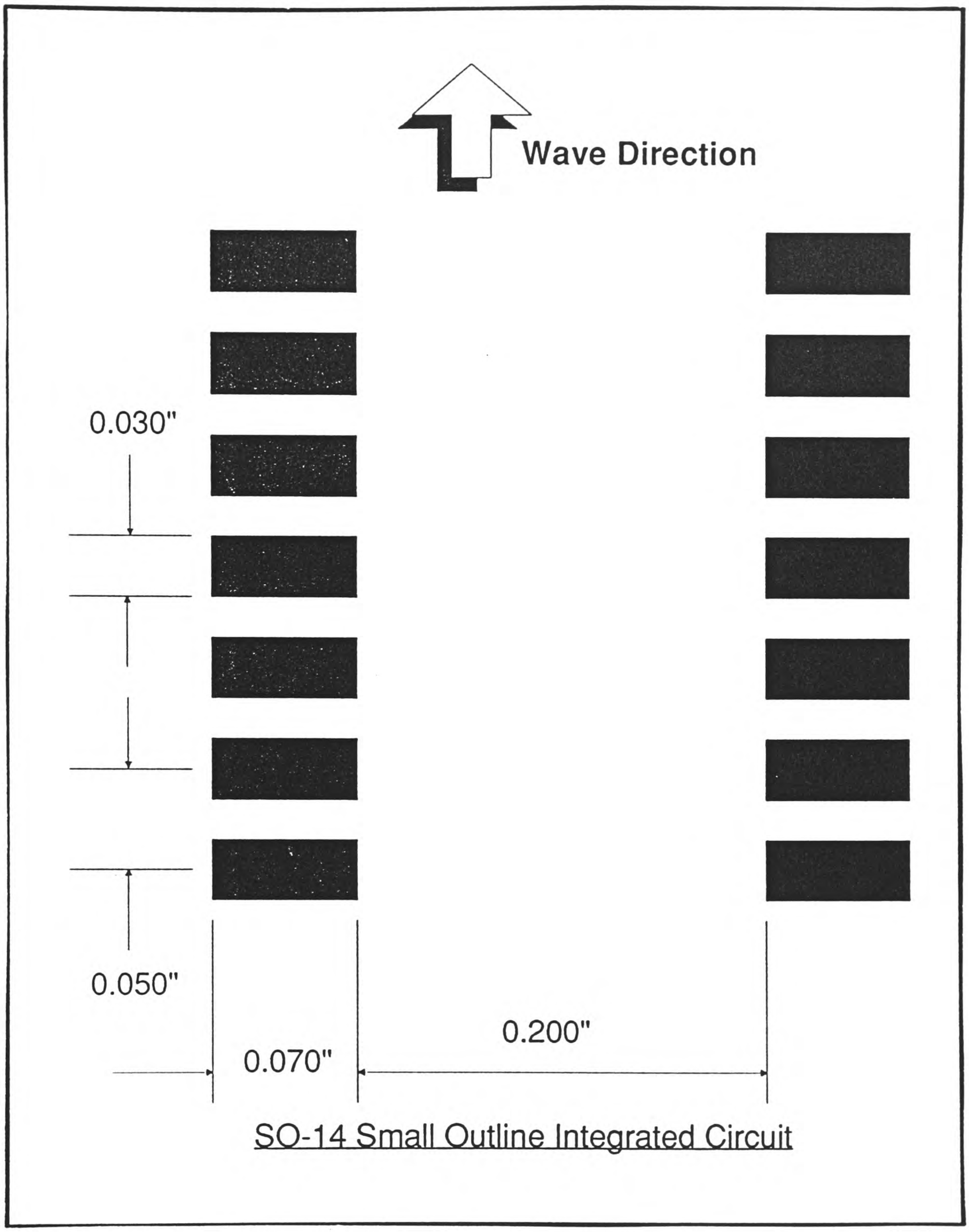

Wave Direction
0.030"
0.050"
0.070"
0.200"
SO-14 Small Outline Integrated Circuit

Figure A-2

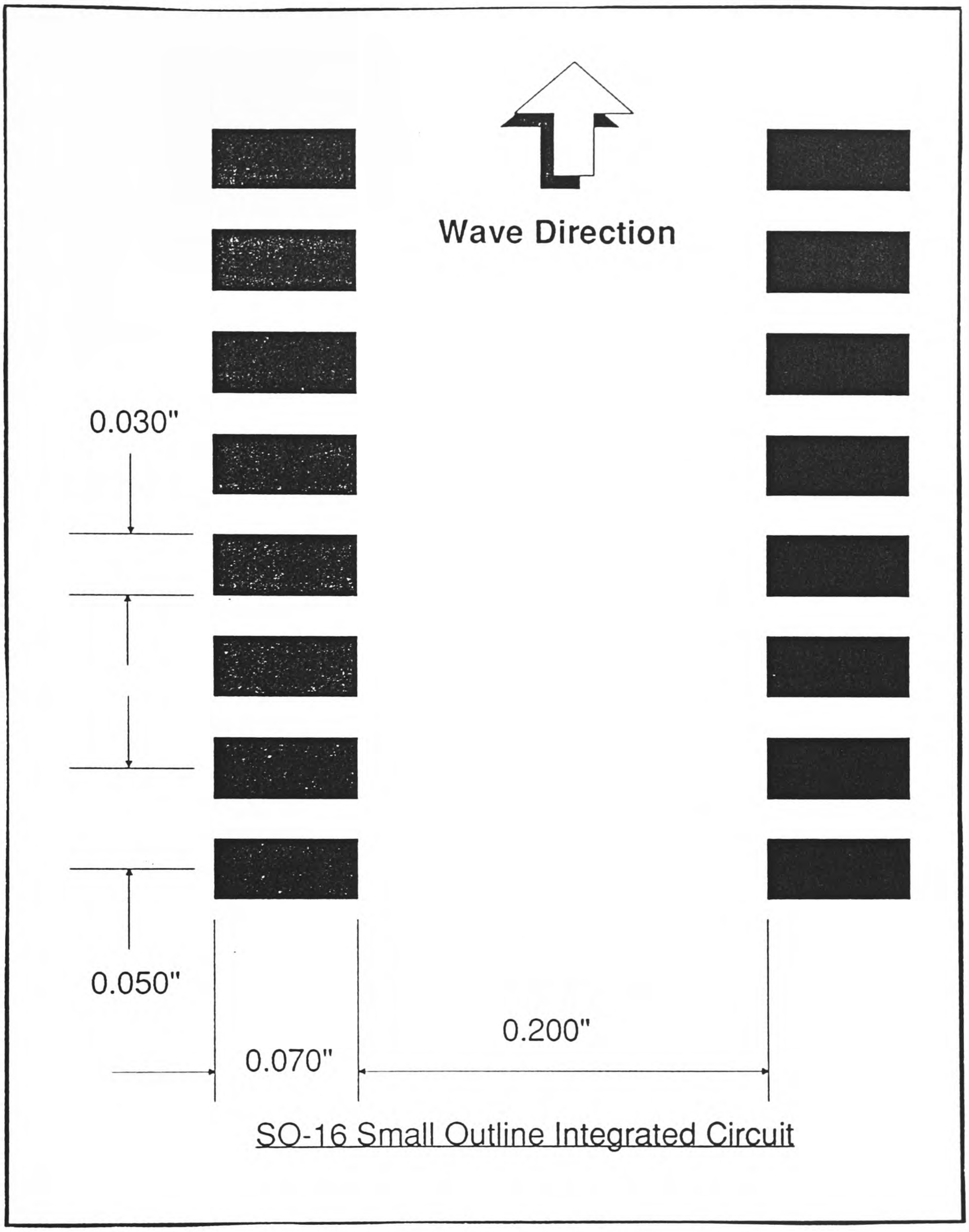

Wave Direction
0.030"
0.050"
0.070"
0.200"
SO-16 Small Outline Integrated Circuit

Figure A-3

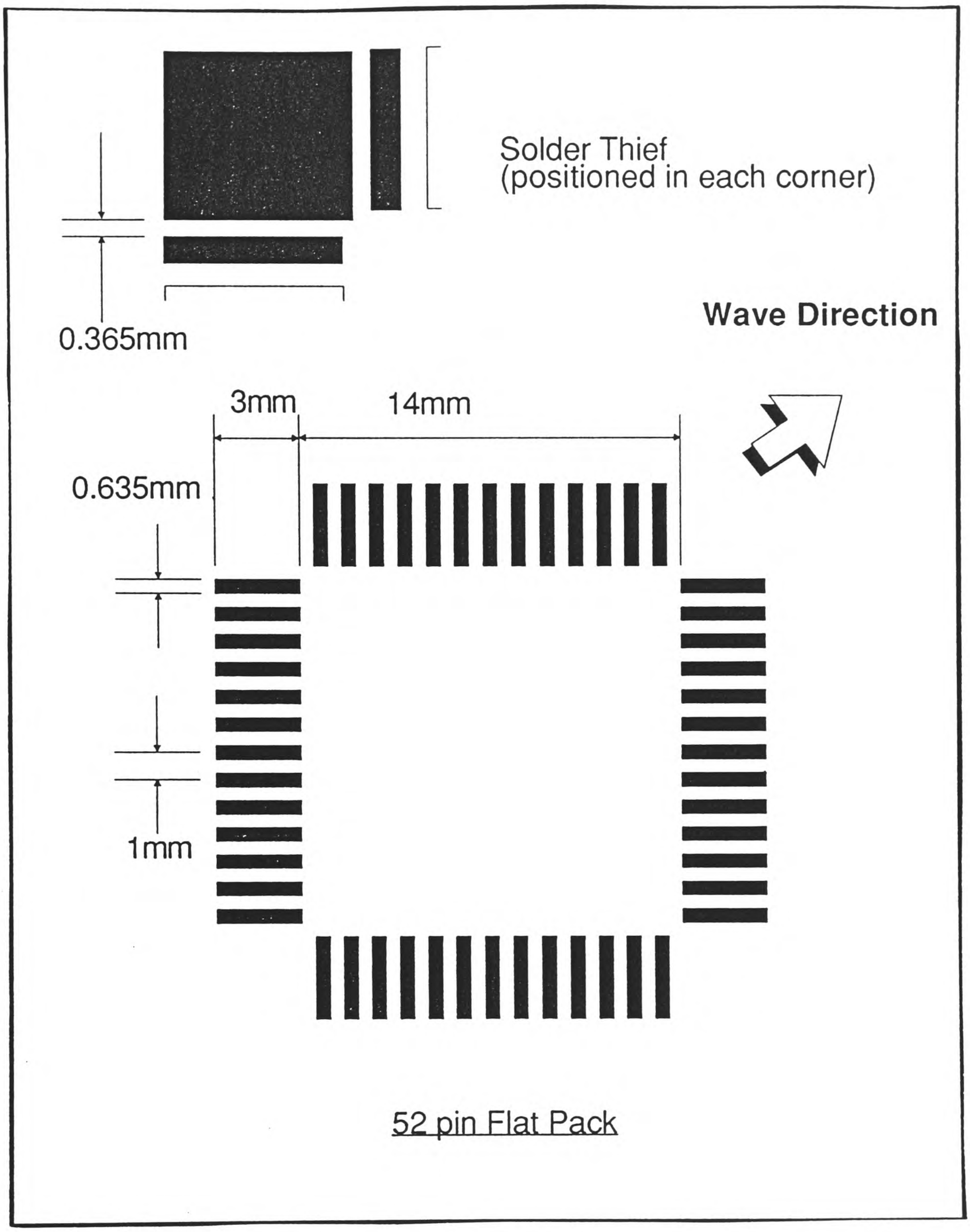

Solder Thief
(positioned in each corner)
0.365mm
Wave Direction
3mm
14mm
0.635mm
1mm
52 pin Flat Pack

