INFRARED TESTING OF ELECTRONIC COMPONENTS

Phase I Report

Contract No. NAS 8-20131

5 April 1965 through 29 June 1965

OR 6610 June 1965

Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama

Prepared by: W. R. Randle
Senior Engineer

Approved by: D. D. Seltzer
Technical Project Leader

O. J. Schaefer
Project Manager

Martin-Marietta Corporation
Orlando, Florida

FOREWORD

This Phase I report was prepared for the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama, by the Orlando Division of the Martin-Marietta Corporation in accordance with Exhibit A of Contract No. NAS 8-20131, dated 5 April 1965.

CONTENTS

TABLES

SUMMARY

The questionnaire, technical report, and personal interview surveys conducted as Phase I of this contract have revealed a strong, active interest in developing infrared (IR) test techniques for electronics. This interest is manifested in government funded investigations, in-house government investigations, company funded investigations, and commercial development of instrumentation for infrared programs.

This survey establishes that there are at least 32 industrial organizations exploring and/or applying IR techniques to electronic components and subsystems. Three government agencies (NASA, RADC, WPAFB) have awarded at least seven feasibility and development IR programs to industry. The Signal Corp Engineering Laboratories (SCEL) are currently considering directing an IR study in fault detection and isolation in electronic systems. At least four government agencies are conducting in-house IR programs, these being RADC, NASL, NEL, and WPAFB.

A large percentage of the work performed to date has been in the area of feasibility studies....with more specific applications being investigated as time passes. The general trend in the use of IR appears to be one of diminishing activity relative to screening applications with emphasis shifting strongly toward design evaluation and new design techniques development. Greatest industry interest (43 percent) is directed to design packaging of circuit boards, thin films, and integrated circuits – while 34 percent is directed to failure analysis and diagnostic measurements. In contrast, government agencies indicated a primary interest in directing IR applications to failure analysis and diagnostic measurements (55 percent). This was followed by process control of circuit boards, thin films, integrated circuits, and multi-layer boards (37 percent).

Of the total number of companies engaged in IR techniques, 25 percent indicated that normal and/or accelerated life testing techniques had been employed to correlate IR radiation with component life.

The major problem areas that were emphasized in this survey include:

1. Emissivity equalization for a wide diversity of applications

2. Scanning of circuits and/or devices with higher speeds and more rapid data recording and analysis

3 Simplification of data presentation and interpretation directed at skill levels required to operate IR systems

4 Spatial resolution of IR instrumentation to less than one mil to permit application to microcircuits

5 Response time improvement combined with instrumentation sensitivity, temperature resolution, and temperature range for divergent applications on microcircuits.

Although considerable knowledge must yet be developed before useful applications become a reality, the acquisition and interpretation of usable data is considered to be of paramount importance in attaining this goal. However, there is little doubt that IR will become a powerful test technique for electronics and increasingly will play a significant role in future electronic design and production activities.

ACKNOWLEDGEMENTS

The Martin Company wishes to express its sincere appreciation to the many industrial organizations and government agencies who participated by contributing both time and information during the personal interview and/or the questionnaire survey portion of the program. Without their cooperation and expression of interest, Phase I could not have been successfully completed.

Industry and Institutions

AC Spark Plug Electronics Division	Milwaukee, Wisconsin
Aerojet-General Corporation	Azusa, California
Applied Science Laboratory of Johns Hopkins University	Silver Springs, Maryland
Argonne National Laboratory	Argonne, Illinois
ARINC Research Corporation	Washington, D. C.
AUL Instruments, Incorporated	Long Island City, New York
North American Aviation	Anaheim, California
AVCO Corporation	Lowell, Massachusetts
Block Engineering, Incorporated	Cambridge, Massachusetts
The Boeing Company	Michoud, Louisiana
The Boeing Company	Seattle, Washington
Brown Engineering	Huntsville, Alabama
Collins Radio Company	Cedar Rapids, Iowa
Cutler-Hammer	Deer Park, Long Island, New York
Douglas Missile Division	Santa Monica, California
General American Transportation Corporation	Niles, Illinois
General Electric Company	Philadelphia, Pennsylvania
General Electric Company	Ithaca, New York
General Dynamics/Convair	San Diego, California
Honeywell, Incorporated	Minneapolis, Minnesota
Honeywell Data Processing	Newton Highlands, Massachusetts
IBM General Products Division	San Jose, California
IBM Space Guidance Division	Owego, New York
Jet Propulsion Laboratory	Pasadena, California
Ling Temco Vought	Dallas, Texas
Lockheed-Georgia Company	Marietta, Georgia

Industry and Institutions (Cont)

Lockheed Missile and Space Division	Sunnyvale, California
Massachusetts Institute of Technology	Cambridge, Massachusetts
Melpar, Incorporated	Falls Church, Virginia
Motorola, Incorporated	Scottsdale, Arizona
Philco Corporation	Lansdale, Pennsylvania
Pyrotell Corporation	Mamaroneck, New York
Optics Technology, Incorporated	Palo Alto, California
Radio Corporation of America	Somerville, New Jersey
Sylvania Electric	Woburn, Massachusetts
The Raytheon Company	Norwood, Massachusetts
Tektronix, Incorporated	Beaverton, Oregon
Texas Instruments, Incorporated	Dallas, Texas
Thiokol Chemical Corporation	Huntsville, Alabama
Univac Division of Sperry Rand Corporation	St. Paul, Minnesota
Washington State University	Pullman, Washington
Western Electric Company	Allentown, Pennsylvania
Westinghouse Electronic Corporation	Youngwood, Pennsylvania

Government Agencies

Air Force Aero Propulsion Laboratory	Wright-Patterson Air Force Base, Ohio
Air Force Cambridge Research Laboratory	Bedford, Massachusetts
Rome Air Development Center	Griffiss Air Force Base, New York
U.S. Army Engineer Research and Development Laboratories	Fort Belvoir, Virginia
U.S. Army Electronic Laboratory	Fort Monmouth, New Jersey
U.S. Army Missile Command	Redstone Arsenal, Alabama
U.S. Navy Air Development Center	Johnsville, Pennsylvania
U.S. Navy Electronics Laboratory	San Diego, California
U.S. Naval Applied Science Laboratory	Brooklyn, New York
U.S. Naval Ordnance Test Station	China Lake, California
U.S. Naval Weapons Station	Concord, California

INTRODUCTION

This report describes the Phase I effort performed under Contract No. NAS 8-20131 during the period 5 April 1965 through 29 June 1965. The purpose of Contract No. NAS 8-20131 is to determine the feasibility of developing a nondestructive testing technique, using infrared (IR) radiation measurement, for detecting incipient failures that are not revealed by present electrical testing methods. Work under the contract is divided into three phases. Phase I involved surveying literature and industry to determine the state-of-the-art relative to:

1. IR radiation sensing and measurement instrumentation,

2. IR technology as applied to the nondestructive testing of electrical and electronic components and subsystems,

3. Areas of fabrication and testing presently being investigated for possible application of infrared techniques.

Phase II consists of developing one or more coating materials that will standardize the emissivity of electrical and electronic components to a high constant value while meeting specified mechanical, electrical, and environmental requirements.

Phase III will include an investigation of technology as a nondestructive testing technique for electrical and electronic parts, components, and subassemblies to determine the feasibility for further development and extensive application.

Initiation of Phase II and III effort is contingent upon approval by the Contracting Officer of Phase I.