Figure A-4

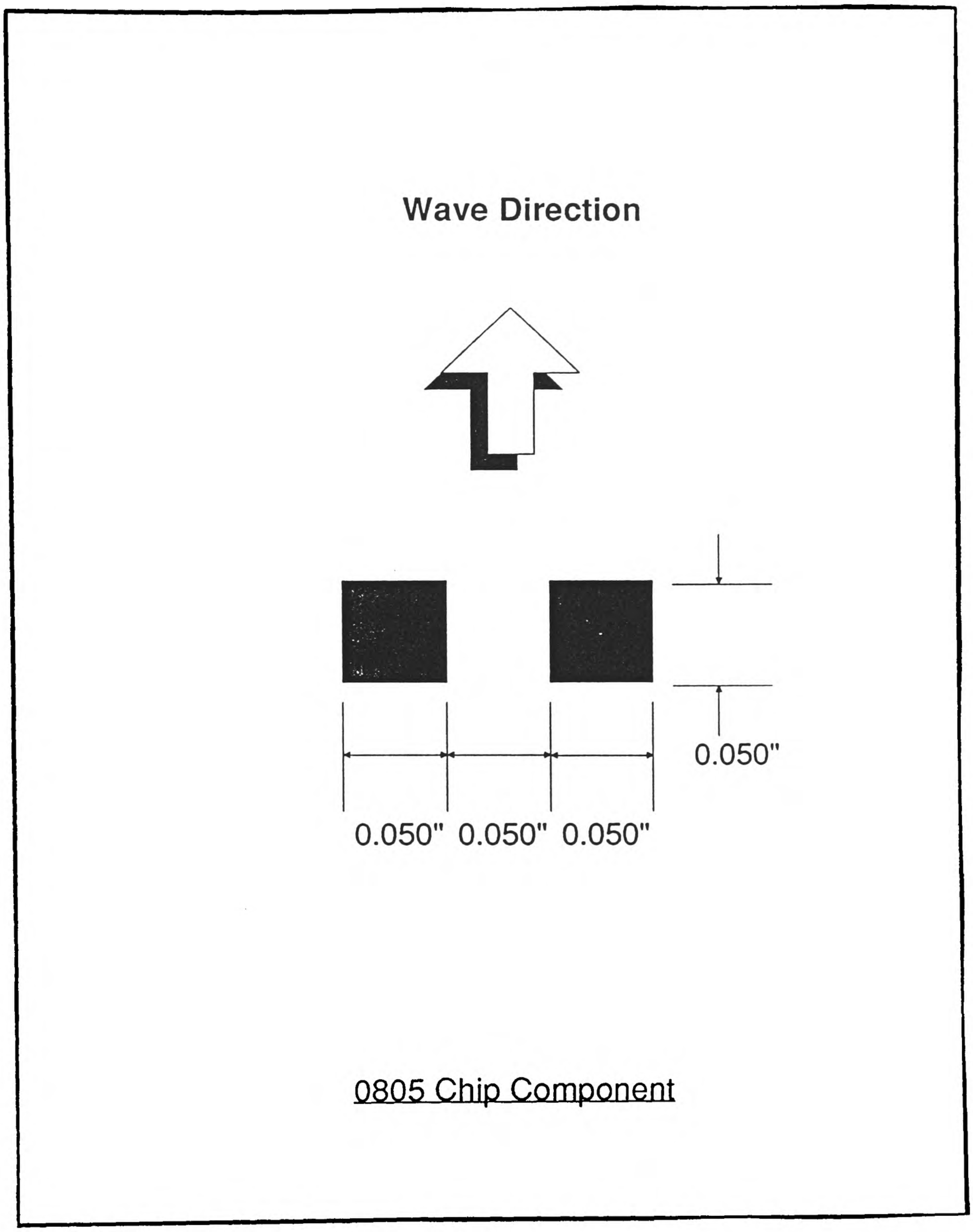


Figure A-5

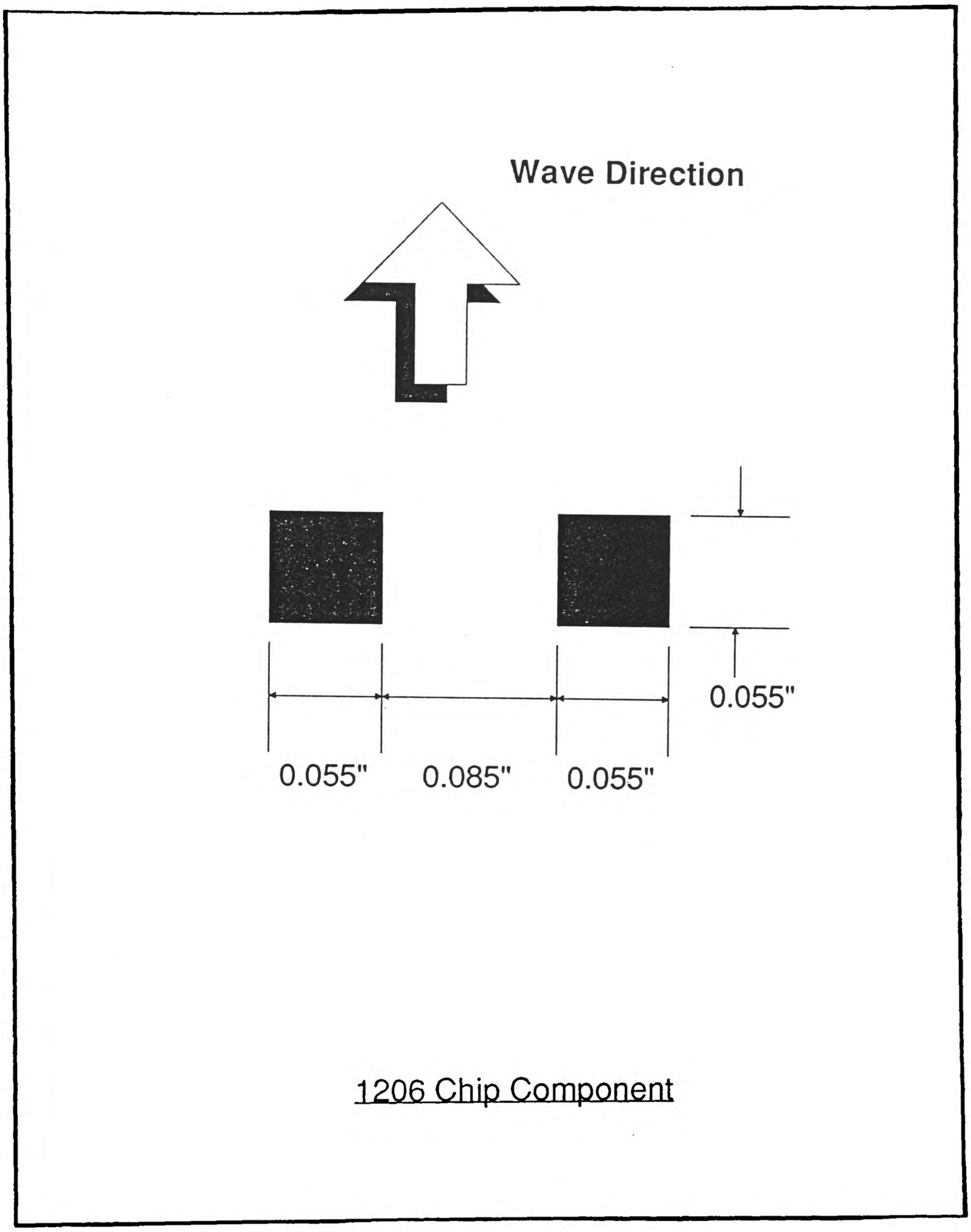


Figure A-6

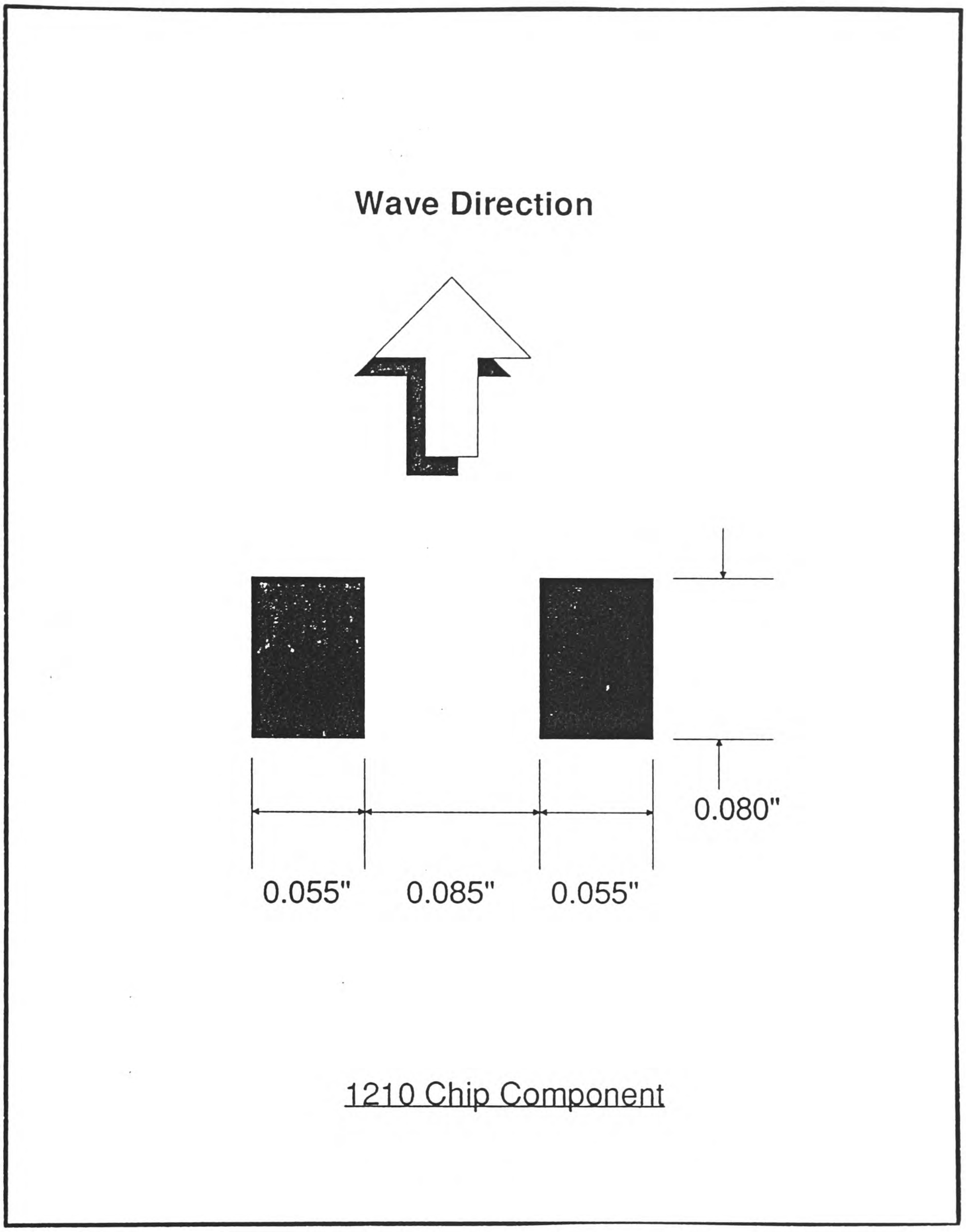


Figure A-7

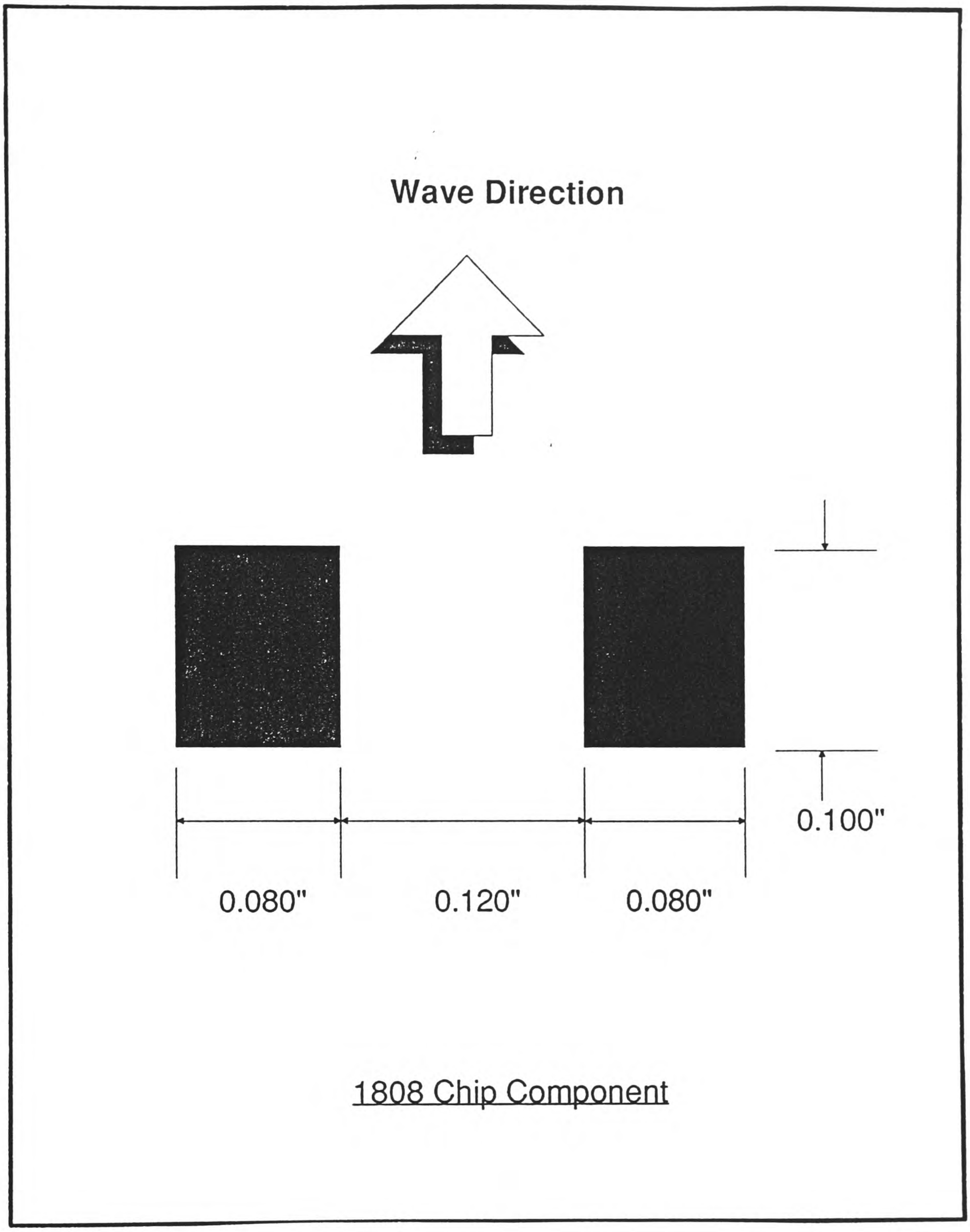


Figure A-8

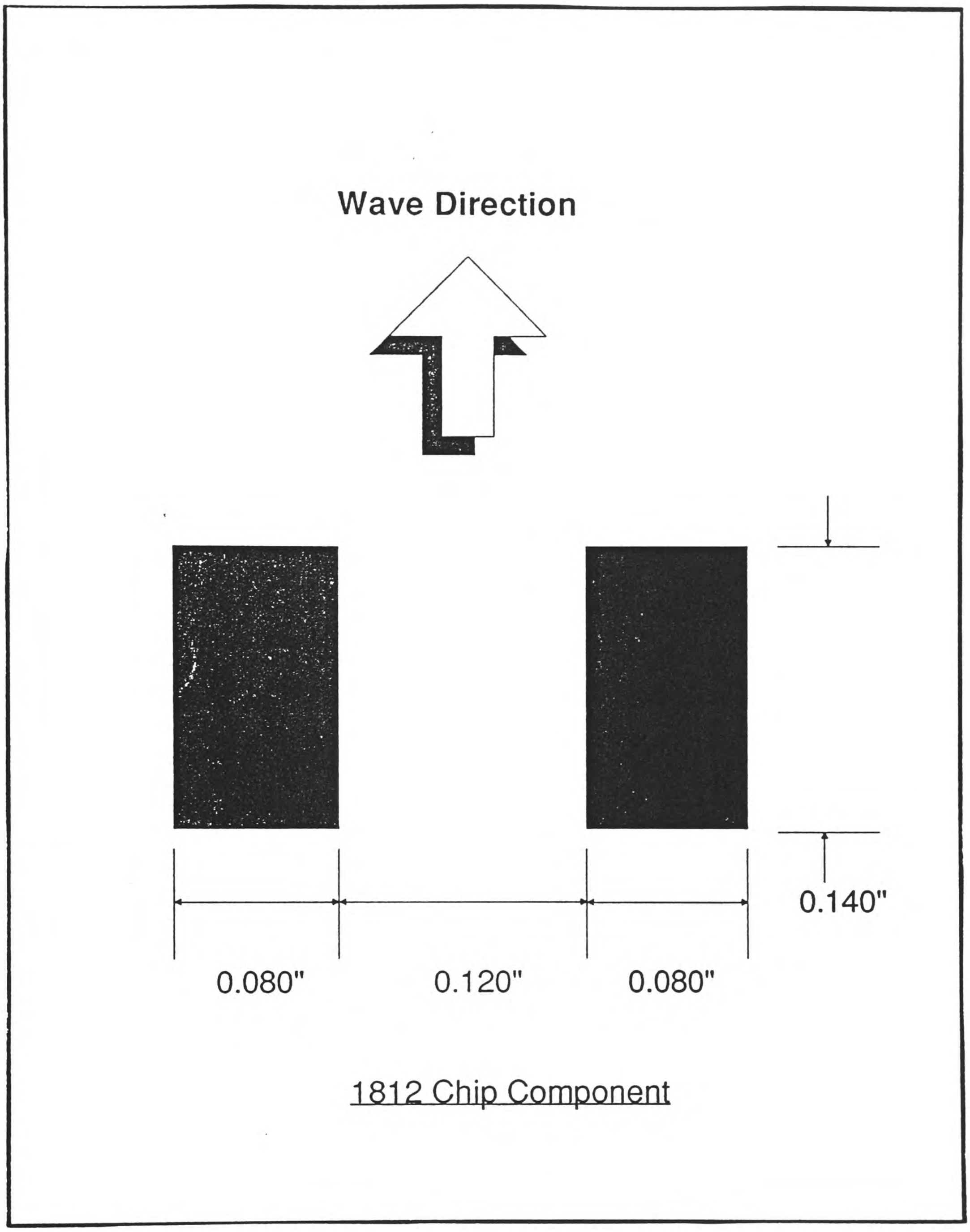


Figure A-9

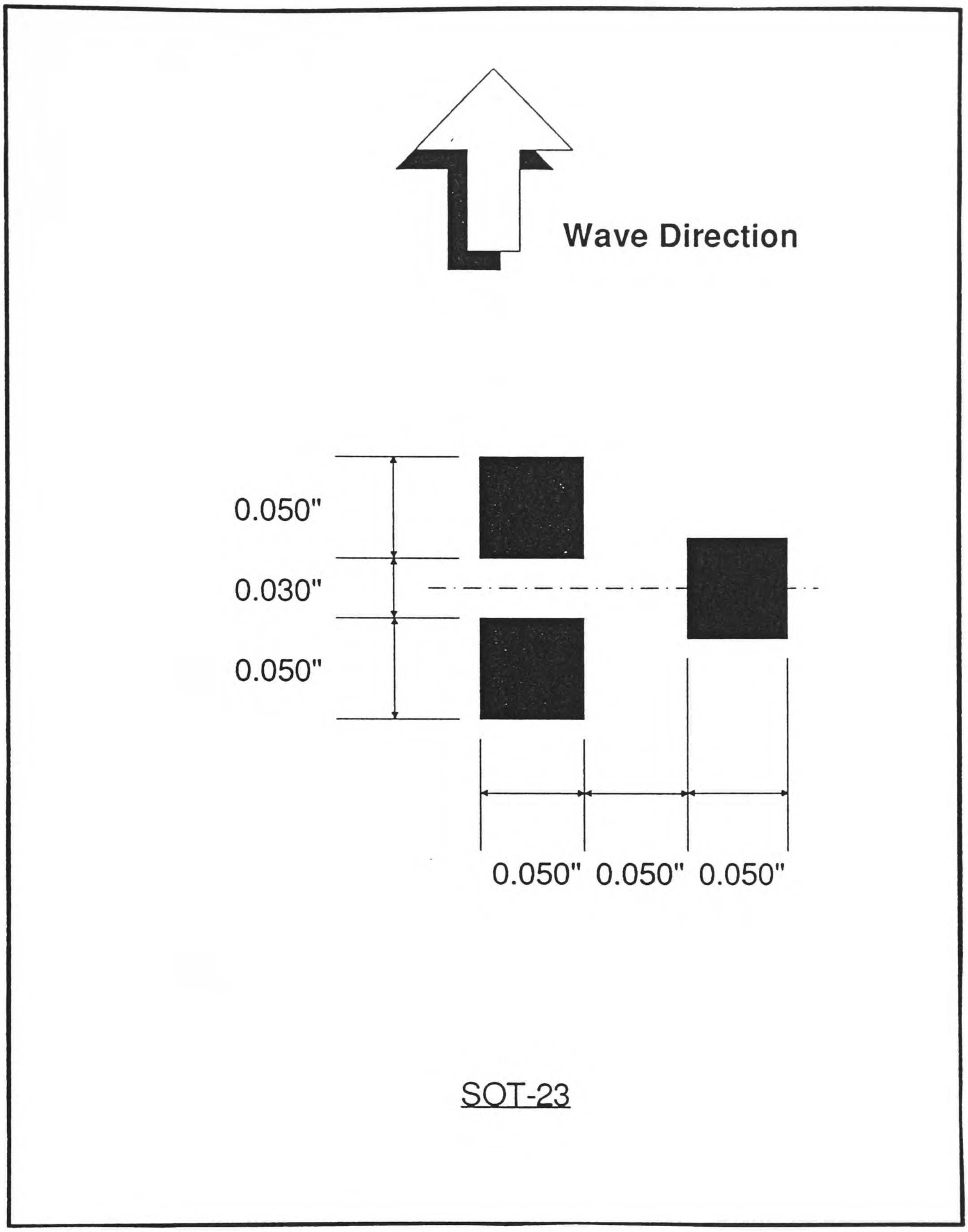


Figure A-10

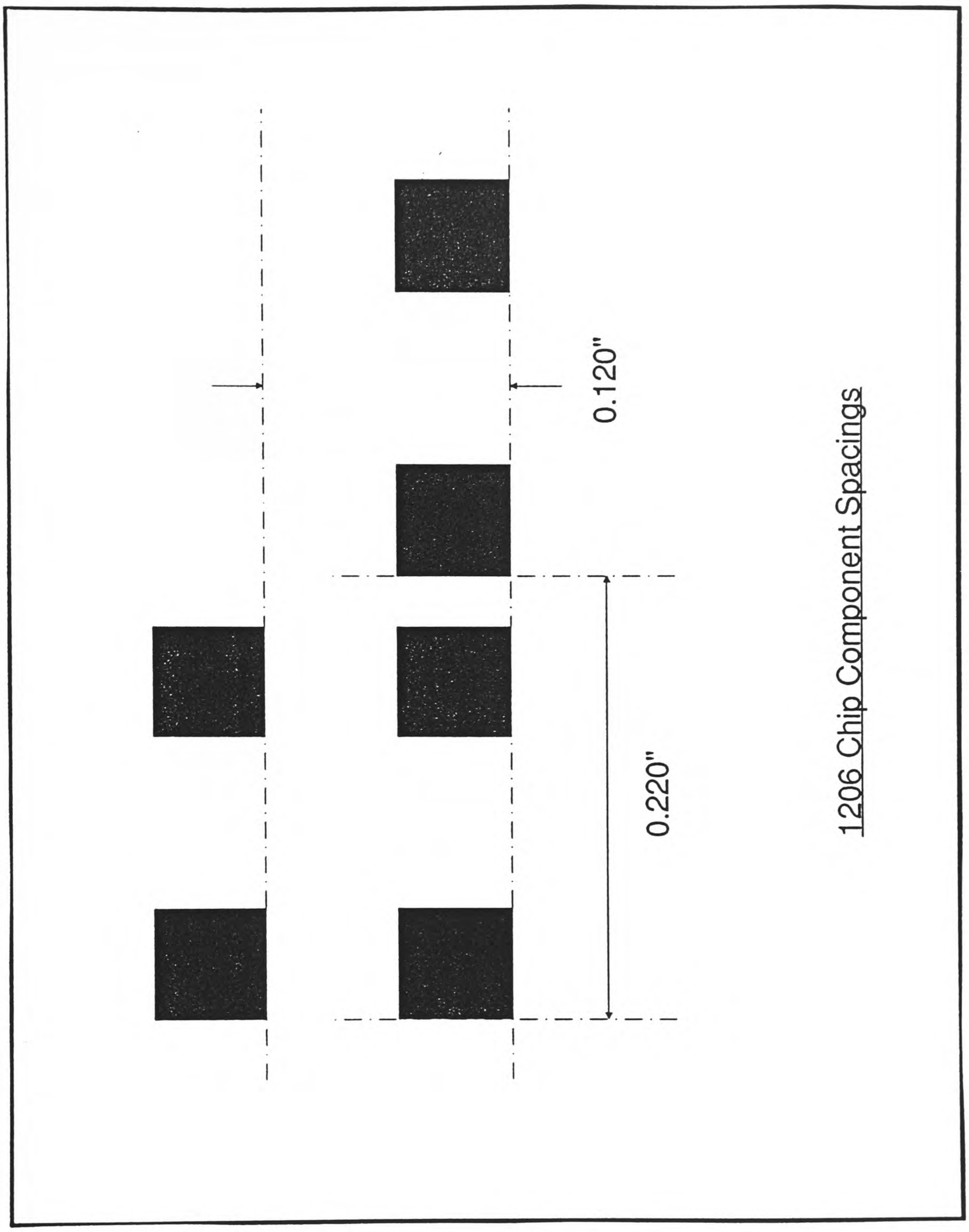

1206 Chip Component Spacings

Figure B-1

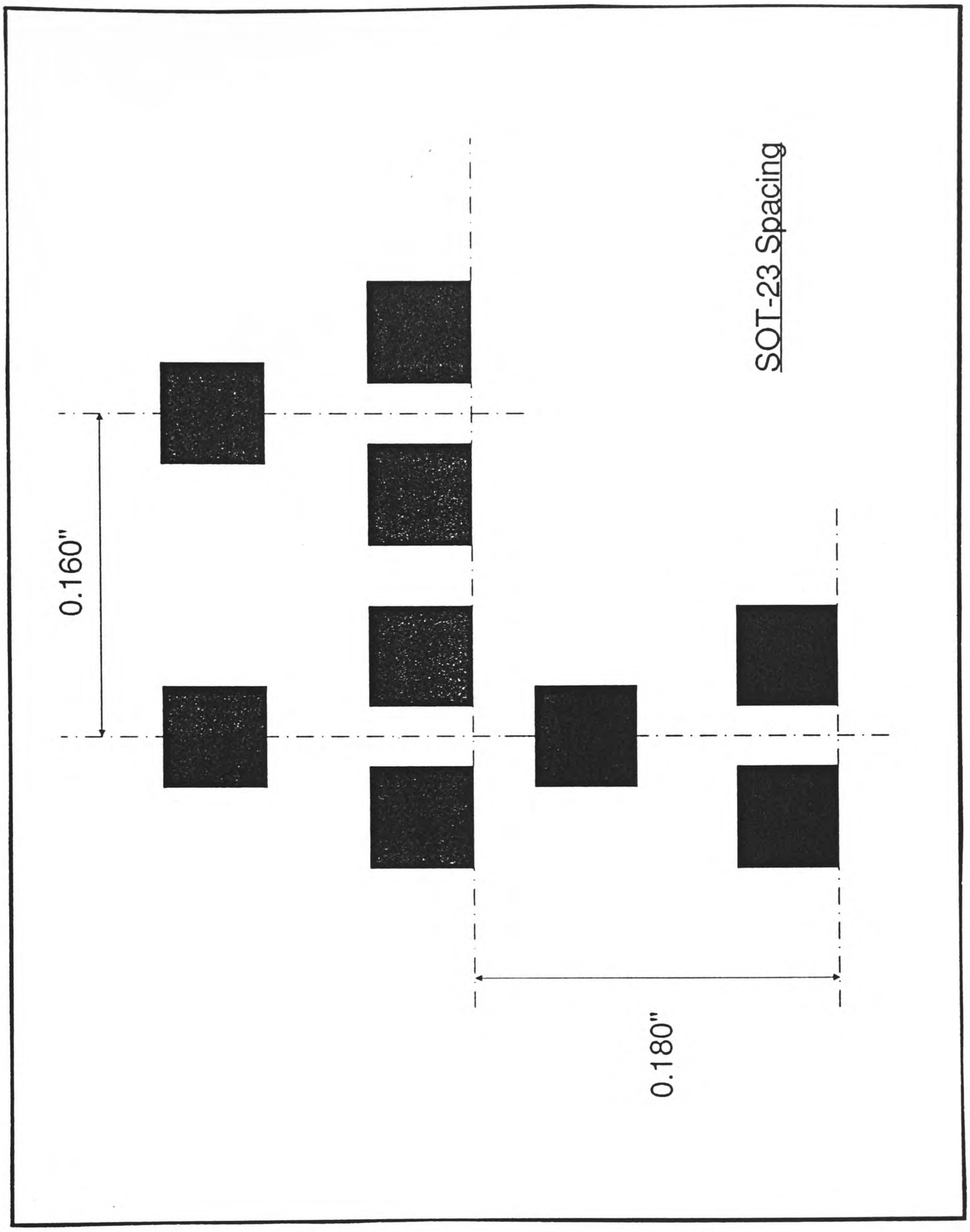
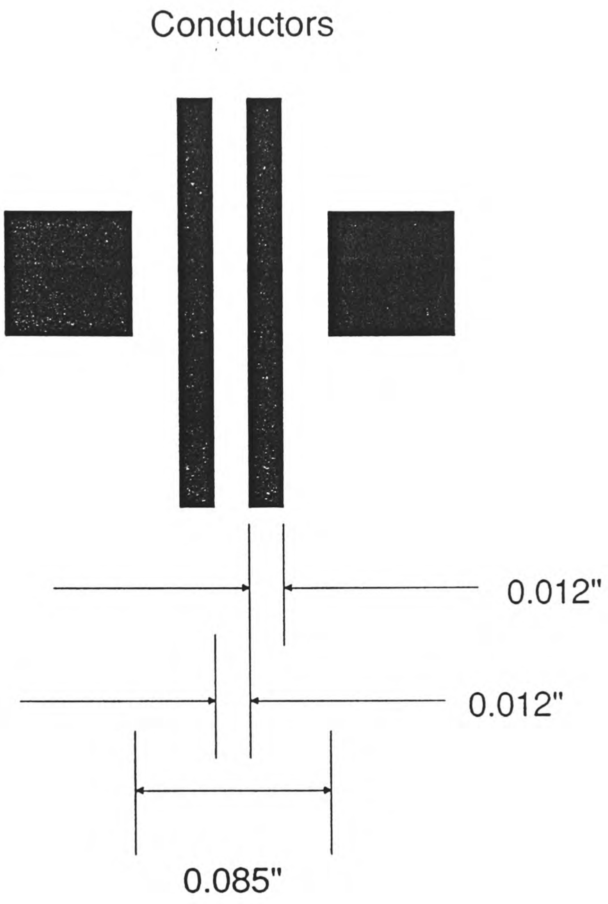
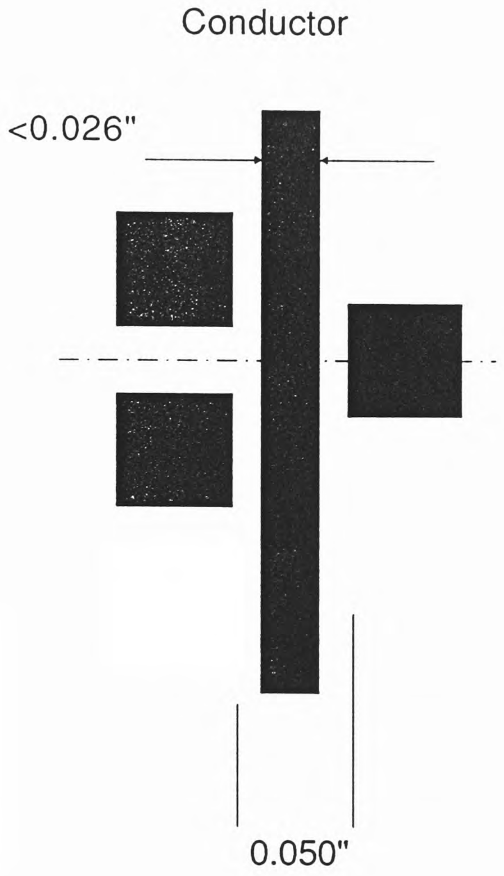


Figure B-2



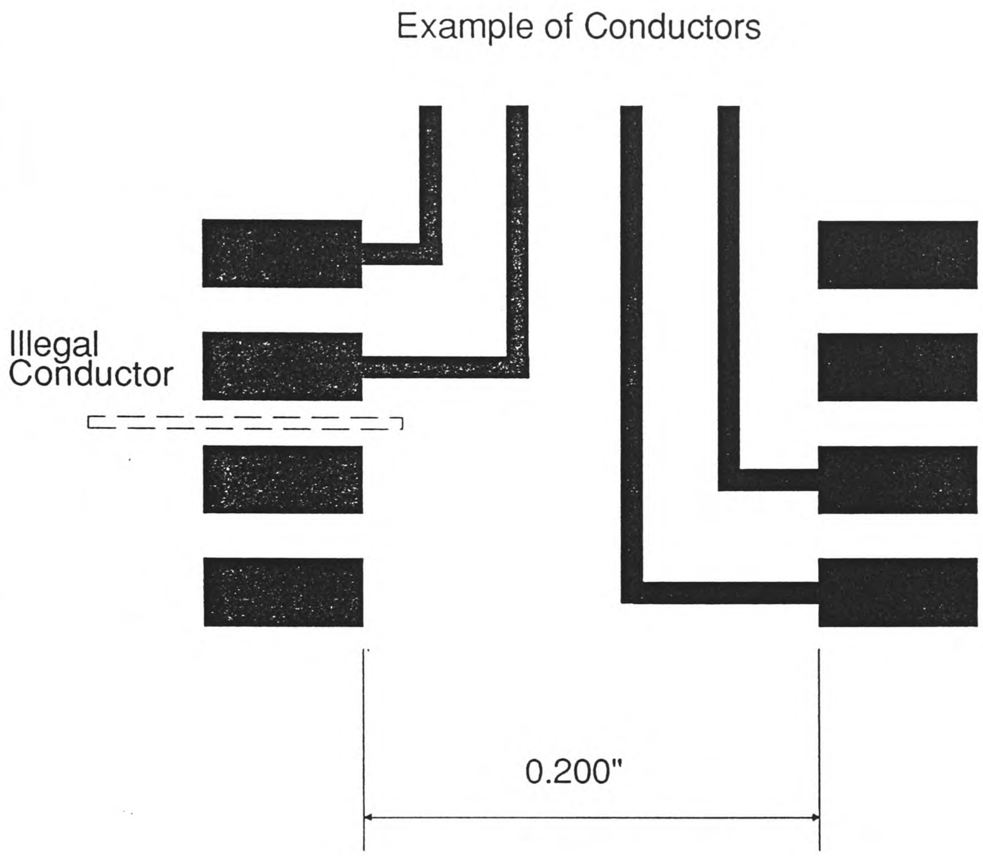
1206 Chip Component Track Routing

Figure C-1



SOT-23 Track Routing

Figure C-2



SO-8 Small Outline Integrated Circuit Conductor Routing

Figure C-3

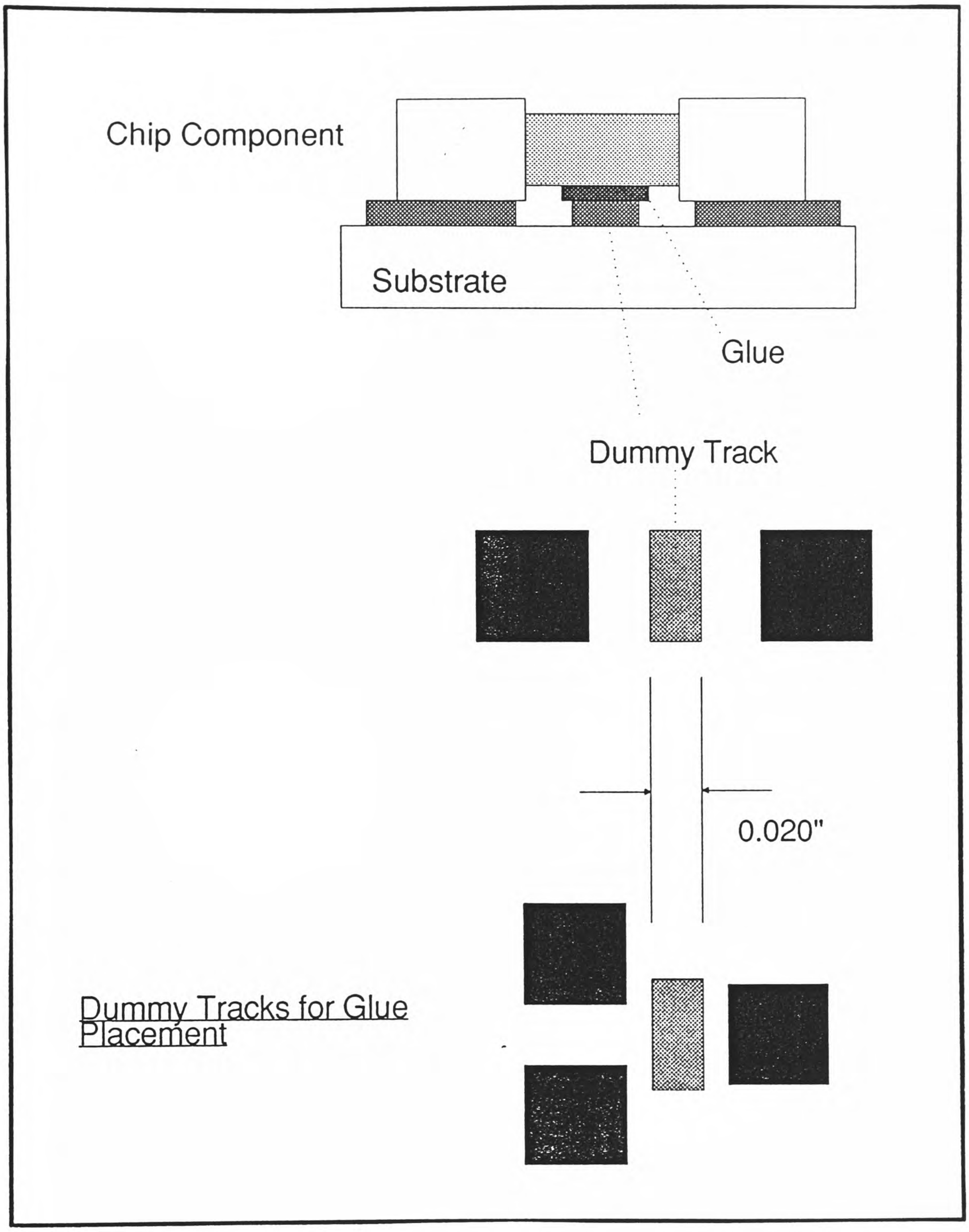

Chip Component
Substrate
Glue
Dummy Track
0.020"
Dummy Tracks for Glue Placement

Figure C-4

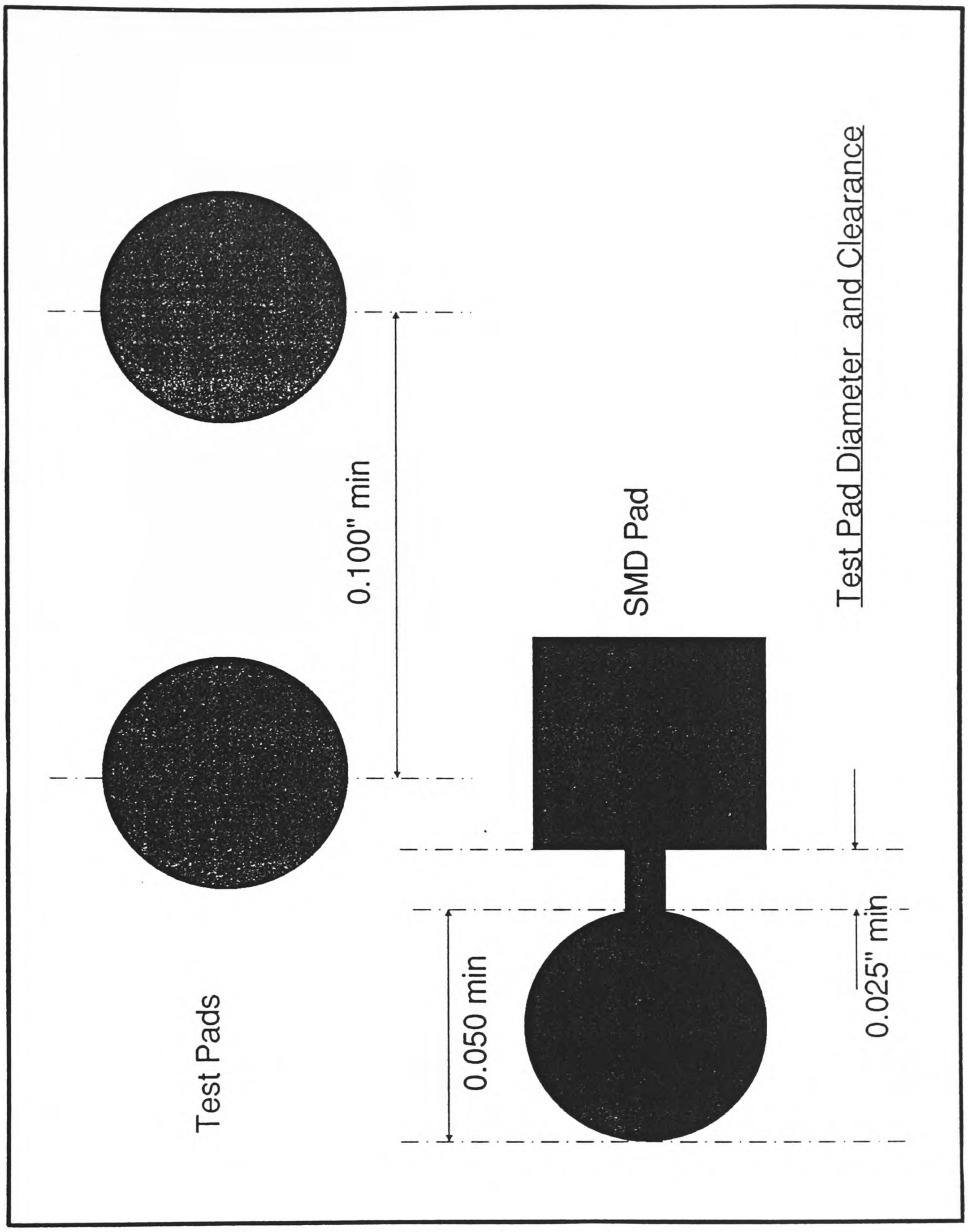

Test Pad Diameter and Clearance
SMD Pad
0.100" min
Test Pads
0.050 min
0.025" min