I. DISCUSSION OF PHASE I ACTIVITIES

A. QUESTIONNAIRE SURVEY

1. Planning and preparation

A major objective of Phase I was to determine the amount and type of effort expended by industry and the government in the IR radiation measurement field directed towards application in the field of electronics. A questionnaire appeared to be best suited for contacting a reasonably extensive and representative cross section of potential respondents in a minimum of time. On the basis of this approach, consideration was given to:

1 Layout of the general plan

2 Formulation of questions

3 Selection of questionnaire addressees.

The general plan was to reach a representative cross section of industry and government organizations known to be interested or engaged in electronically oriented infrared (IR) programs by submitting questionnaires. The addressees were allowed approximately 3 weeks in which to reply. After the reply cutoff date, the information from all replies was tabulated, tables for meaningful presentation were developed, and an analysis interpreting the results was prepared. It was anticipated that the questionnaire replies would be used to advantage in the selection of organizations to be personally visited for the purpose of discussing programs in greater detail; thus the identity of respondents was requested.

Questions for inclusion in the survey were formulated so as to be answered easily and accurately. It was recognized that some form of objective, single answer question would be preferred over the type of question requiring an essay answer. With this in mind, questions were developed which required a minimum of time and effort in answering. As can be seen from a review of the questionnaires shown in Appendix A, the yes-or-no, and multiple-choice item type of question was used predominately. Particular care was taken to avoid the unduly inquisitive question which might induce violations of proprietary or security requirements.

Rather than selecting the list of questionnaire addressees by taking a random sample of all industry and government organizations thought to be capable of conducting infrared programs, the selection was made on a more purposeful basis. That is, a list of organizations known to be interested or involved in infrared measurement programs was generated by reviewing attendance lists of companies represented at various technical symposiums. The most productive symposiums were the Infrared Techniques for Electronics Committee (ITEC) and the Society for Nondestructive Test (SNT). Another approach which was used to obtain a representative list of questionnaire addressees was one of contacting and requesting equipment user names from leading manufacturers of infrared instrumentation. This method yielded limited information since the user lists were considered proprietary by the manufacturers and thus not available for this purpose.

2. Industry Survey Results

Survey questionnaires, both industrial and governmental, were distributed with the cover letter shown in Appendix A to organizations known to be interested or engaged in IR measurements. A total of 124 industry and 25 government questionnaires were distributed resulting in a response of 47 and 11 replies respectively. Of the 66 separate companies and universities contacted, 32 or 49 percent indicated that infrared techniques have been explored or applied by their organization relative to the measurement of infrared radiation of electronic components, subsystems, or systems. Included within the industrial survey were responses from four universities that had indicated interest in infrared by having representation at ITEC and SNT symposiums. The mailings to this group were minimal so as to place the major emphasis on the industrial grouping. Questionnaire results also indicated that four of the companies responding had two or more separate infrared programs underway at different divisions.

Table I summarizes the major areas where infrared techniques have been or will be applied by these companies. As anticipated from the results of an earlier survey conducted within Martin which indicated that transistors, diodes and resistors were the greatest source of failures in modern electronic systems, these components are receiving special attention relative to infrared testing. These components, of course, are used in circuit board assemblies thus accounting for the emphasis being placed on circuit boards as shown in Table I.

TABLE I

Application of IR Techniques to Components and Subsystems

Component or Subsystem	Number of Affirmative Replies	Percentage*
Transistors	20	62.5
Circuit Board Subassemblies	19	59.4
Resistors	18	56.3
Integrated Circuits	16	50.0
Thin Films	14	43.7
Diodes	13	40.6
Interconnections	11	34.4
Multilayer Boards	7	21.9

* Based on 32 companies and universities indicating that infrared techniques have been explored or applied.

Questionnaire results further indicate that IR measurements have been applied in the areas shown in Table II. Prior articles and papers presented at symposiums have indicated an interest in using IR measurements as a method of selective screening; however, a shifting trend is noted that places emphasis on electronic design-packaging and failure analysis uses.

TABLE II

Application of IR Techniques to Functional Areas

Area of Activity	Number of Affirmative Replies	Percentage*
Design Packaging of Circuit Boards, Thin Films, or Integrated Circuits	14	43.7
Failure Analysis/Diagnostic Measurements	11	34.4
Selective Screening of Components	9	28.1
Assist in Design of Components	6	18.8
Process Control of Circuit Boards, Thin Films, or Integrated Circuits	4	12.5

* Based on 32 companies and universities indicating that IR techniques have been explored or applied.

Table III indicates the techniques employed or planned to compensate for emissivity variations encountered in measuring infrared radiation. It is apparent that a special coating of high emissivity is considered by industry as being the most desirable as a compensating means.

TABLE III

Techniques Employed to Compensate for Emissivity Variations

Techniques	Number of Affirmative Replies	Percentage
Specially developed conformal coating of high emissivity	18	56.3
Standard materials of known emissivity	13	40.6
Filters	6	18.8
Dual Optical System	3	9.4

Nine companies or 28 percent of those companies who now have IR programs are engaged in the manufacture of infrared radiation measurement equipment; 16 or 50 percent manufacture electronic or electrical components and 27 or 85 percent fabricate or assemble electronic and electrical subsystems and systems.

Both normal and accelerated life testing techniques have been employed to correlate IR radiation with component life. Response shows that five companies or 16 percent have used normal testing, while six or 19 percent have used accelerated life testing. Twenty-four companies or 75 percent indicated no correlative life testing program.

3. Government Survey Results

The purpose of this questionnaire was to determine the interest and activity, both past and current, in IR radiation measurement of electronic components, subsystems, and systems. Table IV shows the areas of interest or application as reported by the 11 Government agencies who responded to the questionnaire. Table V shows contracts awarded by various government agencies to contractors.

TABLE IV

Reported Areas of Government Interest and Application

Area of Interest or Application	Number of Affirmative Replies
Component, Subsystem, or System	
Integrated Circuits	5
Resistors	5
Transistors	4
Diodes	4
Circuit Boards	4
Thin Films	3
Interconnections	2
Multilayer Boards	0
Application	
Failure Analysis and Diagnostic Measurements	6
Process Control of Circuit Boards/Thin Films, Integrated Circuits or Multilayer Boards	4
Design and Packaging of Circuit Boards/Thin Films, Integrated Circuits or Multilayer Boards	3
Fault Detection Instrumentation and Systems	3
Selective Screening of Electronic Components	3
Design of Electronic Components	2
Emissivity Coating Development for Standardizing Infrared Radiation Measurements	2
Infrared Radiation Measurement Instrumentation and System Improvements (Application: Electronic/ Electrical)	2

Considerable interest in IR techniques for selective screening of components has been indicated by one of the governmental agencies. As shown in Table V, Rome Air Development Center (RADC) has awarded two contracts for the purpose of determining the feasibility of using IR and/or other nondestructive techniques for selective screening of components. RADC has also awarded two other contracts in the area of reliability testing and prediction techniques where IR and other nondestructive test methods are being evaluated.