Figure D-1

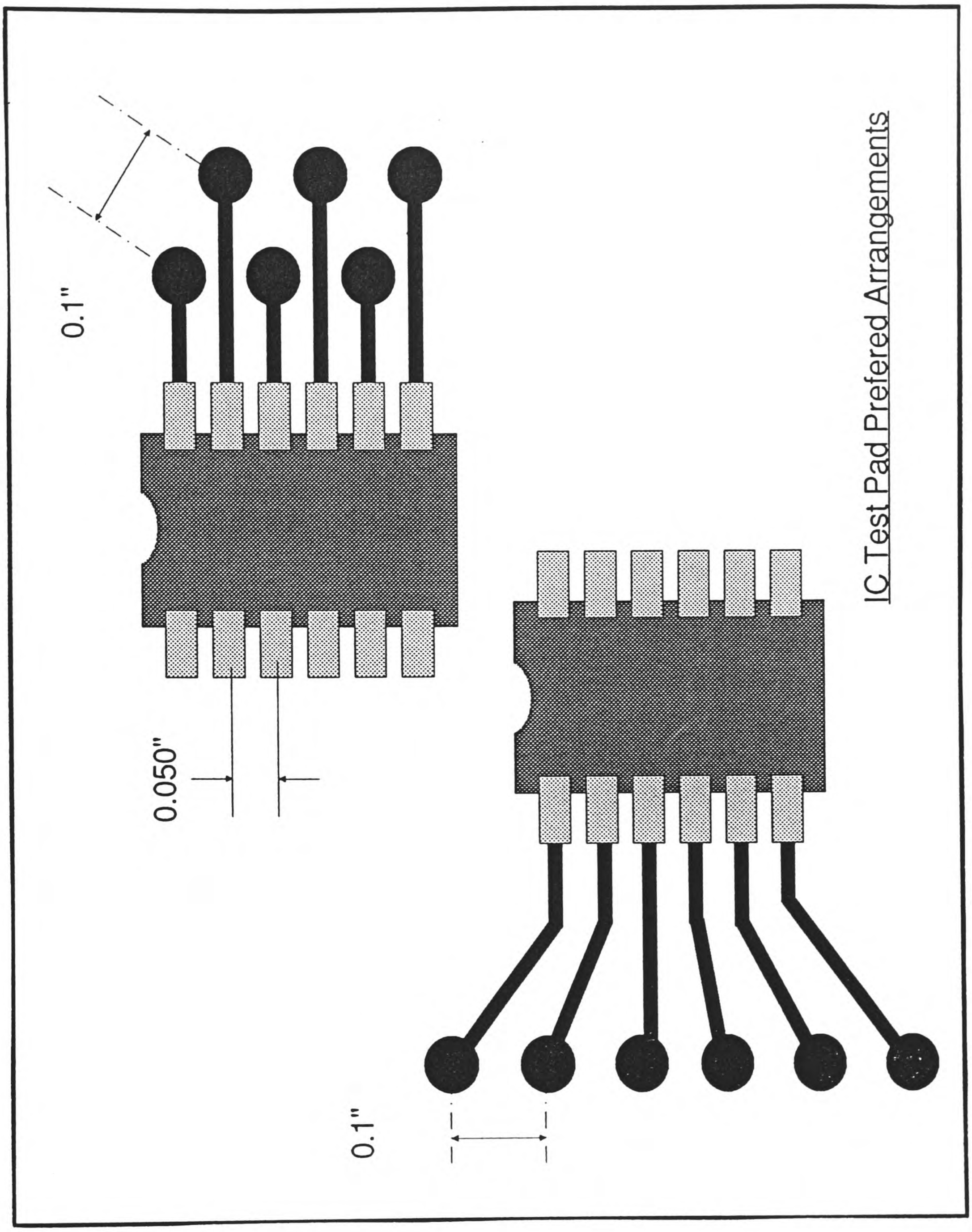
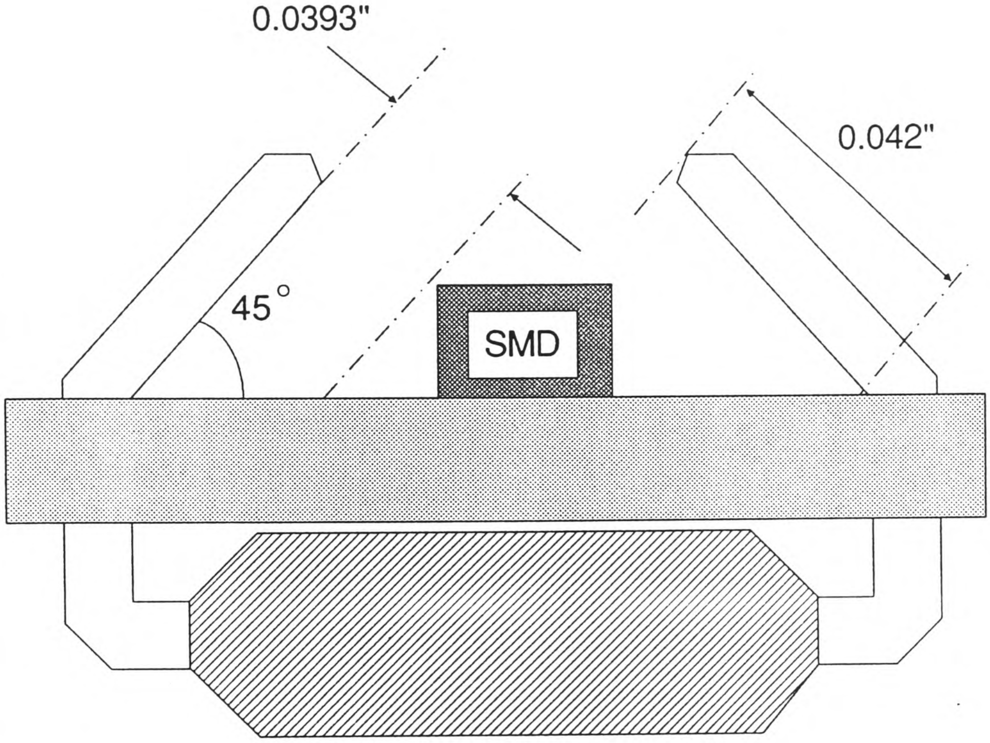


Figure D-2



Placement under Universal Axial Components

Figure E-1

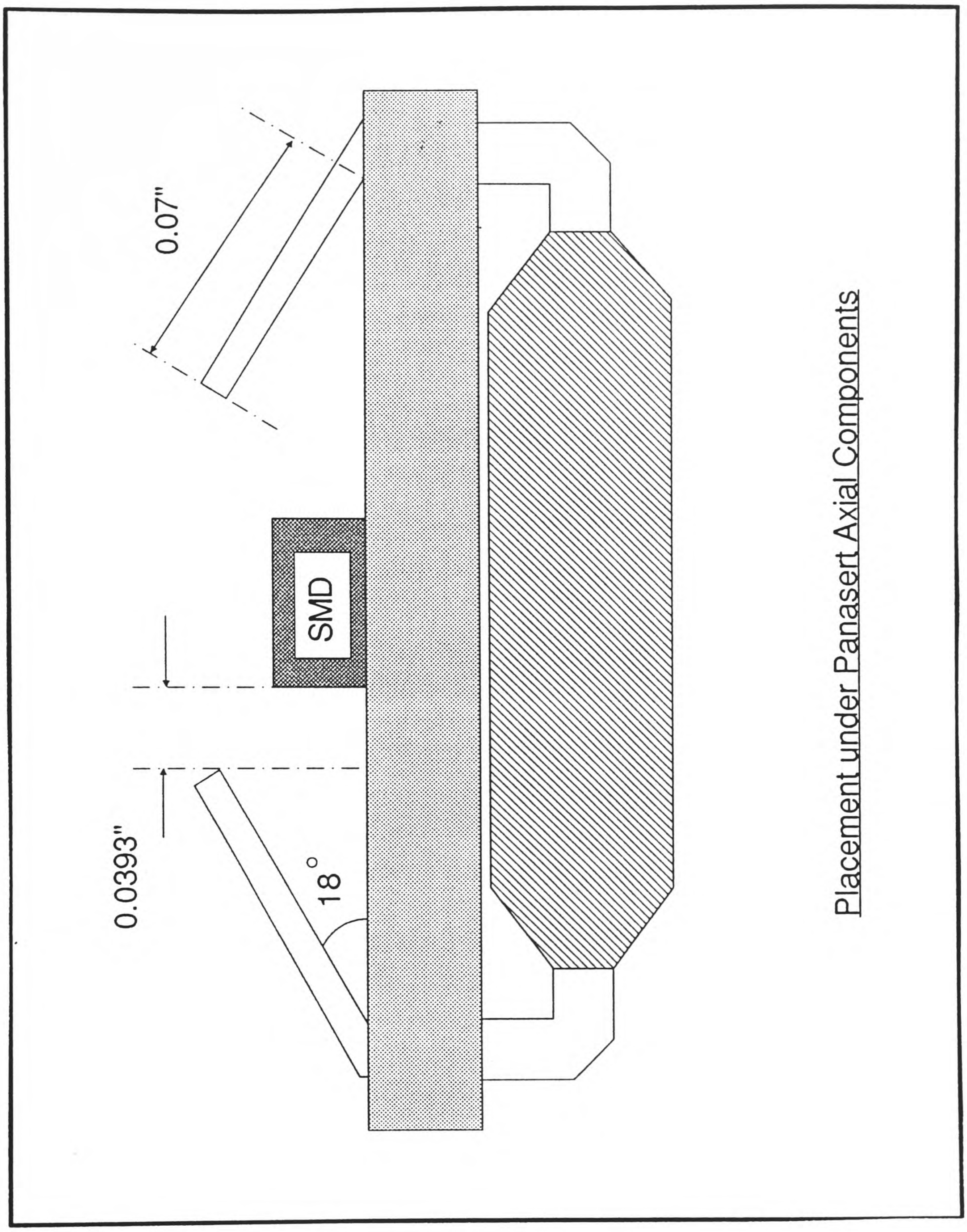

Placement under Panasert Axial Components

Figure E-2

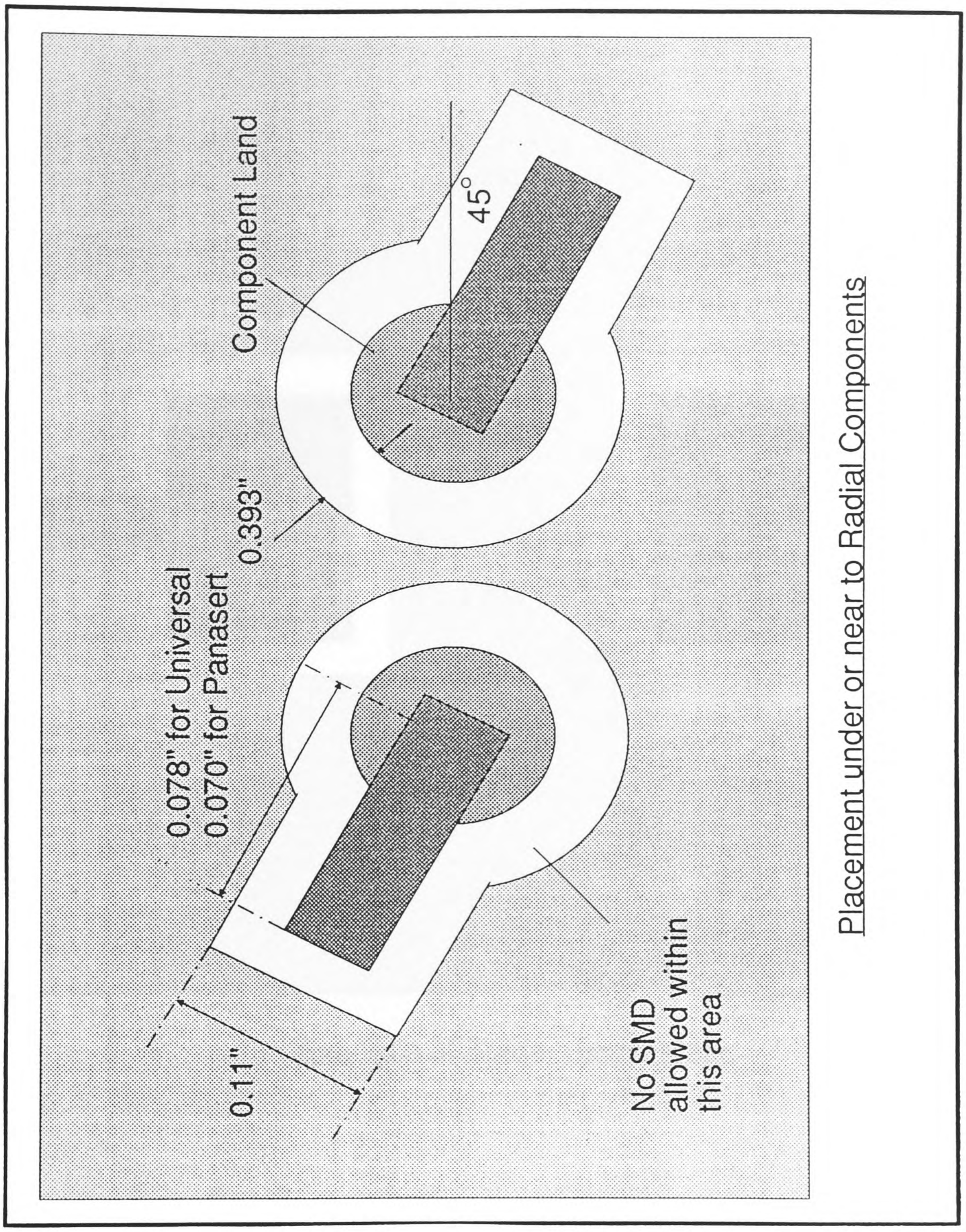
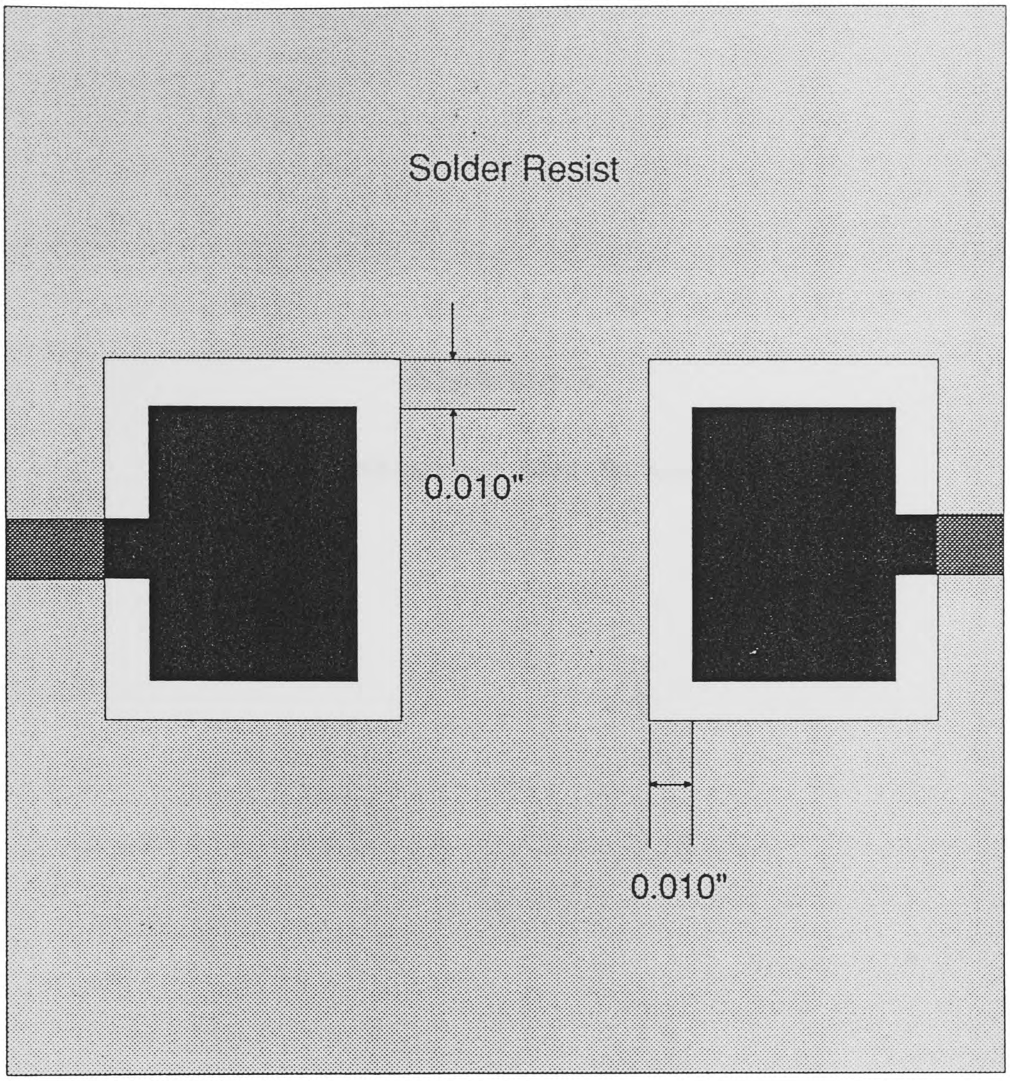

Component Land
45°
0.393"
0.078" for Universal
0.070" for Panasert
0.11"
No SMD allowed within this area
Placement under or near to Radial Components

Figure E-3



Example of Solder Resist Mask

Figure F-1

Appendix 2

Practical Capacitor and Inductor Models

1-0 Introduction

Capacitors and inductors are common devices within radio frequency circuits but they are never perfect components. At high frequencies a capacitor departs from its ideal impedance characteristic and becomes inductive, while an inductor becomes capacitive. This appendix introduces simple simulation models which predict the behaviour of capacitors and inductors when operated close to their self-resonant frequencies. Simulation results are included as a guide to predicting the behaviour of such practical components in radio frequency circuits.