Wright-Patterson Air Force Base has awarded a contract to investigate the possible use of IR measurement for isolating electronic faults in circuit boards. The National Aeronautics and Space Administration, Manned Space

TABLE V

Contract Awards - Infrared Radiation Measurements, Electronic Components, Subsystems, Instrumentations

Agency and Monitor	Contract No.	Title	Company Awarded Contract	Completion Date
NASA Huntsville Alabama (T. Morris	NAS-8-20131	Infrared Testing of Electronic Components	Martin-Marietta Corporation Orlando, Florida (D. D. Seltzer)	May 1966
NASA OSSA (J. Miles)	NAS-7-100 Code 186-68-02-20-55	Thermal Camera	Jet Propulsion Laboratory Pasadena, California (D. E. Linderman)	
NASA Huntsville Alabama (E. Mitchell)	NAS-8-11715	IR Measurements in Real Time	General Electric Ithaca, New York (W. M. Teegarden)	
Rome Air Development Center, New York (A. Feduccia)	AF 30(602)-3259	Nondestructive Reliability Screening of Semiconductor Diodes	Motorola Phoenix, Arizona (K. Davidson)	May 1965
Rome Air Development Center, New York (A. Feduccia)	AF 30(602)-3452	Reliability Screening Using Infrared	Sylvania Woburn, Massachusetts (Dr. B. Selikson)	October 1965

TABLE V (Cont)

Agency and Monitor	Contract No.	Title	Company Awarded Contract	Completion Date
Rome Air Development Center, New York (R. C. Hallow)	AF 30(602)-3723	Reliability Testing and Prediction Techniques for Integrated Circuits	Texas Instruments Dallas, Texas (Dr. D. A. Peterman)	November 1966
Rome Air Development Center, New York (R. C. Hallow)	AF 30(602)-3727	Reliability Testing and Prediction Techniques for High Power Silicon Transistors	Texas Instruments Dallas, Texas (Dr. D. A. Peterman)	November 1966
Wright-Patterson AFB, Ohio (R. A. Herman)	AF 33(615)-2430	Investigation of Infrared Radiation for Checkout Application	Raytheon Company Norwood, Massachusetts (Dr. R. Vanzetti)	-------
NASA Huntsville Alabama	NAS-8-11604	Fast Scan IR Microscope	Raytheon Company Norwood, Massachusetts (Dr. R. Vanzetti)	-------
Wright Patterson AFB, Ohio (A. Prettyman)	AF 33(615)-1952	Long Wavelength Infrared Fiber Optics	Optics Technology, Incorporated Belmont, California	-------

Flight Center at Huntsville has awarded a contract to develop a fast scan infrared microscope. Two other contracts awarded by NASA agencies are titled "Thermal Camera" and "IR Measurements in Real Time," but little is known of the details.

Several in-house IR radiation programs and related emissivity programs as applied to electronic/electrical components, subsystems, and systems are reported by government agencies. These are as follows:

1 U.S. Navy Electronics Laboratory - San Diego, California
* "A High Speed IR Mapping System for Reliability Assessment of Miniature Electronic Circuits:"
* Equipment in use: Modified Philco Thermal Plotter

2 Rome Air Development Center - Griffiss Air Force Base, New York
* "IR Analysis of Cermet Resistors"
* "IR Analysis of Silicon Integrated Circuits"
* Equipment in use: Barnes 1-81A Radiometer and Philco Thermal Plotter

3 U.S. Naval Weapons Station - Concord, California
* "Nondestructive Testing of Solder Joints and Electronic Circuit Board Components"
* Equipment in use: Barnes T 4-IR Camera and Lockheed Model VI Scanning System

4 U.S. Navy Applied Science Laboratory
* "Emissivity Equalization by Thermosetting Coatings."
* Equipment in use: Barnes T 4-IR camera

B. TECHNICAL REPORT SURVEY

As part of Phase I, reports, magazine articles, and technical papers concerned with the development of IR techniques for electronics were reviewed. Twenty-four reports covering the period from December 1962 to March 1965 were also reviewed. (See bibliography at the end of this report.)

Abstracts of the reviewed articles will be found in Appendix B. They have been prepared to point up highlights and to avoid tabulated data and technical details. Furthermore, they contain no opinions or conclusions of the abstracter. It should be noted that the report survey indicates a gradual transition is occuring from the early exploratory probing of a peripheral nature to more specific applications, data accumulation, and detailed descriptions of methodology. This does not mean that any specific areas of application are being dropped by industry as a whole, nor does it mean that all are now looking toward the same few applications. Different groups have simply had time to assess the value of the many potential applications with relationship to their own general fields of endeavor and to select a limited number for more concentrated research. Some typical applications under current investigation are:

1 Selective screening of transistors

2 Development of new design criteria for thin film circuits

3 Selective screening of resistors

4 Development of high speed thermal mapping techniques for microelectronics

5 Investigation of materials to equalize emissivity.

Several general impressions were left with the reviewer after considering the articles as a collective array of information. These include:

1 Excessive redundancy in describing the fundamentals of infrared theory

2 Great repetition in enumerating the broad potential applications of infrared techniques to electronic components and circuitry

3 Duplication in describing the problem of emissivity

4 Considerable reiteration relative to description of instrumentation, their application, and capabilities

5 Lack of implementation detail concerning conduct of the IR studies

6 Lack of empirical data to substantiate views and opinions expressed.

These impressions are not expressed as criticisms of the authors. Rather, the shortcomings are felt to be a natural consequence of the broad range of possible applications of IR and the newness of the technology at the time the reports were written.

C. PERSONAL INTERVIEW SURVEY

1. Industry

To supplement the information obtained from the questionnaires and the technical report survey and to provide up-to-date detail of industry's efforts in developing IR techniques for electronics, eight companies were visited and their IR investigation task leaders interviewed. The companies were selected to provide a wide cross section of areas of application, instrumentation employed, and basic company product orientation. The eight companies were:

1. Raytheon Company, Norwood, Massachusetts
2. Sylvania Electric, Woburn, Massachusetts
3. IBM, Owego, New York
4. Western Electric Company, Allentown, Pennsylvania
5. Philco Corporation, Lansdale, Pennsylvania
6. The Boeing Company, Michoud, Louisiana
7. Texas Instruments, Incorporated, Dallas, Texas
8. General Dynamics/Convair, San Diego, California

Interview summaries for each contact are in Appendix B of this report. They are reported as stated by the personnel interviewed and reflect no opinions, concurrence, or disagreement on the part of the interviewer. Areas of application under investigation are listed in Table VI.

TABLE VI

Areas of Application Being Investigated

Application	No. of Companies
Analysis of conventional printed circuit board design to improve thermal characteristics	3
Troubleshooting defective printed circuit boards	2
Receiving inspection of printed circuit boards	1

TABLE VI (Cont)

Application	No. of Companies
Development of improved guidelines and techniques for designers of thin film circuits and resistors	3
Elimination of life tests now performed to assess the reliability of production thin film circuits by substituting infrared analysis	1
Analysis of thermal characteristics to improve design of transistors, more accurately determine power handling capability, and improve reliability	1
Inspection of completed, cased transistors to screen out those having short life expectancy	1
Developing improved guidelines and techniques for designers of integrated circuits along with a precise evaluation capability	2
Development of a true scanning microradiometer having high scanning speed and spatial resolution superior to those instruments currently available	1
Investigating the use of IR fibre optics as a means of monitoring the output of components that are inaccessible	1
Developing a better understanding of the significance of IR radiation as related to semiconductor devices and determining the most beneficial application(s)	1

IR instrumentation employed in investigations by these eight companies included all known commercially available types suited to applications in electronics, and some developed specifically for individual purposes. Table VII itemizes these instruments.

The majority of the investigators felt that the best application of IR in the near future would lie in the areas of developing design guidelines and in evaluating designs for "hot spots" detrimental to reliability.

All companies felt very strongly that IR techniques will play a major role in future design, evaluation, and test of electronic components, circuits, and subsystems.

Materials used to equalize emissivity ranged from flat black paint to hair spray to none at all.

TABLE VII

Types of Instruments Used in Investigations

Instrument	No. in Use
Philco Microradiometer	5
Barnes Microradiometer	1
Baird Atomic Evaporograph	1
Barnes 8-inch Radiometer with Camera Scanning Attachment	1
Specially designed Servo Corporation system	1
Company developed microradiometer	1
Company developed single line scan radiometer	1
Barnes Emissometer	1

2. Government

Visits were made to four government installations to review IR activities directed at electronic components and subsystems. These were:

1 Rome Air Development Center (RADC) - Griffiss Air Force Base, Rome, New York (A. Feduccia)

2 Navy Applied Science Laboratory (NASL) - Brooklyn Navy Yard, Brooklyn, New York, (N. Burrowes)

3 Signal Corps Engineering Laboratories (SCEL) - Fort Monmouth, New Jersey (A. Rosenblum, H. Wheeler, D. Beaman)

4 Navy Electronics Laboratory (NEL) - San Diego, California, (R. Fraser)

a. Rome Air Development Center

RADC has awarded four tasks to industry on reliability screening, and, on reliability testing and prediction techniques. All four tasks involve the application of IR measurements. However, two of the tasks include other forms of nondestructive test. The efforts are directed in each task on a specific component, such as diodes, transistors, and integrated circuits.

RADC has also directed several in-house explorations using IR analysis on cermet resistors and silicon integrated circuits. Mr. A. Feduccia of RADC expressed that this survey may assist in assessing the actual effort being directed by government agencies and industries to obtain data, thus permitting an evaluation to be made on infrared applications.

Mr. Feduccia also indicated that the programs are exploratory in nature and that data being accumulated may be able to contribute to the decision as to whether IR may be applied in reliability screening and prediction techniques of components and integrated circuits.

b. Navy Applied Science Laboratory

An in-house study on emissivity coatings had been undertaken by NASL. Fifty coatings were surveyed of which twelve were selected for further study. Resins selected were polyesters, epoxies, silicones, and polyurethanes which solidify at room or moderately high temperatures. The criteria used in the selection included chemical and moisture resistance, dielectric strength, adhesion to surface, ease of application, thermal conductivity, and temperature range. The emissivity indices of the coatings ranged from 0.774 to 0.916. Their effectiveness in equalizing emissivity was demonstrated.

Information from a study by Mr. N. Burrowes of NASL is shown in Tables VIII and IX[1]. This study identifies a number of materials of high emissivity, but with various disadvantages in terms of application and/or characteristics required to withstand environmental conditions. Mr. N. Burrowes indicated further work was necessary.

c. Signal Corps Engineering Laboratories

Interest has been indicated by SCEL in a future program exploiting recent infrared findings. The purpose of this program will be to provide a practical means of employing infrared to improve capabilities in the field of nondestructive testing and to facilitate the detection and isolation of faults in electronic circuitry.

(1) Emissivity Equalization by Thermosetting Coatings, N. R. Burrowes, U.S. Navy Applied Science Laboratory; Brooklyn Navy Yard, Brooklyn, New York.

TABLE VIII

Advantages and Disadvantages of Major Thermosetting Materials

Material	Advantages	Disadvantages
Polyesters	1. Good chemical resistance.	1. Not suitable for high frequency applications.
	2. Low water absorption.	2. Relatively high shrinkage.
	3. High dielectric strength.	3. Limited temperature range.
Epoxies	1. Outstanding adhesion to clean surfaces.	1. High temperature produced by exothermic reaction.
	2. Excellent electrical properties.	2. Some epoxies are highly toxic.
	3. High mechanical strength.	
	4. High thermal stability.	
	5. Good chemical resistance.	
	6. Low shrinkage.	
Silicones	1. Available in many states including fluids, gels, elastomers, foams.	1. Poor adhesive properties.
	2. Good ozone resistance.	2. Poor resistance to abrasion.
	3. High operating temperatures.	3. Low tensile strength.
	4. Good electrical properties.	
	5. Relatively high thermal conductivity.	
Polyurethanes	1. Strong, tough.	1. Susceptible to moisture during casting process.
	2. High abrasion resistance.	2. Low thermal conductivity.
	3. High thermal resistance.	
	4. High surface adhesion.	

TABLE IX

Properties of Coatings

	Coating	No. of Components	Main Constituent	Pot Life	Cure*	Operating Temp. °C	Emissivity Index
Columbia Technical Corp. Woodside 77, N.Y.	Humiseal Type x342(A-B)	2	Polyester	20 min.	Overnight at room temp.	130	0.826
	Humiseal Type 1H34	1	Silicone	6 mos.	Room temp. or 1-2 hrs. at 200°C	180	0.876
	Humiseal Type 1F18	1	Acrylic	1 yr.	Room temp. or 1 hr. at 130°C	155	0.774
3M Company Electrical Prod. Div., St. Paul 19, Minnesota	"Scotchcast" Brand Resin No. 8	2	Epoxy	1-2 hrs.	Room temp. or 2 hrs. at 60°C	130	0.896
Ciba Products Co. Fairlawn, N.J.	Araldite ‡ 488E-32	1	Epoxy	1 yr.	Room temp.	130	0.871
Dow Corning Corp. Electronic Prod. Div., Midland, Michigan	Sylguard 182	2	Silicone	8 hrs.	Room temp. or 4 hrs. at 65°C	200	0.828
General Electric Silicone Prod. Div. Midland, Michigan	LTV 602	2	Silicone	2-3 hrs.	Room temp. or 5 hrs. at 65°C	200	0.827
Hysol Corp. Olean, N.Y.	Hysol PC 12-007(A-B)	2	Epoxy	1-2 hrs.	2 hrs. at 60°C	130	0.916
	Hysol PC 15 (A-B)	2	Urethane	2-3 hrs.	10 min. at 52°C	130	0.914
	Hysol PC 21 (A-B)	2	Epoxy	1-2 hrs.	2 hrs. at 60°C	130	0.890
Sterling Varnish Company Swickley, Pa.	Sterling † E 251-33	2	Epoxy	35 min.	2 hrs at room temp.	130	0.860
	Sterling† E 252-46	2	Epoxy	2-3 hrs.	Room temp.	130	0.866

* Curing conditions flexible check manufacturers literature
† Found difficult to spray
‡ Dielectric strength not determined

d. Navy Electronics Laboratory

NEL is directing an in-house program to develop a high-speed IR mapping system for reliability assessment of production-run miniature circuits.(2) A large portion of the effort was conducted on thin-film resistors. Reported results by NEL are:

1 A system consisting of a cryogenically cooled IR detector, a scanning mechanism, electronic circuitry, and a modified facsimile machine has been developed.

2 A thermal map of 1-in.-sq. circuit can be made in a 30 minute period. Mapping resolution is sufficient to display large IR energy level changes occurring in a 0.001 inch square circuit area.

3 Present circuitry permits mapping of specimens at environmental temperatures of 60 to 70°C.

NEL further reported the use of silicone grease as an emissivity coating, however, unsatisfactory results were obtained. Currently, NEL is attempting to establish guidelines for a thermal specification for the procurement of integrated circuits.

---

(2) A High-Speed Infrared Mapping System for Reliability Assessment of Miniature Electronic Circuits, H. F. Dean and R. M. Fraser, U.S. Navy Electronics Laboratory, San Diego, California.

II. PROBLEM AREAS

Aside from the normal technical obstacles that must be overcome in the development of any new technique, several points were raised almost unanimously as being present or potential problems for which no solution is currently in sight.

A. SCANNING A CIRCUIT OR DEVICE

With the exception of the Baird Atomic Evaporograph, which uses a photograph of an infrared sensitive membrane to cover the field of view, the scanning of an area is a mechanized process requiring from several seconds to minutes to accomplish. Higher speed is desired to obtain data more rapidly and is necessary for analyzing component's or circuit's responses to step function inputs.

B. SPATIAL RESOLUTION

The best resolution available today is on the order of a 1 mil diameter spot. Most groups involved in microcircuit or transistor chip analysis feel that this is marginal today since wires with a diameter smaller than 0.001 inch are now in use. Resolution must be improved for future use.

C. DATA PRESENTATION

Although routine use of IR examination on anything like an assembly line basis is still some distance in the future, some companies are already concerned with the high skill level necessary to obtain and interpret data on a circuit or component. No specific development approach was suggested, but desires leaned toward a television picture type of readout that might be readily superimposed on or otherwise compared with a master.

D. RESPONSE TIME

Although not generally considered a serious problem at present, most groups felt that no single type of currently available IR instrumentation combines the qualities of rapid response time, sensitivity, temperature resolution, and range required for investigation of diverse applications.