2-0 Capacitors For Radio Frequency Applications

Capacitors are generally constructed by depositing a metal coating onto a dielectric. The capacitance of the component will be determined by the construction and the permitivity of the dielectric substance as governed by the equation of a simple plate capacitor:

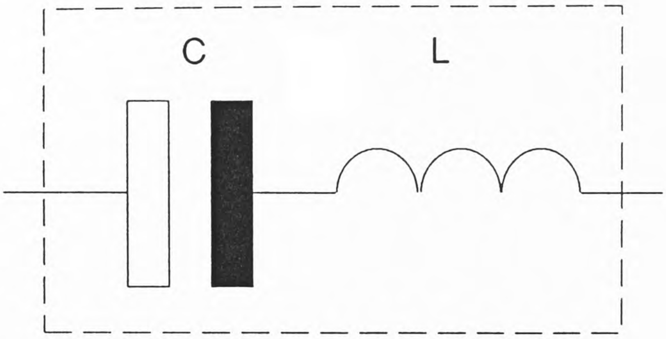
$$C = \frac{a\varepsilon}{d} F \text{ ...... } \textit{equation 1}$$

where ε is the dielectric permitivity, a is the metal plate area and d is the separation. The major impurities of the component are due to the inductance of the component leads or terminations and resistive losses due to material conductance and dielectric power loss. A multilayer construction is preferred for high frequency applications because it minimises series inductance and so maximises the component's self resonant frequency.

The simple capacitor simulation model depicted in figure 1 includes only the series inductance because the resistance tends to be very small, and when used in a circuit with inductances the losses associated with the inductors tend to be predominant.

Figure 2 shows the result of a simulation in which the ratio of the equivalent capacitance of the component to its low frequency value is plotted against the frequency it is operated at. Figure 1 also includes details of how the results are extracted from the impedance equations for the component. The results show that the effective capacitance of the component becomes magnified as it is operated closer to its self resonant frequency limit. A capacitor operated within a filter or tuned circuit at a frequency of half its self resonant frequency, for example, will exhibit an effective capacitance of 135% of its low frequency value. At self resonance its impedance becomes resistive and at higher frequencies the component is inductive.

Silver mica and ceramics are commonly utilised for high frequency capacitors and tend to exhibit positive temperature coefficients (approximately 0.0025 %/°C for mica and 0.01 %/°C for ceramic). Special ceramics materials such as titanium dioxide have marked negative coefficients (-0.068 %/°C for the N750 dielectric). These are useful for



Z = component impedance

C = nominal capacitance value

$L = \frac{1}{W_0^2 C}$ where W_0 = self resonant frequency (rad.sec^{-1})

$Z = jWL - \frac{j}{WC}$ but $Z = - \frac{j}{WC_{eff}}$ when $W < W_0$

$\therefore \quad \frac{1}{WC_{eff}} = \frac{1}{WC} - WL$ where $L = \frac{1}{W_0^2 C}$

$$\frac{1}{WC_{eff}} = \frac{W_0^2 C - W^2 C}{W\, W_0^2\, C^2}$$

Hence $\boxed{\left(\frac{C_{eff}}{C}\right) = \frac{1}{1 - \left(\frac{W}{W_0}\right)^2}}$

Figure 1 Simple model of a capacitor showing how its effective capacitance may be derived.

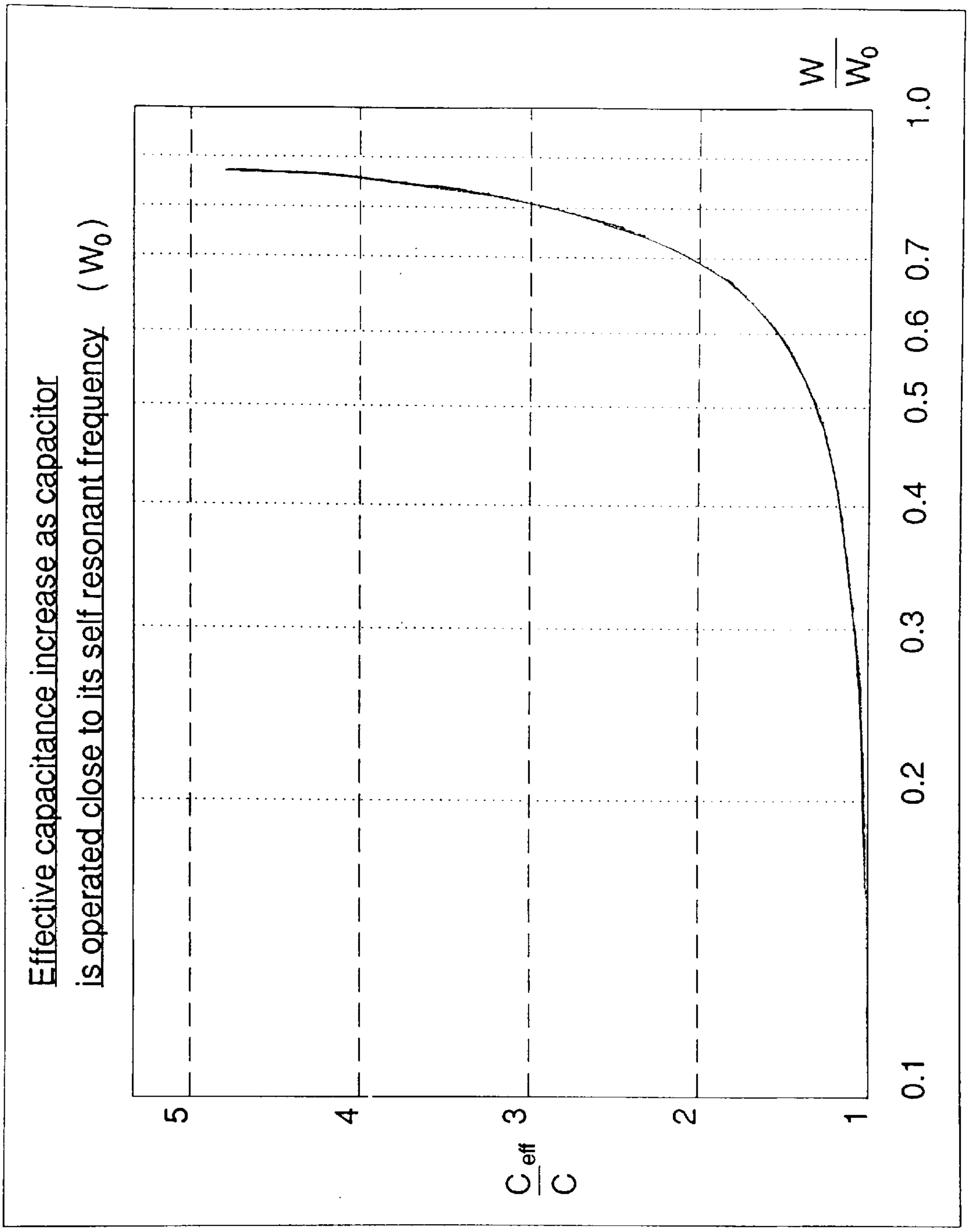


Figure 2 Plot of the effective capacitance of a capacitor when it is operated close to its self resonant frequency

compensating for the positive temperature coefficient inherent in inductors, whereas mixed dielectrics can produce capacitors with essentially zero temperature coefficients (NPO dielectric). When capacitor stability with age is an important factor the COG dielectric has negligible aging to 10,000 hours whereas the less stable Y5U dielectric may change by as much as -15% in the same period.

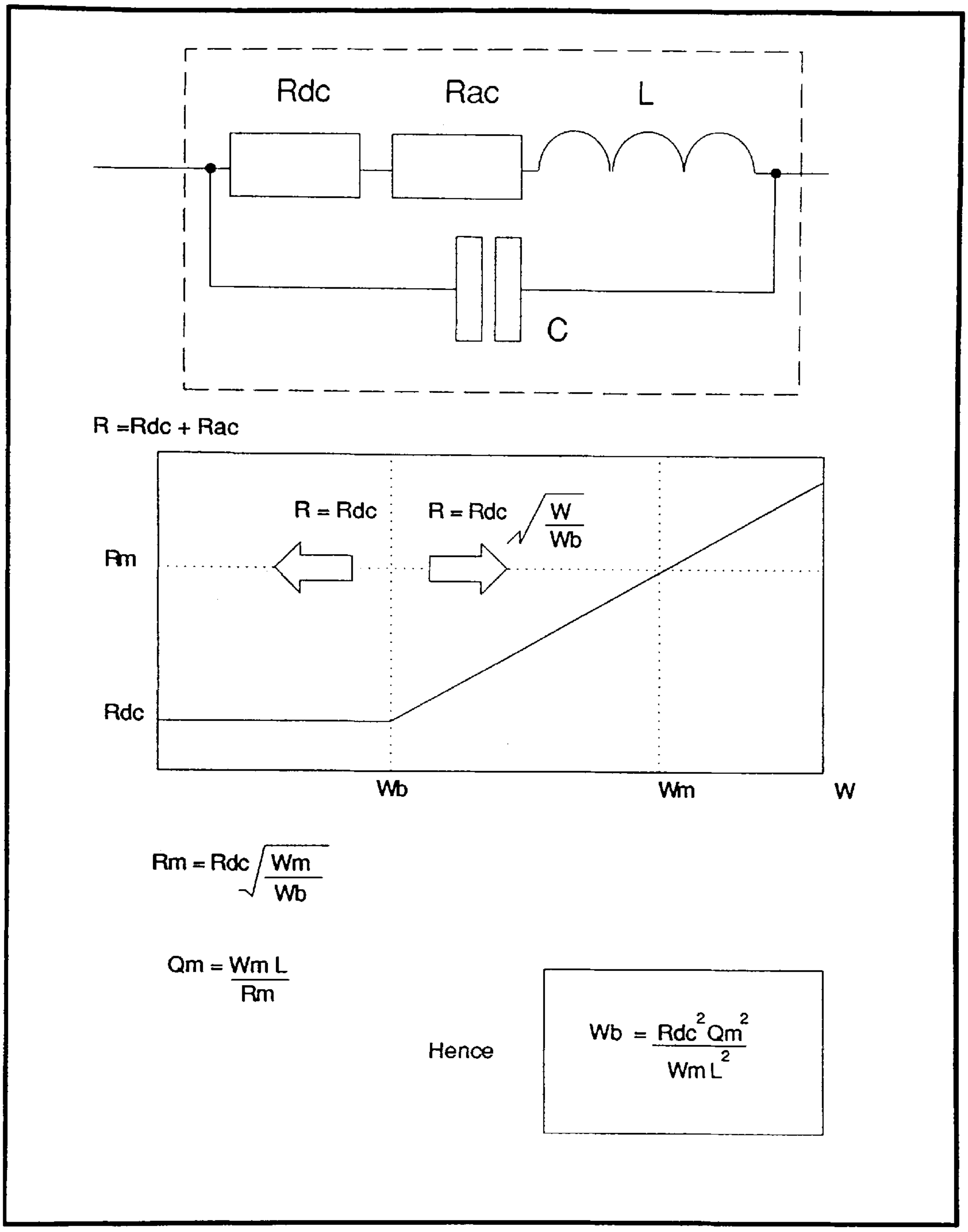
3-0 Inductors

Figure 3 shows a simple model of an inductor where C represents the stray capacitance between its end terminals and windings. The loss resistance is simulated with two components; R_{dc} is the constant DC resistance as measured at low frequencies and R_{ac} the higher frequency skin effect resistance. Real inductor losses are also composed of hysterisis losses in the core and also eddy current losses within conductors coupling with its magnetic field. The skin effect was often found to be the predominant loss and the model gave a good understanding of the performance to be expected from a device.

The inductance of a conductor is found from the fundamental equation:

$$\frac{N\Phi \times 10^{-8}}{I} \text{ Henrys } \ldots\ldots \textit{ equation 2}$$

where N is the number of turns (which may be unity), Φ is the flux density linking the turns and I is the current in amps.



$$Rm = Rdc\sqrt{\frac{Wm}{Wb}}$$

$$Qm = \frac{Wm\,L}{Rm}$$

Hence

$$\boxed{Wb = \frac{Rdc^2\,Qm^2}{Wm\,L^2}}$$

Figure 3 Simple model of a practical inductor including skin effect

From this fundamental equation the skin effect may be predicted because the centre of a conductor, having a greater flux density due to the surrounding electron flow will demonstrate a greater inductance. This higher inductance at the centre of the conductor forces high frequency currents to flow predominantly at the surface. An after effect of this action is an overall flux density change throughout the wire and a decrease in the overall inductance as the frequency is increased. The skin depth of a conductor is given from:

$$\text{Skin depth} = \delta = \frac{2}{w\mu\sigma} \text{ Metres} \ldots\ldots \textit{equation 3}$$

where μ is the conductor permeability, w is the radian frequency and σ is its conductivity. Moving deeper into the material, the current falls off exponentially and when the depth is greater than 4δ the current density has practically fallen to zero. At high frequencies, the ac resistance of the wire can be considered to be inversely proportional to the skin depth and hence proportional to the square root of the operating frequency. The simple model including skin effect operates by calculating the loss resistance as shown in the graph also illustrated in figure 3. The figure describes how the value of W_b is calculated from the DC value of an inductors resistance and high frequency operating Q_m at a measured frequency W_m. These values are normally the two basic parameters supplied in component data sheets.