E. EMISSIVITY EQUALIZATION

A need was expressed for a coating material which would provide uniformly high emissivity for all surfaces. None of the companies contacted revealed any effort to develop such a material. It was generally agreed that a material which would serve as a satisfactory emissivity coating would not meet all the requirements of conformal coatings such as the commonly used Hysol compounds. A coating that would not require removal following IR examination, but could be left as a primer for conformal coating would be quite acceptable. In the interim, most companies will use laboratory type coatings or standard materials, such as flat black paint, of known emissivity.

F. ADMINISTRATIVE DIFFICULTIES

Most groups contacted believed that their programs had been adversely affected by purported oversimplification which had been attached to the development of IR techniques in various talks and articles. These groups felt that IR techniques will definitely have an important place in future electronics design. From experience they realize that an extensive and diligent effort will be required for some time in obtaining the necessary data, learning how to interpret it, and putting it to use. One person stated: "It's just like being at the point where we were learning to use X-rays."

III. CONCLUSIONS

The most obvious conclusion to be drawn from this survey is that there is a great deal of interest in developing infrared techniques for electronics. There has been a phenomenal growth of investigation in the past 2 1/2 years, from just one or two active programs to at least 32. Two companies are now producing microradiometers commercially as a direct result of this interest and several more are under development. There are at least seven programs being funded by three Government agencies and more apparently are planned. Furthermore, the Society for Nondestructive Testing now formally includes a section devoted to IR techniques for electronics, a merger with the originally independent ITEC.

The use of IR techniques for application in the field of electronics appears certain since many of the studies conducted indicate a high probability of successful application. Based on present efforts, the first applications will probably be in the areas of design analysis and improvement of design techniques for components and circuits and their packaging. Routine inspection will probably be among the last areas of application developed. For those companies involved in the design or use of microminiature circuits and subsystems, IR appears to be the ideal tool for precise thermal analyses and assisting in confirming difficult and complex mathematical thermal calculations.

Many of the efforts in industry are independent and appear to be going through a learning period with some duplication of effort. Additionally, many companies are obviously working on the development of IR techniques whose details will be considered proprietary as long as it is believed they have an edge on their competitors. The situation, however, could be beneficial in the long run since, in several instances, the same area of application is being approached from more than one direction.

Although responses indicated that all types of components were being investigated, most of the effort is directed toward semiconductor devices. Apparently, these components are considered a great thermal problem.

Instrumentation received considerable unfavorable comment with regard to its suitability for many investigations. There is undoubtedly a good basis for many of the complaints, but some stem from inexperience with both the acquisition and evaluation of infrared data.

The problem of emissivity correction is a consistent problem. All materials in use as corrective coatings on which details are known are interim compounds which are only suitable for laboratory investigations at best. The Navy Applied Science Laboratory has investigated several commercially available coating materials which were potentially suitable for emissivity correction. To date, no one coating has been found which provides satisfactory emissivity correction and which will perform satisfactorily under environmental conditions. No other efforts in this field were found.

The possible areas of application for IR techniques for electronics are virtually unlimited. The real problem seems to be that of sorting the potentially successful applications from the many possible applications, and then integrating these into the appropriate area. This will require considerable effort and time being spent in some very basic areas of investigation such as acquiring, presenting, and interpreting the data and its variations.

IV. FUTURE PLANS

Effort currently planned for accomplishment during Phases II and III of Contract No. NAS 8-20131 is described in the following paragraphs.

A. PHASE II

During Phase II, one or more transparent coatings for electrical/electronic components to standardize the emissivity to a constant high value will be developed. This will involve evaluating Martin's existing and/or modified coating formulations to obtain higher emissivity values, in addition to evaluating the effect of adding selected thermosetting resin systems to those formulations.

The Martin formulations will be compared with selected materials which are currently available on the market as sealants for electronic equipment. The selected materials will be used as standards in terms of handling characteristics, thermal, physical, electrical and chemical properties and will be compared with modified formulations and/or dual coating application. From the standards and/or Martin formulations, a variety of compounds will be screened from which one or more with outstanding properties for a specific application may be selected. Screening will be dependent on the materials ability to pass basic requirements for handling, infrared absorption, emissivity, dielectric strength, moisture absorption, and thermal shock.

The coatings successfully passing the screening tests will then be environmentally tested for such conditions as resistance to fungus, humidity, salt spray, and low and high temperature. Other coating characteristics measured will include compatibility with:

1 Environments experienced by flight and ground hardware.

2 Presently used conformal coatings and potting compounds.

3 Presently used soldering fluxes, flux residue and cleaning solvents.

B. PHASE III

The investigation of IR technology as a nondestructive testing technique for electrical/electronic parts, components, and subsystems to determine the feasibility for further development and extensive application. This will be accomplished by:

1 Conducting life tests on various groupings of transistors to determine the feasibility of correlating infrared radiation and life expectancy of electrical/electronic devices.

2 Scanning and "fingerprinting" circuit assemblies to determine the feasibility of using infrared radiation measurements to establish temperature tolerances and to assist in the analysis of circuit designs.

3 "Fingerprinting" circuit assemblies to determine the feasibility of using infrared in evaluating thermal design in packaging techniques. The evaluation of thermal design in packaging will include tests on three elements of packaging: heat sink design, component mounting on heat sinks, and component density on circuit boards.

4 Preparing a specification adequate for the procurement of a radiometer, associated fixtures, and equipment.

APPENDIX A

LETTERS OF INQUIRY AND QUESTIONNAIRES

This appendix contains reproductions of the letters of inquiry and questionnaires exactly as sent to various government agencies and to industrial organizations.

MARTIN COMPANY

ORLANDO DIVISION
Orlando,
Florida 32805

April 30, 1965

GOVERNMENT INQUIRY

In support of NASA contract NAS 8-20131, we are conducting a program of study and investigation relative to the application of infrared testing and evaluation of electronic/electrical components and subsystems.

In order to evaluate the magnitude and type of effort being expended and/or sponsored by governmental agencies, we have prepared and enclosed a questionnaire (Enclosure 1). Similar questionnaires have been directed to the electronic/electrical industry.

On the basis of past participation and interest expressed by your agency at previous Infrared Techniques for Electronics Committee (ITEC), Society for Nondestructive Testing (SNT) and similar symposiums, we would like to enlist your cooperation.

Identification of respondents in sufficient detail on either a letter of transmittal or directly on the questionnaire is desirable for additional referral in future correspondence.

Your attention to this request is sincerely appreciated and a response by May 20, 1965 is desired.

Very truly yours,

DDS/eo

Enclosure 1

D. D. Seltzer
Technical Project Leader

Response mailing address:
MARTIN COMPANY
P.O. Box 5837
Orlando, Florida 32805
Att: D. D. Seltzer
Advanced Quality Technology
Mail Point 110 (Phone: 305 - 855-6100 - Ext. 3879)

SURVEY QUESTIONNAIRE

INFRARED RADIATION MEASUREMENT
OF ELECTRONIC AND ELECTRICAL
COMPONENTS, SUBSYSTEMS, AND
SYSTEMS

The purpose of this questionnaire is to determine the current and past activity in infrared radiation measurement of electronic and electrical components, subsystems, and systems performed at or funded by your installation.

1. Name of installation performing work.

2. Name of contracting agency.

3. Personnel cognizant of effort.

Name	Agency and/or Company	Mailing Address

4. Description of current and past in-house infrared radiation programs (electronic/electrical)

Title of Subject	Author(s)	Report No.	*Brief Project Description/ or Scope/or Statement of Work

*Prepared scopes and descriptions are acceptable and may be attached.

5. Description of current and past government agency sponsored infrared radiation programs (electronic/electrical).

Title of Subject**	Contract No.	Cognizant Agency	Cognizant Monitor	Company or Installation Conducting Program*

* Include company/installation address.
** Attach brief description of project, scope, or statement of work.