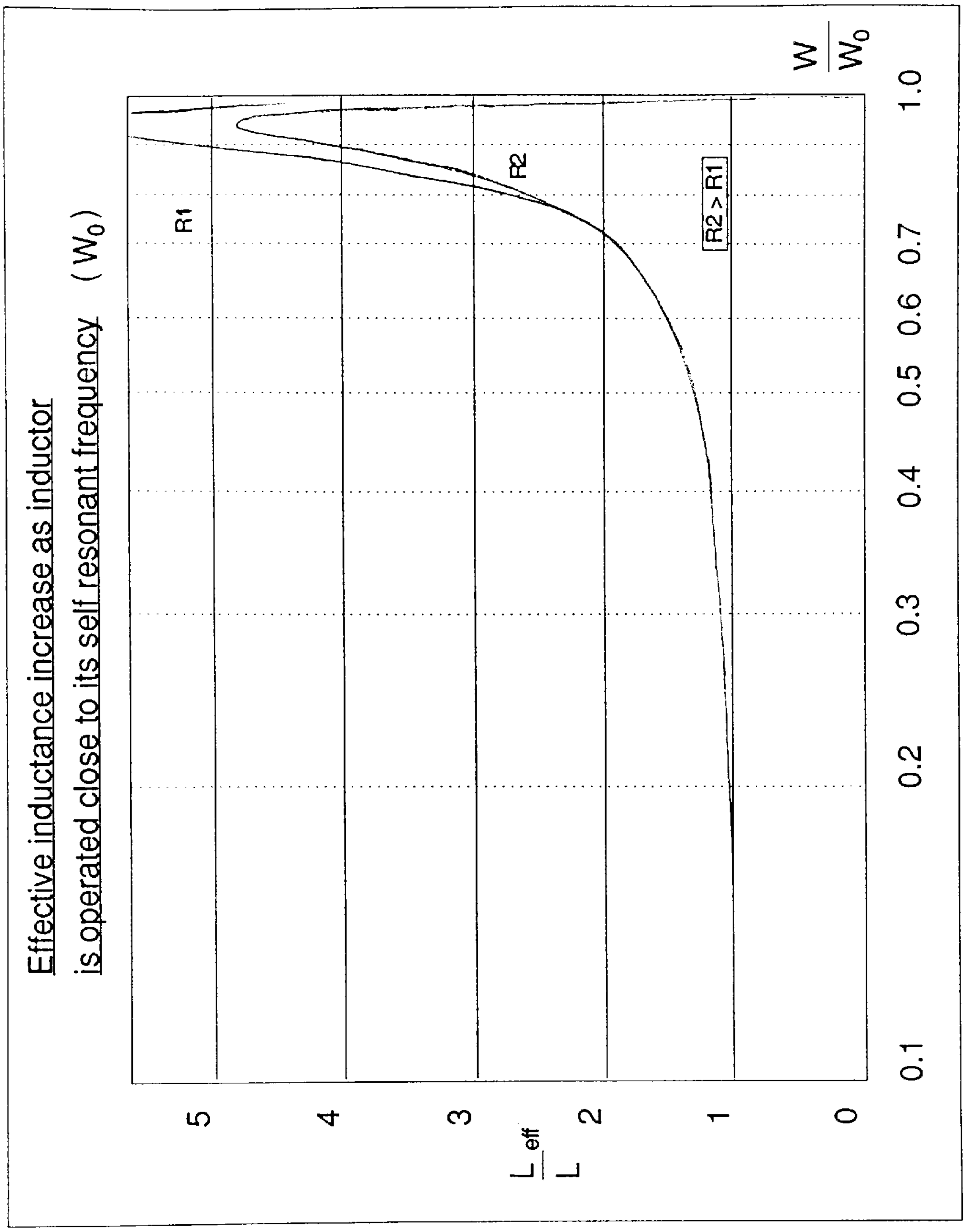


Figure 4 Plot of effective inductance as the inductor model is operated near to its self resonance frequency

Figure 4 shows results of simulations of the effective component inductance as it approaches its self resonant frequency. The shape near to self resonance is effected by the inductors series resistance value (R1 and R2) but the general shape is irrespective of the skin effect component. The graph in figure 5 illustrates the effect of skin effect on the effective series resistance of the inductor, comparing the cases when the resistance is constant, W_b is one tenth the value of W_0 and W_b is one hundredth the value. The graph shows that the self resonant frequency of the component can be reduced when the skin effect becomes significant as predicted from:

$$W_0 = \sqrt{\left(\frac{1}{LC} - \frac{R^2}{L^2}\right)} \quad \ldots\ldots \textit{ equation 4}$$

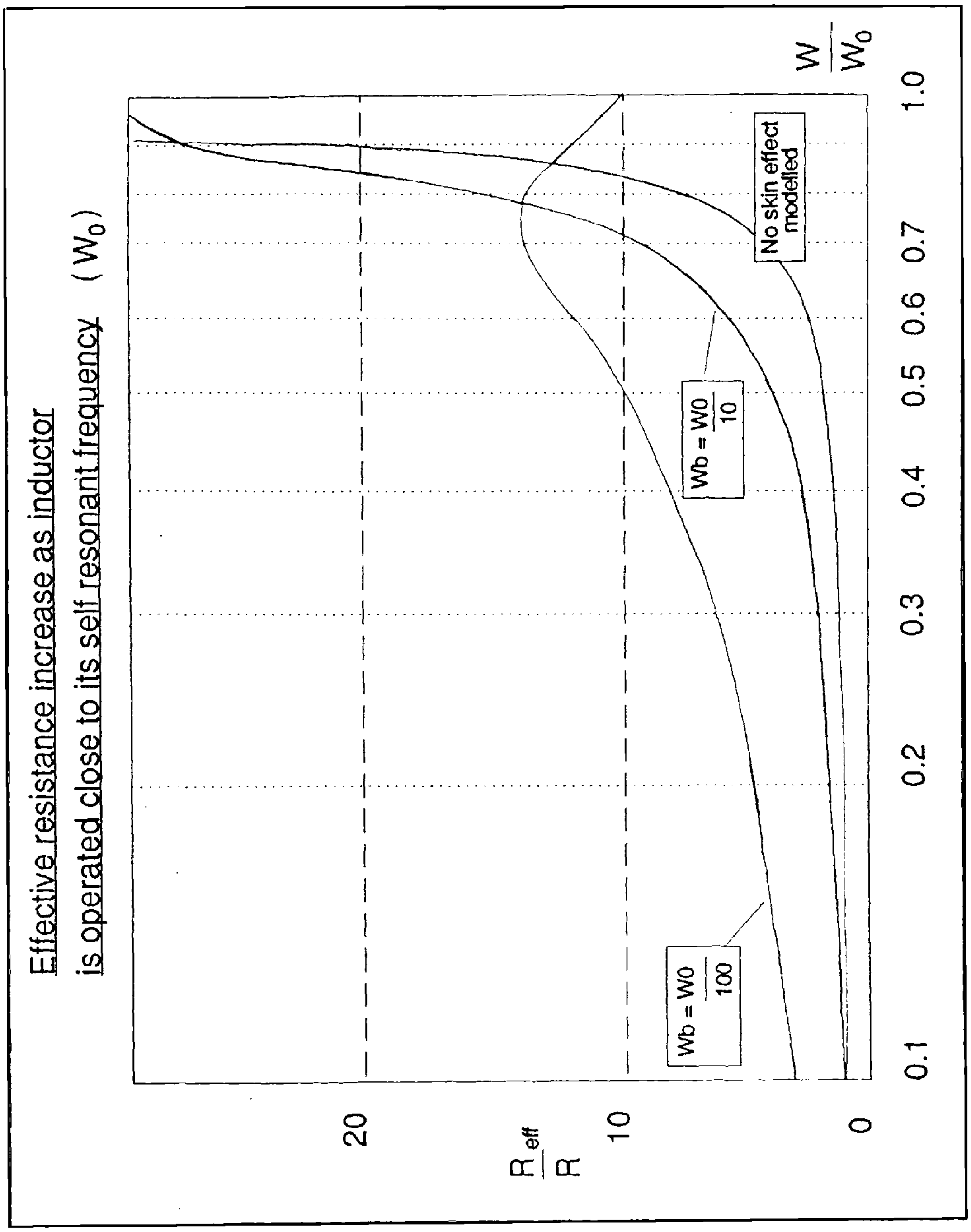


Figure 5 The effective resistance of the inductor model when operated close to its self resonance frequency

Appendix D

Data Sheets

National Semiconductor

PRELIMINARY
May 1984

LM3361A Low Voltage/Power Narrow Band FM IF System

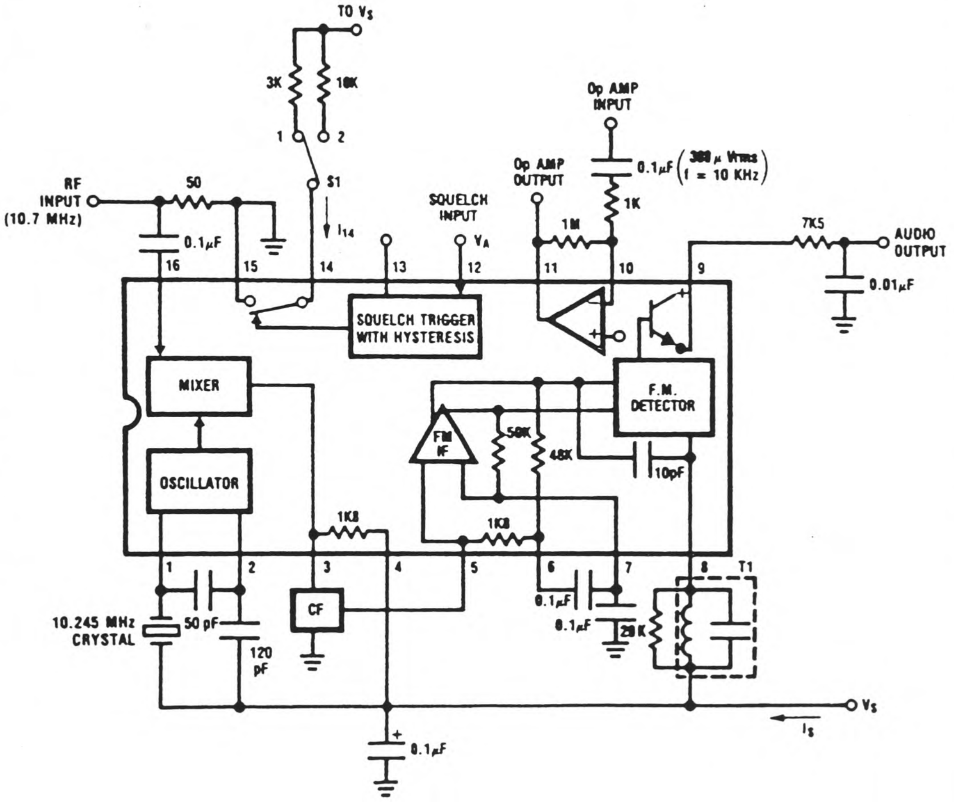
General Description

The LM3361A contains a complete narrow band FM demodulation system operable to less than 2V supply voltage. Blocks within the device include an oscillator, mixer, FM IF limiting amplifier, FM demodulator, op amp, scan control, and mute switch. The LM3361A is similar to the MC3361 with the following improvements: the LM3361A has higher voltage swing both at the op amp and audio outputs. It also has lower nominal drain current and a squelch circuit that draws significantly less current than the MC3361. Device pinout functions are identical with some slightly different operating characteristics.

Features

- Functions at low supply voltage (less than 2V)
- Highly sensitive (−3 dB limiting at 2.0 μV input typical)
- High audio output (increased 6 dB over MC3361)
- Low drain current (2.8 mA typ., $V_{CC} = 3.6V$)
- Minimal drain current increase when squelched
- Low external parts count

Block Diagram And Test Circuit



TL/H/5586–1

T1-TOKO RMC-2A6597HM
CF-MURATA CFU 455E

RRD-B30M54/Printed in U. S. A.

Absolute Maximum Ratings

Package dissipation (Note 1)	1500 mW	Operating ambient temperature range	0° to 70°C
Power supply voltage (V_S)	12 V	Storage temperature range	−55° to +150°C
RF input voltage (V_S>3.6V)	1 Vrms	Lead temp. (Soldering 10 seconds)	300°C
Mute function (pin 14)	−.7 to 5 Vp		

Parameters Guaranteed By Electrical Testing

(Test ckt, $T_A = 25°C$, $V_S = 3.6V$, $f_O = 10.7$ MHz, $\Delta f = \pm 3$ KHz, $f_{MOD} = 1$ KHz, 50Ω source)

Parameter	Measure	Min	Typ	Max	Units
Supply Voltage Range	V_S	2.0	3.6	9.0	V
Supply Current					
Squelch Off	I_S		2.8	5.0	mA
Squelch On	I_S		3.6	6.0	mA
RF Input for −3 dB Limiting	RF Input		2.0	6.0	μV
Recovered Audio at Audio Output	Audio Output	200	350		mV_{RMS}
Audio Out DC	V_9	1.2	1.5	1.8	V_{DC}
Op Amp Gain	v_{11}/v_{IN}	40	55		dB
Op amp Output DC	V_{10}	0.4	0.7		V_{DC}
Op Amp Input Bias Current	$(V_{10}-V_{11})/1M\Omega$		20	75	nA
Scan voltage					
Pin 12 high (2V)	V_{13}		0	0.5	V_{DC}
Pin 12 Low (0V)	V_{13}	3.0	3.4		V_{DC}
Mute Switch Impedance, Pin 12 0V Switch S1 from pos.1 to pos.2	$\Delta V_{14}/\Delta I_{14}$		15	30	ohms

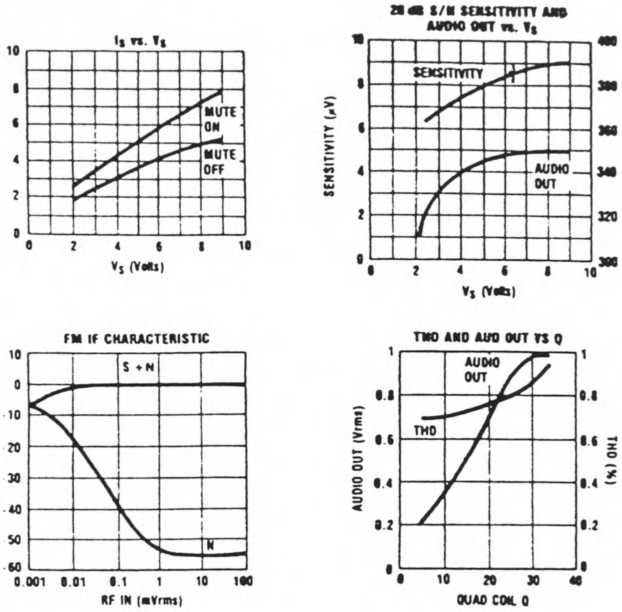
Design Parameters Not Tested or Guaranteed

	Typ	
Mixer Conversion Gain (Note 2.)	46	V/V
Mixer Input Resistance	3.6	Kohm
Mixer Input Capacitance	2.2	pF
Detector output impedance	500	ohm
Trigger Hysterisis	100	mV
Mute off impedance (measure pin 14 with pin 12 @ 2V)	10	Mohm
Squelch threshold	.65	V_{DC}
Detector center frequency slope	0.15	V/KHz

Note 1. For operation above 25°C ambient temperature, the device must be derated based on 150°C maximum junction temperature and a thermal resistance θ_{JA} of 80°C/W.

Note 2. Mixer gain is supply dependent and effects overall sensitivity accordingly (See Typical Performance Characteristics).

Typical Performance Characteristics (Test Circuits)

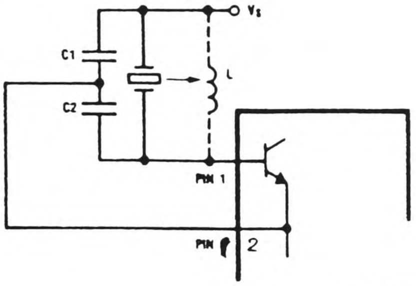


TL/H/5586-2

Applications Information (See Internal Schematic)

OSCILLATOR

The Colpitts type oscillator is internally biased with a regulated current source which assures proper operation over a wide supply range. The collector, base, and emitter terminals are at pins 4, 1, and 2 respectively. The crystal, which is used in the parallel resonant mode, may be replaced with an appropriate inductor if the application does not require the stability of a crystal oscillator. In this case, the resonant frequency will be determined by the inductor in parallel with the series combination of C1 and C2.



TL/H/5586-4

so $C_T = (C1)(C2)/(C1 + C2)$

and $f_O = .159/\sqrt{L(C_T)}$

MIXER

The mixer is double balanced to reduce spurious responses. The upper pairs are switched by the oscillator while the RF input is applied to the lower pair (pin 16). R43 sets the mixer input impedance at 3.6 kΩ. The mixer output impedance of 1.8 kΩ will properly match the input impedance of a ceramic filter which is used as a bandpass filter coupling the mixer output to the IF limiting amplifier.

IF LIMITER

The IF amplifier consists of six differential gain stages, with the input impedance set by R2 at 1.8 kΩ to properly terminate the ceramic filter driving the IF. The IF alone (without mixer) has a −3 dB limiting sensitivity of approximately 50 μV. The system bandwidth is limited to about 5 MHz due to high impedances in the IF which are necessary to meet low power requirements. The IF output is connected to the external quad coil at pin 8 via an internal 10 pF capacitor.

FM DEMOD AUDIO OUT

A conventional quadrature detector is used to demodulate the FM signal. The Q of the quad coil, which is determined by the external resistor placed across it, has multiple affects on the audio output. Increasing the Q increases output level but because of nonlinearities in the tank phase characteristic, also increases distortion (see Typical Performance Characteristics). For proper operation, the voltage swing on pin 8 should be adequate to drive the upper rank of the multiplier into switching (about 100 mVrms). This voltage level is dependent on the internal 10 pF capacitor and the tank R_p voltage divider network. After detection and de-emphasis, the audio output at pin 9 is buffered by an emitter follower.

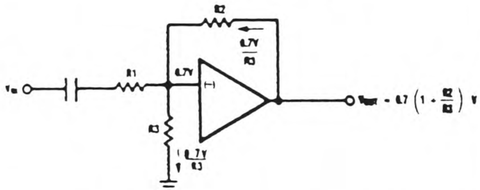
OP AMP

The op amp inverting input (pin 10) which is internally referenced to .7V, receives dc bias from the output at pin 11 through the external feedback network. Because of the low D.C. bias, maximum swing on the op amp output with 10% distortion is 500mVrms. This can be increased when operating on supplies over 2.3V by adding a resistor from the op amp input to ground which raises the quiescent D.C. at the output allowing more swing (see figure below for selection of added resistor). The op amp is normally utilized as either a bandpass filter to extract a specific frequency from the audio output, such as a ring or dial tone, or as a high pass filter to detect noise due to no input at the mixer. The latter condition will generate a signal at the op amp oput, which when applied to pin 12 can mute the external audio amp.

for max swing: $V_{OUT} = (V_S - V_{BE})/2$ (from internal circuit)

$$\text{so } (V_S - V_{BE})/2 = .7\left(1 + \frac{R2}{R3}\right)$$

$$\text{and } \cdot \frac{R2}{R3} = \left(\frac{V_S - V_{BE}}{1.4}\right) - 1$$



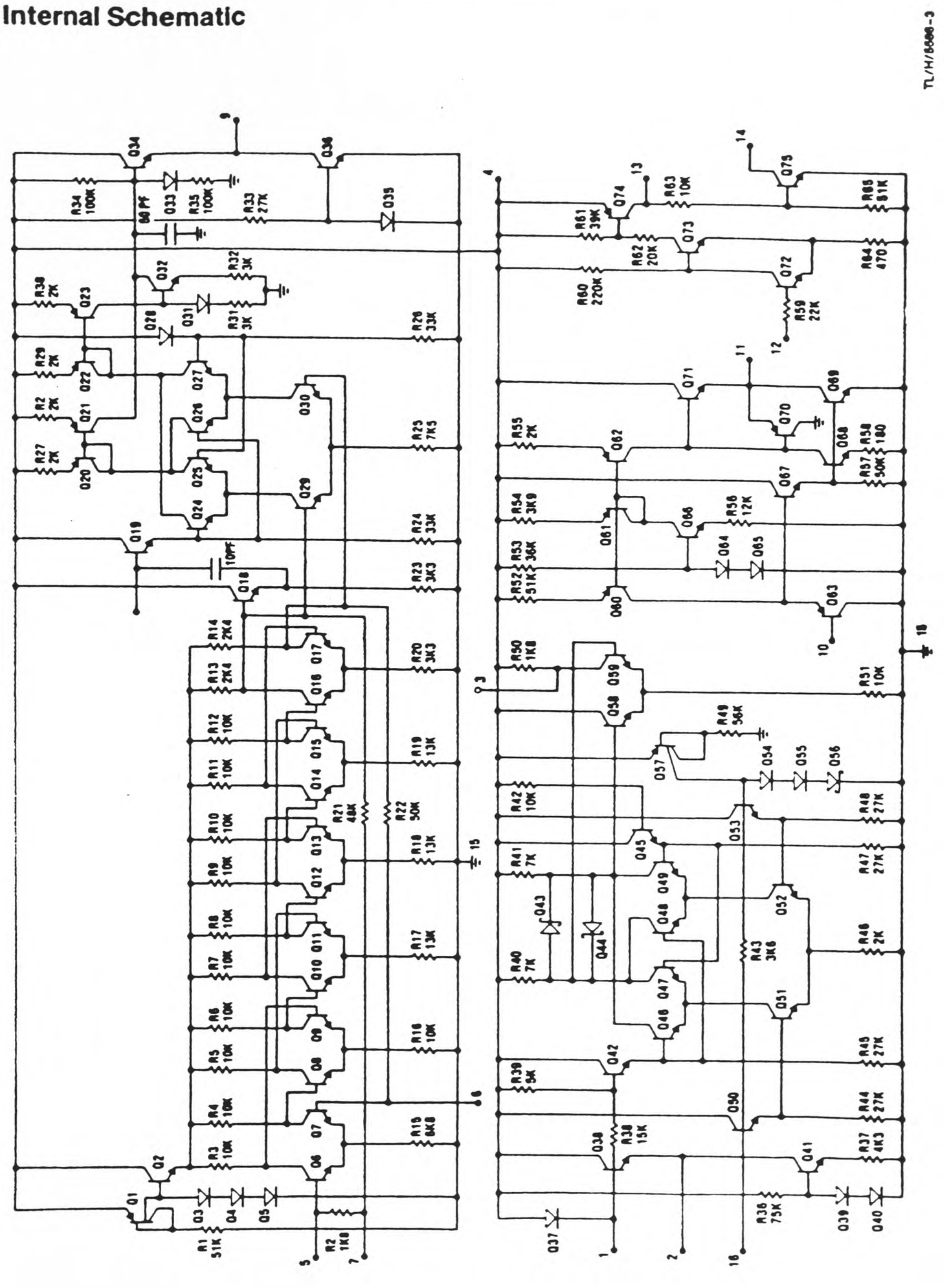
TL/H/5586-5

Increasing OP Amp Swing

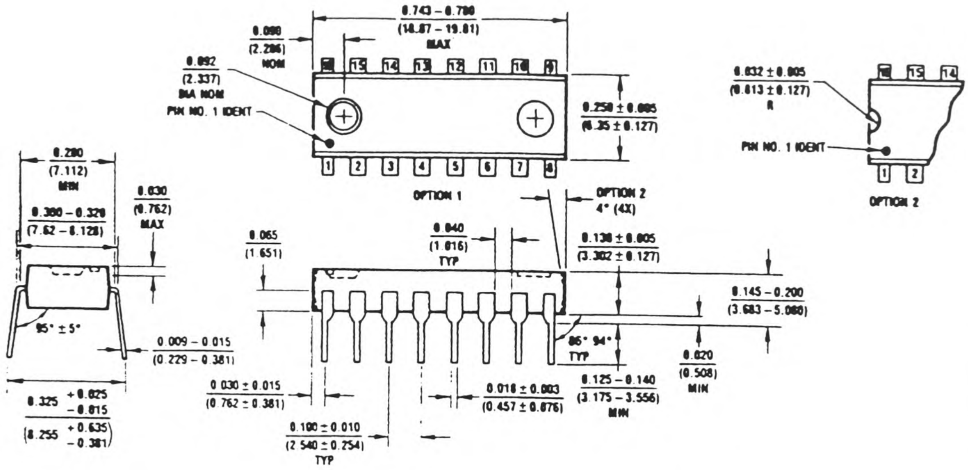
SQUELCH TRIGGER CIRCUIT

The squelch trigger circuit is configured such that a low bias on the input (pin 12) will force pin 13 high (200 mV below supply), where it can support at least a 1 mA load, and pin 14 to be a low impedance, typically 15Ω to ground. Connecting pin 14 to a high impedance ground reference point in the audio path between pin 9 and the audio amp will mute the audio output. Pulling pin 12 above mute threshold (.65V) will force pin 13 to an impedance of about 60 kΩ to ground and pin 14 will be an open circuit. There is 100 mV of hysterisis at pin 12 which effectively prevents jitter.

Internal Schematic



Physical Dimensions inches (millimeters)



Molded Dual-In-Line Package (N)
Order Number LM3361AN
NS Package Number N16E

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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Telex AA32096

CA3083

General-Purpose High-Current N-P-N Transistor Array

Features:

- *High I_C: 100 mA max.*
- *Low V_{CEsat} (at 50 mA): 0.7V max.*
- *Matched pair (Q1 and Q2) -*
  V_{IO} (V_{BE} matched): ± 5 mV max.
  I_{IO} (at 1 mA): 2.5 μA max.
- *5 independent transistors plus separate substrate connection*

RCA-CA3083 is a versatile array of five high-current (to 100mA) n-p-n transistors on a common monolithic substrate. In addition, two of these transistors (Q1 and Q2) are matched at low currents (i.e. 1mA) for applications in which offset parameters are of special importance.

Independent connections for each transistor plus a separate terminal for the substrate permit maximum flexibility in circuit design. The CA3083 is supplied in a 16-lead dual-in-line frit-seal ceramic package. The CA3083 is also available in chip form.

Applications:

- *Signal processing and switching systems operating from DC to VHF*
- *Lamp and relay driver*
- *Differential amplifier*
- *Temperature-compensated amplifier*
- *Thyristor firing*
- *See RCA Application Note, ICAN-5296 "Application of the RCA-CA3018 Circuit Transistor Array" for suggested applications*

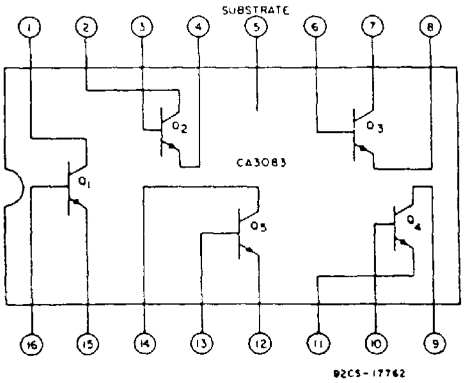


Fig. 1 — Functional diagram of the CA3083.

MAXIMUM RATINGS, Absolute-Maximum Values at T_A = 25°C

Power Dissipation:		
Any one transistor	500	mW
Total package	750	mW
Above 55°C	Derate linearly 6.67	mW/°C
Ambient Temperature Range:		
Operating	−55 to +125	°C
Storage	−65 to +150	°C
Lead Temperature (During Soldering):		
At distance 1/16" ±1/32" (1.59 mm ±0.79 mm) from case for 10 seconds max.	265	°C
The following ratings apply for each transistor in the device:		
Collector-to-Emitter Voltage (V_{CEO})	15	V
Collector-to-Base Voltage (V_{CBO})	20	V
Collector-to-Substrate Voltage (V_{CIO})■	20	V
Emitter-to-Base Voltage (V_{EBO})	5	V
Collector Current (I_C)	100	mA
Base Current (I_B)	20	mA

■ The collector of each transistor of the CA3083 is isolated from the substrate by an integral diode. The substrate must be connected to a voltage which is more negative than any collector voltage in order to maintain isolation between transistors and provide normal transistor action. To avoid undesired coupling between transistors, the substrate terminal (5) should be maintained at either DC or signal (AC) ground. A suitable bypass capacitor can be used to establish a signal ground.

ELECTRICAL CHARACTERISTICS at T_A = 25°C
For Equipment Design

CHARACTERISTICS	SYMBOL	TEST CONDITIONS		LIMITS			UNITS
			Typ. Char. Curve Fig. No.	Min.	Typ.	Max.	
For Each Transistor:							
Collector-to-Base Breakdown Voltage	$V_{(BR)CBO}$	I_C = 100μA, I_E = 0	–	20	60	–	V
Collector-to-Emitter Breakdown Voltage	$V_{(BR)CEO}$	I_C = 1mA, I_B = 0	–	15	24	–	V
Collector-to-Substrate Breakdown Voltage	$V_{(BR)CIO}$	I_{CI} = 100μA, I_B = 0, I_E = 0	–	20	60	–	V
Emitter-to-Base Breakdown Voltage	$V_{(BR)EBO}$	I_E = 500μA, I_C = 0	–	5	6.9	–	V
Collector-Cutoff-Current	I_{CEO}	V_{CE} = 10V, I_B = 0	–	–	–	10	μA
Collector-Cutoff-Current	I_{CBO}	V_{CB} = 10V, I_E = 0	–	–	–	1	μA
DC Forward-Current Transfer Ratio	h_{FE}	V_{CE} = 3V, I_C = 10mA	2	40	76	–	
		V_{CE} = 3V, I_C = 50mA		40	75	–	
Base-to-Emitter Voltage	V_{BE}	V_{CE} = 3V, I_C = 10mA	3	0.65	0.74	0.85	V
Collector-to-Emitter Saturation Voltage	V_{CEsat}	I_C = 50mA, I_B = 5mA	4	–	0.40	0.70	V
Gain-Bandwidth Product	f_T	V_{CE} = 3 V I_C = 10 mA		–	450	–	MHz
For Transistors Q1 and Q2 (As a Differential Amplifier):							
Absolute Input Offset Voltage	$\|V_{IO}\|$	V_{CE} = 3V, I_C = 1mA	7	–	1.2	5	mV
Absolute Input Offset Current	$\|I_{IO}\|$		8	–	0.7	2.5	μA

TYPICAL STATIC CHARACTERISTICS FOR EACH TRANSISTOR

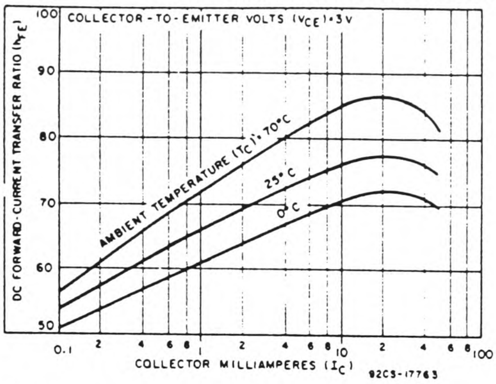


Fig.2 – h_{FE} vs I_C

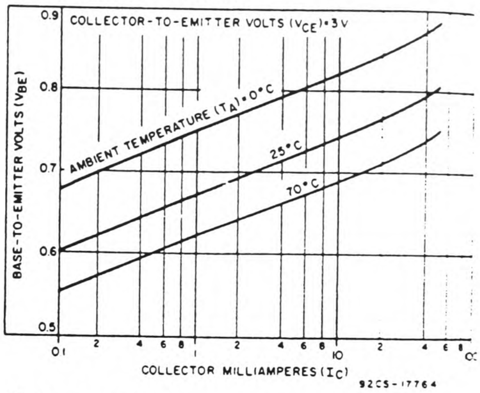


Fig.3 – V_{BE} vs I_C

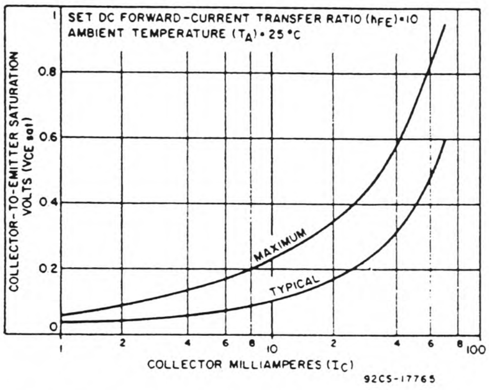


Fig.4 – V_{CEsat} vs I_C at 25°C

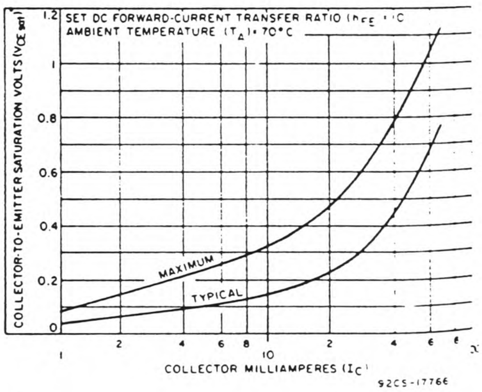


Fig.5 – V_{CEsat} vs I_C at 70°C

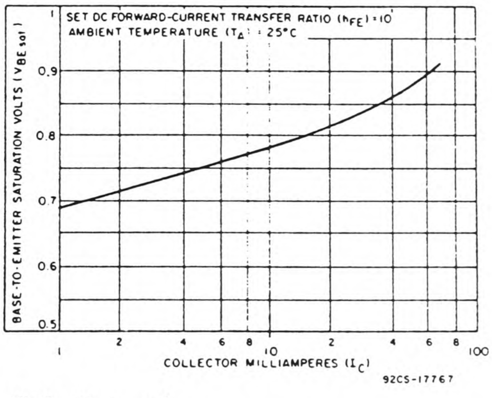


Fig.6 – V_{BEsat} vs I_C

Mixers

S 042 P
S 042 E

Bipolar circuit

Symmetrical mixer for frequencies up to 200 MHz. It can be driven from an external source or from the built-in oscillator. The input signals are suppressed at the outputs. In addition to the usual mixer applications in receivers, converters, and demodulators for AM and FM, the S 042 can also be used as an electronic polarity switch, multiplier etc.

- Versatile application
- Wide range of supply voltage
- Few external components
- High conversion transconductance
- Low noise figure

Type	Ordering code	Package outline
S 042 P	Q67000-A335	DIP 14
S 042 E	Q67000-A627	5 J 10 DIN 41873/sim. to TO 100

Maximum ratings

Supply voltage		V_S	15	V
Storage temperature range		T_{stg}	−40 to 125	°C
Junction temperature		T_j	150	°C
Thermal resistance (system-air)	S 042 P:	$R_{th\,SA}$	90	K/W
	S 042 E:	$R_{th\,SA}$	190	K/W

Range of operation

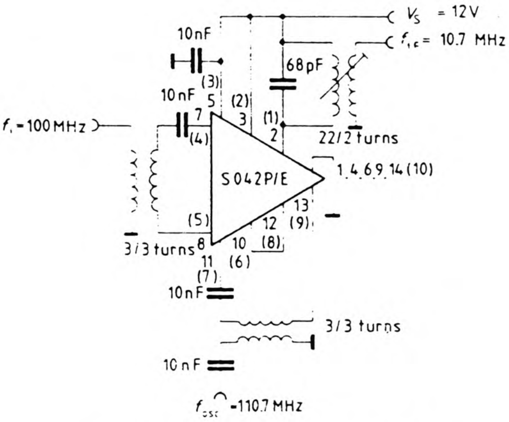
Supply voltage range	V_S	4 to 15	V
Ambient temperature range	T_{amb}	−15 to 70	°C

Characteristics (V_S = 12 V, T_{amb} = 25° C)

		min	typ	max	
Current consumption	$I_S = I_2 + I_3 + I_5$	1.4	2.15	2.9	mA
Output current	$I_2 = I_3$	0.36	0.52	0.68	mA
Output current difference	$I_3 - I_2$	−60		60	mA
Supply current	I_5	0.7	1.1	1.6	mA
Power gain (f_i = 100 MHz, f_{osc} = 110.7 MHz)	G_p	14	16.5		dB
Breakdown voltage ($I_{2,3}$ = 10 mA; $V_{7,8}$ = 0 V)	V_2, V_3	25			V
Output capacitance	$C_{2\text{-}M}$, $C_{3\text{-}M}$		6		pF
Conversion transconductance (f = 455 kHz)	$S = \frac{I_2}{V_7 - V_8} = \frac{I_3}{V_7 - V_8}$		5		mS
Noise figure	NF		7		dB

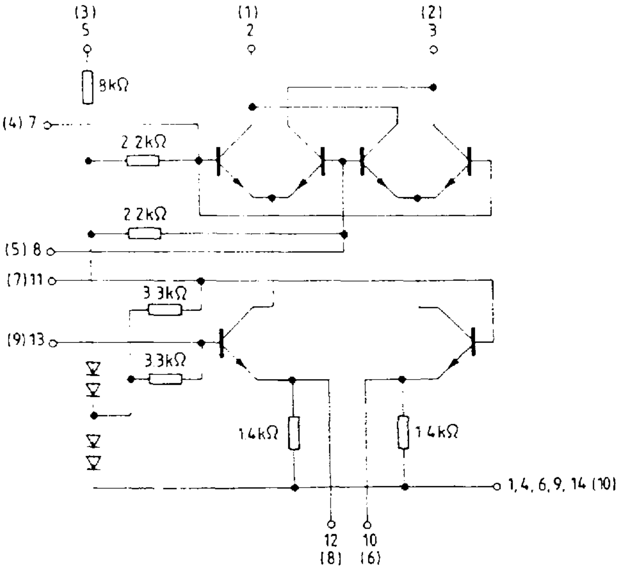
All connections mentioned in the index are referred to S 042 P (e.g. I_2)

Test circuit



Connections in parentheses apply to S 042 E

Circuit diagram

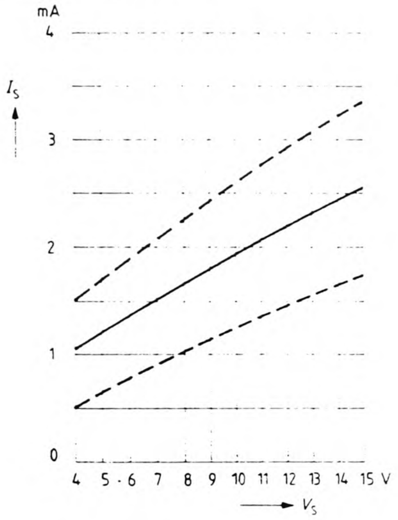


Connections in parentheses apply to S 042 E

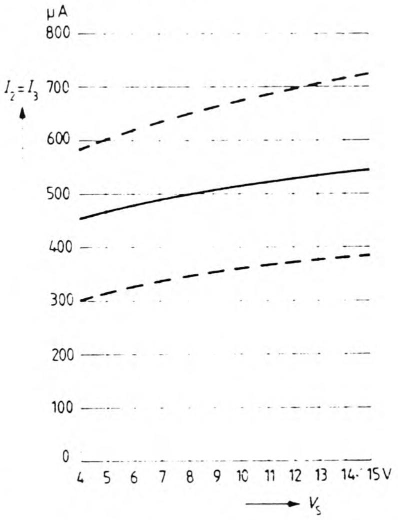
A galvanic connection between pins 7 and 8 and pins 11 and 13 through coupling windings is recommended.