6. Reports issued:

Title of Subject	Report Identification No.	Source of Report Availability

7. Areas of Interest and/or Application of Infrared Radiation Measurements.

a. Components:

(1) Transistors ______________

(2) Diodes ______________

(3) Resistors ______________

(4) Other (specify) ______________

b. Subsystems & Systems:

(1) Circuit board subassemblies ______________

(2) Thin films ______________

(3) Integrated circuits ______________

(4) Multi-layer boards ______________

(5) Interconnections ______________

(6) Other (specify) ______________

Areas of Interest and/or Application of Infrared Radiation Measurements. (continued)

c. Selective screening of components. ________

d. Design of components. ________

e. Process control of circuit boards, thin films, integrated circuits, multi-layer boards, or interconnections. ________

f. Design and packaging of circuit boards, thin films, integrated circuits, or multi-layer boards. ________

g. Failure analysis and diagnostic measurements. ________

h. Fault detection instrumentation and systems. ________

i. Emissivity coating development for standardizing infrared radiation measurements. ________

j. Infrared Radiation Measurement Instrumentation and Systems Improvements (Application: Electronic/ Electrical) ________

k. Other (specify) ________________________

____

8. Infrared Radiation Measurement Instrumentation Currently in Use by Agency (Application: Electronic/Electrical)

Manufacturer	Model

ORLANDO
DIVISION
Orlando,
Florida 32805

April 30, 1965

INDUSTRY INQUIRY

In support of NASA contract NAS 8-20131, we are conducting a program of study and investigation relative to the application of infrared testing and evaluation of electronic/electrical components and subsystems.

In order to evaluate the magnitude and type of effort being expended by industry in the infrared radiation measurements field, we have prepared and enclosed a questionnaire (Enclosure 1).

From the information submitted, an evaluation will be made to determine areas open for additional effort by industry. This information will then be compiled into a statistical format for NASA. There will be no attempt to compare one organization's programs with those of others. Identification of respondents is desirable for additional referral in future correspondence.

On the basis of past participation and interest expressed by your organization at previous Infrared Techniques for Electronics Committee (ITEC) and Society for Nondestructive Testing (SNT) symposiums - we would like to enlist your cooperation.

Your attention to this request is sincerely appreciated and a response by May 20, 1965 is desired.

Very truly yours,

DDS/eo

D. D. Seltzer
Technical Project Leader

Enclosure 1

Response mailing address:
MARTIN COMPANY
P.O. Box 5837
Orlando, Florida 32805
Att: D. D. Seltzer
Advanced Quality Technology
Mail Point 110 (Phone: 305 - 855-6100 - Ext. 3879)

INDUSTRY SURVEY QUESTIONNAIRE

INFRARED RADIATION MEASUREMENT
OF ELECTRONIC AND ELECTRICAL
COMPONENTS, SUBSYSTEMS, AND
SYSTEMS

1. Have infrared techniques been explored and/or applied by your organization relative to the measurement of infrared radiation (thermal output) of electronic components, subsystem or systems?

a. ________ Yes   b. ________ No

2. In which of the following electronic areas have you directed (or plan to direct) your infrared application?

a. COMPONENTS

(1) Transistors ________
(2) Diodes ________
(3) Resistors ________
(4) Others(specify) ________
____
____

b. SUBSYSTEMS AND SYSTEMS

(1) Circuit board sub-assemblies ________
(2) Thin films ________
(3) Integrated circuits ________
(4) Multilayer boards ________
(5) Interconnections ________
(6) Others (specify) ________
____

3. In which of the following activities has infrared radiation measurement been applied?

a. Assist in the design of components, i.e., transistors, diodes, transistors ________

b. Selective screening of components (for increased reliability) ________

c. Process control of circuit boards, thin films, or integrated circuits ________

d. Design and packaging of circuit boards, thin films, or integrated circuits ________

e. Failure analysis and diagnostic measurements ________

f. Others (specify) ____

____

4. To compensate for emissivity variations or electronic components and subsystems, which of the following systems do you employ or plan to employ?

a. Specially developed conformal coatings of high emissivity __________

b. Filters __________

c. Dual optical systems __________

d. Standard materials of known emissivity __________

e. Others (specify) ____

____

5. Is your company engaged in the	YES	NO
a. manufacture of infrared radiation measurement instrumentation	___	___
b. manufacture of electronic/electrical components	___	___
c. fabrication/assembly of electronic/electrical subsystem and systems	___	___

6. Have any of the following life testing techniques been applied in order to correlate infrared radiation with component life?

a. Normal __________

b. Accelerated __________

c. Others (specify)__________

7. List completed and active (unclassified) infrared radiation measurement programs sponsored by a Government agency:

Title of Contract	Contract Number	Contracting Agency	Name of Customer Technical Monitor

8. Personnel in organization familiar with infrared radiation measurements as related to electronic and electrical components, subsystems, and systems:

a. Name & Company ______________________

b. Title ______________________

c. Organization ______________________

d. Mail Point ______________________

e. Phone ______________________
Area Code - Phone No. - Ext. No.

a. Name & Company ______________________

b. Title ______________________

c. Organization ______________________

d. Mail Point ______________________

e. Phone ______________________
Area Code - Phone No. - Ext. No.

APPENDIX B

ABSTRACTS OF APPLICABLE PUBLICATIONS

This appendix contains the abstracts of publications related to infrared measurement techniques which apply to testing electronic components.

"Component Failures Predicted by Infrared," P. J. Klass (reporting on work by Dr. R. Vanzetti), Aviation Week and Space Technology Magazine, December 1962.

This article reports on early work in the field of IR for electronics performed by Dr. R. Vanzetti of Raytheon Company. This information had been presented by Dr. Vanzetti at the founding meeting of the Infrared Techniques for Electronics Committee on 25 September 1962.

Experiments had indicated that supposedly identical transistors, under like loads in the same environment, differed in the level of their IR radiation. Further more, there appeared to be a correlation between early transistor failure and an abnormal radiation level; those transistors at the extremes of the range of IR output failed first. A temperature versus time plot for the 20 transistors tested is shown.

Other tests indicated that a functioning circuit board might be "fingerprinted" by scanning it for IR levels and that this fingerprint might be analyzed to determine areas of thermal stress due to errors in design or construction. Once a standard "fingerprint" was established for a particular board, it might be used in troubleshooting boards that had malfunctioned. A strip chart recording of a circuit board "fingerprint" is shown.

An abbreviated block diagram of a thermal plotter having a microscopic field of view is appended to Dr. Vanzetti's findings. Philco Corporation is developing this device for infrared analysis of microcircuits.

"Recombination Radiation in Semiconductors and Application to Reliability Studies of Semiconductor Components," P.R. Bratt, Raytheon Company, Burlington, Massachusetts, Second Infrared Techniques for Electronics Committee Meeting, Boston, Massachusetts, May 1963.

The author explains the phenomenon of recombination radiation, IR radiation produced by the semiconductor itself, but not as a function of heat. Potential use of the technique is outlined along with limitations of application.

"Infrared Techniques Enhance Electronic Reliability," Dr. R. Vanzetti, Raytheon Company, Norwood, Massachusetts, Solid State Design Magazine, August 1963

The author briefly describes the phenomenon of IR radiation and the various types of detectors. He describes the differences between strip chart and photographic rendering of infrared measurement including reproductions of both. Emissivity and the problem it presents are covered. Possible applications of the technique are discussed. Except for a "fingerprint" of a low voltage power supply, the test data covered is essentially the same as in the Aviation Week and Space Technology magazine article of December 1962.

"Infrared, Another Medium of Evaluation," Dr. R. Vanzetti, Raytheon Company, Norwood, Massachusetts, Quality Assurance Magazine, December 1963 and January 1964.