Between pins 10 and 14 (ground) and between pins 12 and 14, one resistance each of at least 200 Ω may be connected to increase the currents and thus the conversion transconductance. Pins 10 and 12 may be connected through any impedance. In case of a direct connection between pins 10 and 12, the resistance from this pin to 14 may be at least 100 Ω. Depending on the layout, a capacitor (10 to 50 pF) may be required between pins 7 and 8 to prevent oscillations in the VHF band.

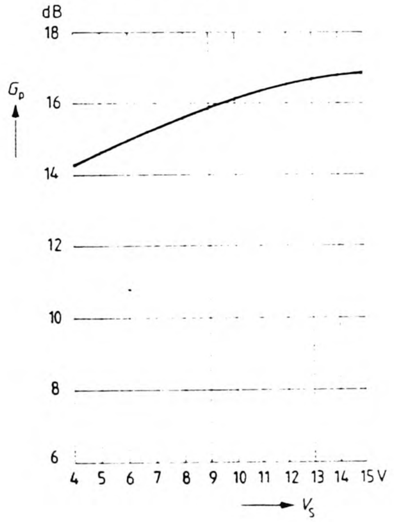
Total current consumption versus supply voltage



Output voltages versus supply voltage

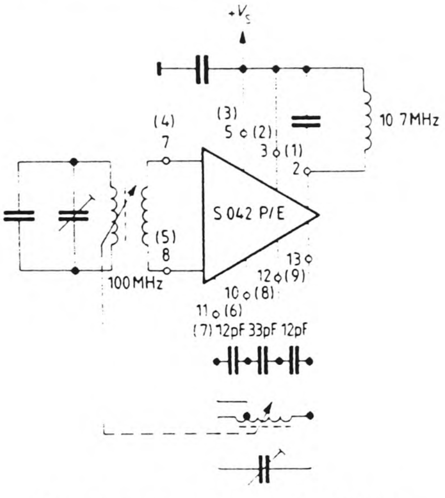


Power gain versus supply voltage



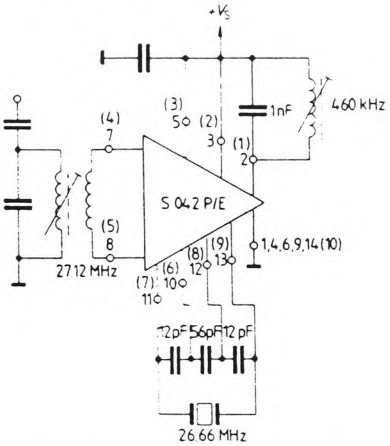
Application circuits

VHF mixer with inductive tuning



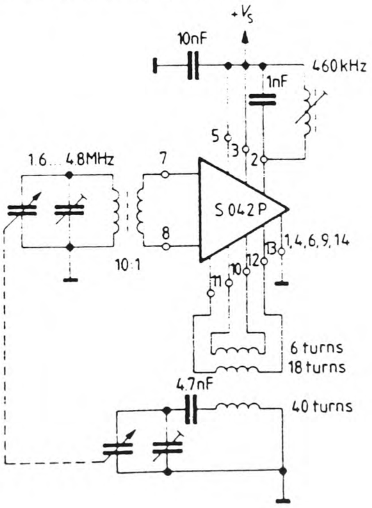
Connections in parentheses apply to S 042 E

Mixer for remote control receivers without oscillator



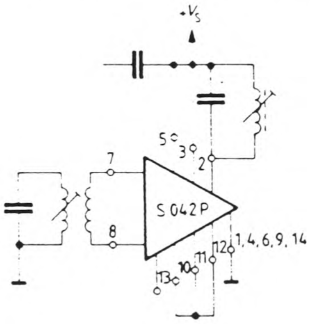
Connections in parentheses apply to S 042 E

Mixer for short wave application in self-oscillating operation



For overtone crystals an adequate inductance is recommended between pins 10 and 12 to avoid oscillations to the fundamental tone.

Differential amplifier with internal neutralization, also suited for use as limiter for frequencies up to 50 MHz, at higher currents up to 100 MHz



Appendix E

Surface Mount Design Guideline Updates

1-0 Introduction

This document is an addition to the design rule set. It includes details of design requirements for the onsert machine acquired during the course of the study and further recommendations for designers of radio frequency assemblies.

2-0 Dynapert 318 Onsert Machine

Based on projections of SMD placement requirements at Autophon, a Dynapert 318 onsertion machine was purchased. It has a placement rate of 4000 components an hour and the ability to dot the glue necessary for wave soldered assemblies, reducing the rate to 2500 pieces per hour.

There is 1470 mm of component feeder place (60") which is capable of handling 60 x 8mm tape or reel component supplies. When larger devices, such as flat packs, are to be placed by the machine, the component supply will take up more than one component space and so the number of different component types able to be placed in one pass will be reduced. Due to this limit it is beneficial to design with a restricted component set when possible.

The Dynapert 318 does not support component verification. Since SMDs are generally supplied pre-tested there should not be problems with tolerances, but it is important that component supplies are loaded into the correct compartment on the machine.

2-1 Fiducial Marks

The Dynapert 318 uses an optical placement verification system to guarantee the correct positioning of SMDs. The system uses fiducial markings to re-calibrate the positioning sequence for each PCB. This also compensates for PCB manufacturing tolerances across the board. The marks are generally diamond shaped and are placed in the corners of PCBs.

3-0 Recommendations for Good Design Practice in Radio Frequency Designs

Resulting from the experience obtained during the development of the **Piccolo** telephone, the following list contains relevant points concerning the use of SMDs at radio frequencies.

3-1 Screened Transformers

Unless assembly thickness is greatly restricted it is advisable to utilise leaded screened transformers within circuit designs. SMD versions are available but tend to be rather more expensive and often can not be wave soldered. In single-sided, mixed technology circuits it is beneficial to employ the largest transformer devices possible because of their price and performance advantage, and the fact that SMDs can be positioned between their leads on the underside of the PCB.

3-2 Surface Mount Capacitors

These parts offer the greatest performance advantage and the effect can be appreciated at relatively low frequencies of several MHz. They have inherently less series inductance than leaded capacitors and their assembly gives high repeatability.

SM capacitors should always be used when their higher self resonant frequency (SRF) is advantageous, or when the capacitor's tolerance is important when operated at over 20 % of its SRF. (See figure 2 in appendix 2 of Appendix C).

Leaded components should be avoided in such applications because their greater lead inductance varies with lead insertion accuracy. (The inductance of a leaded component increases by approximately 1 nH per 1 mm of lead length). Once positioned, stray circuit components may also alter due to the devices being bent into different positions.

Warnings:

1: SRF is only optimised when track lengths to the device are minimised and therefore the PCB lay out must be monitored carefully to achieved the required performance.

2: COG dielectric must be stipulated when tolerance is important. Tolerance advantages are lost when unstable dielectrics are incorporated because of high temperature and aging coefficients.

3-2 Track to Component Coupling

It is necessary to be aware of the fact that track to component coupling is greater in the case of a SMD used to bridge a PCB track. The situation is illustrated in figure 1. Clearly the proximity of a SM capacitor to the wire causes a greater coupling effect. The inclusion of an earth plane also has negligible effect.

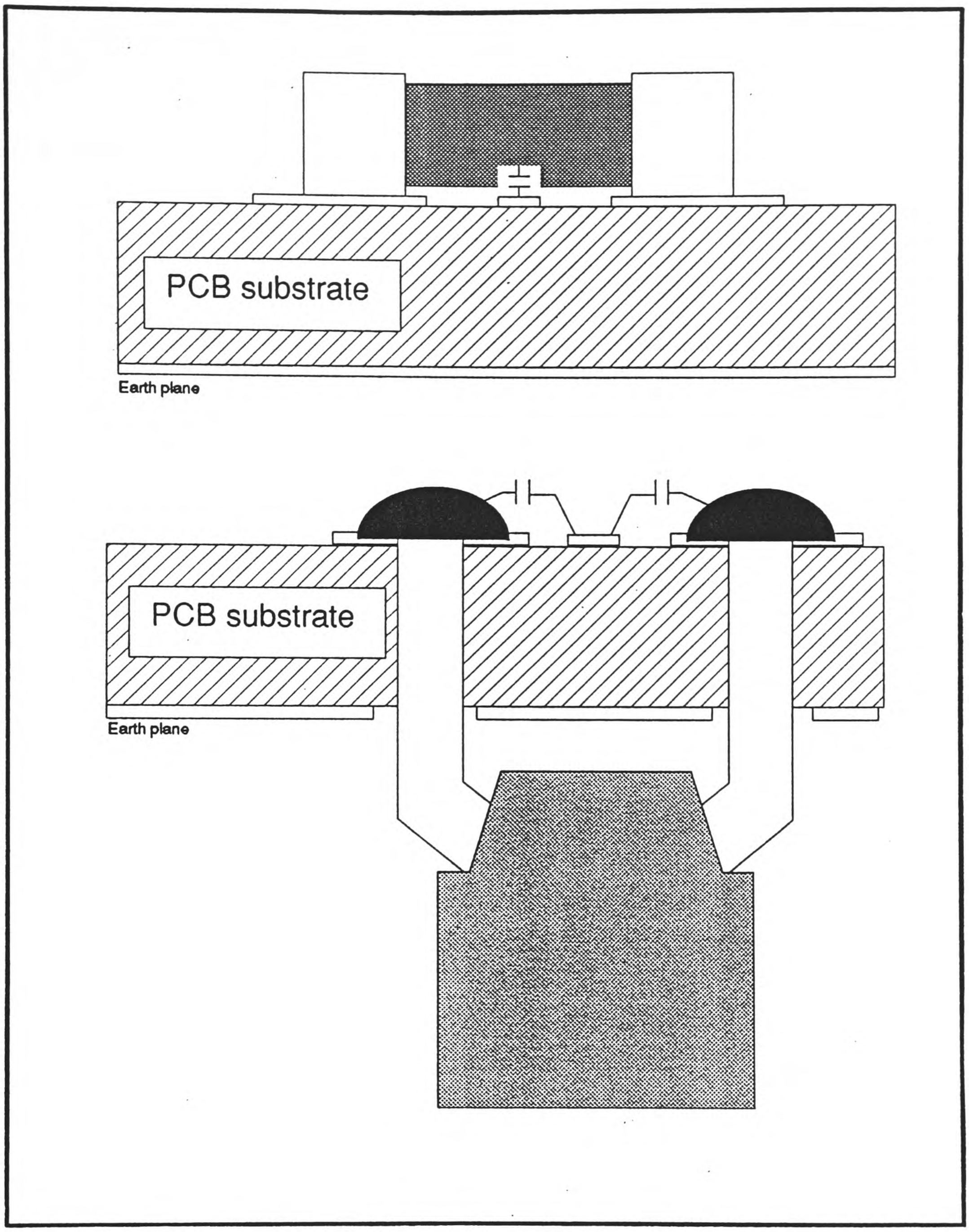


Figure 1 Increased Coupling between Track and Surface Mount Component

This form of coupling can give unexpectedly high levels of RF feedthrough or circuit instability (when positive feedback results) and may necessitate a tracking re-route.

3-4 Leaded/Surface Mount Integrated Circuit Choice

The availability of both leaded and SM integrated circuits in single-sided mixed technology assemblies gives the assembly designer added flexibility to achieve optimum RF layout. This is seen in figure 2 and comes about because of the device pin-out becoming mirror-imaged when mounted on the opposite side of the board. In the example, the layout using a leaded integrated circuit is simpler and results in shorter track lengths. In other situations, the opposite could well be true.

In the situation illustrated, the layout with the leaded part is more suited to the positions of other circuit components, which may have been restricted by assembly space. The use of this component results in minimum track length and board space loss is minimised by positioning SMDs on the underside.

3-5 Combatting Unwanted Coupling due to Miniaturisation

The miniaturisation of circuits can bring with it increased unwanted coupling. This if most often due to space restrictions not allowing optimum layout to be achieved and not because SMDs are more prone to such interference. It is, however, often possible to achieve design specification by rejecting coupling at its entry point.

The most sensitive capacitive coupling points tend to be high impedance nodes. When the high impedance is not necessary, coupling may be reduced by lowering the impedance with an extra component connected to ground.

Mutual inductance can be countered by using screened devices or orienting components to minimise flux linkage.

The solid chip inductor is a useful device, available in SMD chip format, for attenuating unwanted high frequency signals from conducting along power supplies or for damping unwanted resonant networks. Its impedance becomes lossy at high frequencies because of the property of the ferrite material and is functional from several MHz to beyond 1GHz.

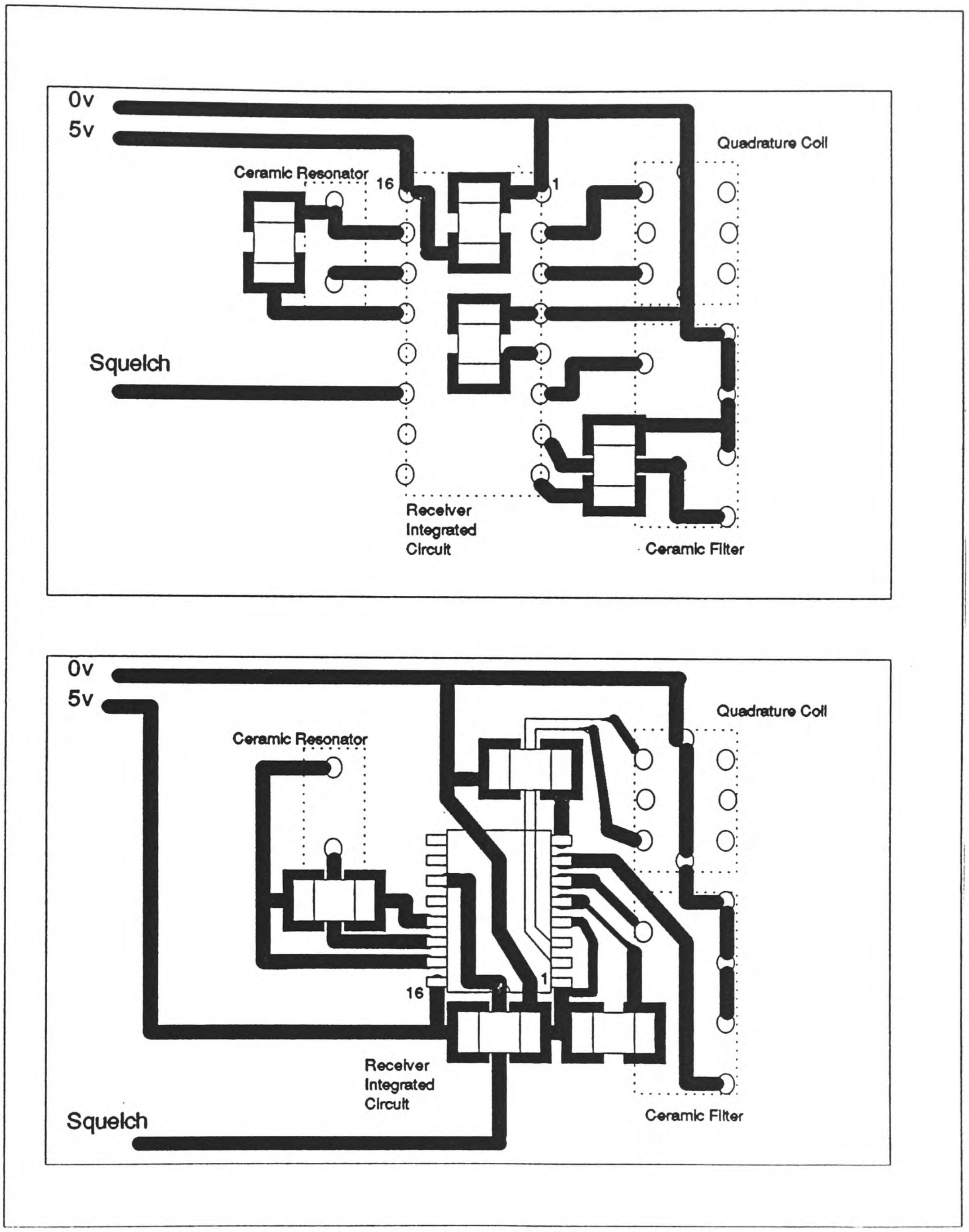


Figure 2 Choice between Leaded and Surface Mounted Integrated Circuit can Result in Optimum Layout