Essentially a rewrite of the article in Solid State Design Magazine, August 1963.

"Nondestructive Testing for Microelectronics: An Appraisal," H. S. Kleinman, ARINC Research Corporation, Washington, D.C., Twenty-fourth Convention, Society for Nondestructive Testing (SNT), October 1964.

This paper describes the progressive increase in use of microelectronics, their use in hybrid circuits, their advantages and disadvantages, typical quality control and reliability problems, and their special concern with heat. The various avenues to solution of quality control and reliability problems are outlined with particular emphasis placed on IR analysis. A mathematical model of the heat transfer from a silicon chip is presented to prove that sensing by a proper radiometer is possible. The author states that the potential of IR techniques and the availability of adequate equipment justify initial test programs.

"The Testing of Electrical Components and Systems Using Thermal Plots," G. Revesz and B. G. Marks, Sierra Electronic Division, Philco, Menlo Park, California, Twenty-fourth National Convention, Society for Nondestructive Testing (SNT), October 1964.

A new form of information display for an IR scanning system has been developed by Philco Corporation. A cathode ray tube is used to present information from the radiometer in any one of three modes:

1 C-Scan which views the entire field and presents different radiation levels as different CRT intensities.

2 B-Scan which scans the field and presents amplitude changes of a synchronized CRT sweep line as representation of radiation changes.

3 A-Scan where thermal transients are displayed while the radiometer "stares" at a single point.

Photo reproductions of the CRT presentation of a scanned printed circuit board and a bank of solar cells are included. A comparison is made of application areas for the scanner and the previously developed microplotter. Advantages and disadvantages are described.

"Evaluation of the Resistance Microwelding Process by Infrared Energy Measurements," S. Leonard and J. K. Lee, Lockheed Missiles and Space Company, Sunnyvale, California, Lockheed Report No. 5-73-64-Z, June 1964.

The changes in heat generated at the interface of 0.020 inch nickel wire leads were measured as welding process parameters were changed. Not pertinent to electronic components.

"Comments on the Evaluation of Semiconductors by External Infrared Measurements," S. S. Loomis, Jr., Brown Engineering Company, Huntsville, Alabama, Third Annual Meeting, Infrared Techniques for Electronics Committee, Huntsville, Alabama, February 1964.

This paper was distributed rather than presented, and analyzes why a cased transistor cannot be evaluated for reliability as an individual component by measuring its IR radiation.

"Fiber Optics, Infrared Region," N. S. Kapany and R. J. Simms, Optics Technology, Incorporated, Belmont, California, Spring Meeting, Optical Society of America, 1964.

This report is not abstracted. It covers early work in IR fiber optics. The latest report presented at the Spring Covention, Society for Nondestructive Testing, February 1965, is abstracted.

"Infrared Fiber Optics," R. J. Simms, Optics Technology, Incorporated, Belmont, California, Third Annual Meeting, Infrared Techniques for Electronics Committee, February 1964.

This report is not abstracted. It covers early work in infrared fiber optics. The latest report presented at the Spring Convention, Society for Nondestructive Testing, February 1965, is abstracted.

"Reliability Screening Using IR Radiation," A. J. Feduccia, Rome Air Development Center, Griffiss Air Force Base, New York, Third Annual Meeting, Infrared Techniques for Electronics Committee, February 1964.

Rome Air Development Center investigations are being conducted in the area of nondestructive screening of components for reliability. Distinct differences in IR profiles have been noted on like carbon composition resistors under like loads. Life tests are being run to correlate these differences to reliability - 2000 hours have not yet produced any failures. PNP germanium power transistors were graded according to their IR emission at rated power. The high IR category accounted for 14 percent of the sample and 36 percent of the failures after 100 hours of testing time. With thin-film resistors, 6000 hours of life testing showed the low IR category to be the failure group. This category accounted for 17 percent of the total population and 64 percent of the failures.

Experiments on metal film resistors indicates that the IR profile, in addition to the emission level, may be a reliability indicator. One resistor of 20 tested had an abnormal profile, and was the only one to drift out of tolerance after 1000 hours of testing. Rome Air Development Center regards the use if IR measurement as a potentially valuable tool in the prediction of component reliability.

"Infrared Technique for Electronic Testing and a Plan for its Implementation," L. R. Judd and J. F. Pina, Boeing Company, Huntsville, Alabama, Third Annual Meeting, Infrared Techniques for Electronics Committee, Huntsville, Alabama, February 1964.

This describes the Boeing plan for a future investigation into the use of IR for evaluating electronic components and assemblies. The applications proposed and technical information presented are those reported earlier in magazine articles by Dr. Vanzetti of Raytheon.(See abstract of "Component Failures Predicted by Infrared," December 1962, and "Infrared Techniques Enhance Electronic Reliability," August 1963.)

"The Thermal Plotter and its Uses in Microcircuit Analysis and Testing," B. G. Marks, G. Revesz, and M. Walker, Philco Corporation, Lansdale Division, Lansdale, Pennsylvania, Third Annual Meeting, Infrared Techniques for Electronics Committee, February 1964.

A treatise on the recently marketed Philco Thermal Plotter - a microradiometer. Examples of demonstration measurements made on microcircuits are shown along with suggested applications for this instrument.

"An Aperture for IR Temperature Measurements of Small Areas," F. J. Arnold, IBM Corporation, Endicott, New York, Third Annual Meeting, Infrared Techniques for Electronics Committee, February 1964.

Determination of the thermal K factor of a small substrate-mounted component required IBM to modify an existing radiometer so that its field of view was reduced from 0.040 inch to approximately 0.022 inch. The modification is covered in detail including materials, physical arrangement, compensation, and calibration. Problems associated with the design, along with advantages and disadvantages of the device, are discussed.

"Infrared Emissivity Equalization Via Use of Special Coatings," Neville Burrowes, U.S. Naval Applied Science Laboratory, New York Naval Base, Brooklyn, New York, Third Annual Meeting, Infrared Techniques for Electronics Committee, February 1964.

This complete paper is not available, but an abstract describes it as covering the investigation of epoxy resins for use as coatings to normalize emissivity. All the resins tested had comparable characteristics and with sufficient coating thickness infrared opacity and high emissivity could be obtained while retaining transparency in the visible spectrum.

"Recent Developments in Infrared Thermography," R. Yoder, Barnes Engineering Company, Stamford, Connecticut, Third Annual Meeting, Infrared Techniques for Electronics Committee, Huntsville, Alabama, February 1964.

A treatise on Barnes fixed spot and scanning radiometers, the scan radiometer used in IR pattern display by photographic means. Examples of demonstration measurements and photographs made with this equipment are shown along with suggested applications for this instrument.

"Infrared Nondestructive Testing for Improvement of Integral Electronic Circuits," H. S. Kleinman and J. D. Reese, ARINC Research Corporation, Washington, D.C., Third Annual Meeting, Infrared Techniques for Electronics Committee, February 1964.

This paper is not abstracted. The same basic ground is covered in a report at the Twenty-fourth Convention, Society for Nondestructive Testing (SNT), October 1964, and is abstracted elsewhere in this report.

"IR Techniques for Electronics, Latest Progress in R&D and Applications," Dr. R. Vanzetti, Raytheon Company, Norwood, Massachusetts, Third Annual Meeting, Infrared Techniques for Electronics Committee, Huntsville, Alabama, February 1964.

Dr. Vanzetti presents his ideas for using IR fibers to monitor performance of energized equipment and for evaluating welded and soldered joints using IR measurement.

He reports on progress in the following 13 areas of R&D which he had termed key areas in his talk at the Second Infrared Techniques for Electronics Committee meeting in May 1963:

1 Emissivity coating material, initial good progress;

2 IR transmitting fibers, development of fibers forthcoming;

3 Recombination radiation of semiconductors, no progress;

4 Detectors and cryogenics, uncoordinated progress;

5 Semiconductors with IR transparent encapsulation, no progress;

6 Longwave IR converters, studies have disclosed feasibility;

7 Optics and scanning systems, uncoordinated progress;

8 Correlation between component power dissipation (current flow) and IR emission, encouraging but uncoordinated effort;

9 RF losses in waveguides, no progress;

10 Weld testing, preliminary work indicates a coorelation between thermal resistance and area of fusion;

11 IR microscope, brilliant progress - one in production and another to be released shortly;

12 Mechanical resonance/thermal increase correlation, no progress;

13 Information display of IR patterns, some progress.

"Cryogenic Methods Applicable to the Use of Long Wavelength Photoconductive Infrared Detectors," G. F. Giggey, Raytheon Company, Burlington, Massachusetts, Third Annual Meeting, Infrared Techniques for Electronics Committee, Huntsville, Alabama, February 1964.

This paper covers two general areas: detectors and cooling systems. Examples of the four types of detectors (thermal, photoconductive, photovoltaic, and photoelectromagnetic) along with their primary operating principles, advantages, and disadvantages are discussed. The necessity for cooling some detectors is explained, and Dewar flask and Stirling cycle systems described.

"A High Speed Infrared Mapping System for Reliability Assessment of Miniature Electronic Circuits and Examples of its Use," H. F. Dean and R. M. Fraser, United States Navy Electronics Laboratory, San Diego 52, California. Place and date of presentation unknown.

A detailed description of a system for automatically mapping the IR output of a 1 by 1 inch microcircuit. The feasibility of developing a high speed facsimile type of readout system is proven. Attempts to solve emissivity problems with silicone grease were not successful. The maps produced exhibited six to seven visually distinguishable shades of gray-to-black coloring which were insufficient for visual determination of small differences in temperature. Densitometer techniques were investigated that would permit measurement in 0.5 degree increments. Reproductions of the maps are included in the paper.

"Tolerance Studies for Infrared Production Testing of Electronics," L. R. Judd and T. J. Magee, Boeing Company, New Orleans, Louisiana, Spring Convention, Society for Nondestructive Testing, February 1965.

The IR test equipment used by Boeing in their IR research and development testing is described, along with calibration techniques. The bulk of the paper describes Boeing's work on various resistor types. The effects of input voltage, spatial positioning, emissivity variations, resistance variations, and ambient fluctuations are described. Life cycle tests are currently under way to determine correlation with IR test results. Preliminary work with printed circuit boards, using two identical multivibrator circuits, indicates that IR testing will be helpful in quickly pinpointing defective or overstressed components. One of the boards, containing a defective transistor, had all resistors associated with the transistor radiating abnormal levels of IR radiation.

"Infrared Fiber Optics and Infrared Nondestructive Testing," R. J. Simms, Optics Technology, Incorporated, Belmont, California. Spring Convention, Society for Nondestructive Testing, February 1962.

The principle of operation of these light pipes is described along with their advantages for viewing inaccessible components and for increasing small signals by using the high numerical aperture of the fibers. An example of measurements of encapsulated resistors is shown. The state of the art currently limits the use of these light pipes because lengths of 2 to 3 inches severely reduce transmission efficiency. Newly developed glasses will operate more efficiently at longer lengths, but production problems do not yet permit the manufacture of the longer lengths. The Research and Technology Division, Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio, is funding an investigation under Contract AF 33(615) - 1952.

"Application of Infrared Technology Development of Thin Film Resistor," P. R. Young, Western Electric Company, Allentown, Pennsylvania, Spring Convention, Society for Nondestructive Testing, February 1965.

The geometric configuration of a thin film resistor may be optimized by analysis of its temperature profile through the use of infrared techniques. The author describes the need for such analysis, methods for making the measurements, and the analysis itself. Examples of actual analyses are shown, along with the before and after configurations of resistors.

"Emissivity Independent Infrared Thermal Testing Method," D. R. Green, Battelle-Northwest, Pacific Northwest Laboratories, a Division of Battelle Memorial Institute, Materials Evaluation Magazine, February 1965.

Concerned with testing cylindrical aluminum clad uranium fuel elements. Nothing pertinent to electronics testing.

"The Relative Contributions of Emissivity and Thermal Conductivity in Infrared Nondestructive Testing," F. E. Alzofon, Lockheed Missiles and Space Company, Sunnyvale, California, Spring Convention, Society for Nondestructive Testing, February, 1965.

The relative magnitude of contributions owing to variations in thermal conductivity and emissivity are estimated for some commonly used aerospace structural materials. Not pertinent to electronics.

"Two Thermal Nondestructive Testing Techniques," D. R. Maley, Research Division, Automation Industries, Incorporated, Boulder, Colorado. Spring Convention, Society for Nondestructive Testing, February 1965.

Concerned with examination on bond quality, plating adhesion, cracks, spot weld quality, etc. Not pertinent to electronics.

APPENDIX C

INTERVIEW SUMMARIES

This appendix contains summaries of the eight interviews conducted during Phase I.

The Boeing Company
Michoud, Louisiana
T. J. Magee

The two major company funded areas of application of infrared techniques that have been investigated are: (1) Examination of conventional printed circircuit boards both for troubleshooting and as an aceptability inspection, using a specially constructed Servo Corporation radiometer with tape controlled specimen positioning table and tape controlled "go no-go" readout and (2) Examination of resistors to determine the feasibility of predicting reliability, using the same radiometer.

Printed circuit boards have been found to have characteristic patterns which are upset when some component has failed catastrophically (shorted or open). Analysis of these patterns yields information which may reduce troubleshooting time by as much as 75 percent. Furthermore, some boards which have passed all functional tests have proven to have defective components when analyzed by IR techniques . . . . . redundant components may fail with no adverse affect on function, and temperature compensating components may fail showing no effect on performance at room temperature.

Abnormal temperature profiles of resistors have been associated with those that either fail early or drift out of tolerance rapidly. Experiments in this area have been limited due to the bulk of effort being devoted to printed circuit analysis.

A coating which would provide uniformly high emissivity and at the same time serve as a base for later conformal coating would significantly aid investigations.

Future plans call for continued investigation of printed circuit boards as the major effort. Design and packaging analysis of these units appears to be a promising field. Solder joint inspection appears unlikely as an application of IR techniques. No effort in the area of microcircuits is planned for the near future.

General Dynamics/Convair
San Diego, California
T. Reese, F. Unmack

The development of IR techniques for electronics has been curtailed for the past several months, but resumption of the effort is now being planned. The programs will be company funded and will employ a Philco Micro-radiometer.

Effort of the immediate future will be devoted to thin film circuit resistors. The objective will be to gain information leading to the establishment of design guide lines, a capability of evaluating designs, and improved process controls. Quality control will ultimately monitor production and feed back IR inspection results for design/process control improvement.

Past investigations have been primarily concerned with conventional printed circuit boards. In one case, the physical layout of a board was modified which resulted in lower failure rates being experienced for a bank of diodes. Should IR inspection again be applied to printed circuit boards in a routine function, all boards will be inspected; instead of only defectives boards.

A problem that will exist with any application of IR in a routine manner to production units is that of data presentation and analysis. Current methods will not be satisfactory since they require a level of skill well above that considered satisfactory for production and inspection.

International Business Machines Corporation
Owego, N. Y.
G. W. Carter

The Analytical Design Engineering Department is interested in applying IR radiation measurements primarily to design and packaging of integrated circuits and related computer electronics. The tasks are company funded. Infrared instrumentation includes a Barnes 8 inch Radiometer with Camera Attachment, a Barnes Microradiometer, a Barnes Emissometer, and a Philco Microradiometer.

The group investigating IR for electronics basically provides engineering support in the area of thermal analysis. It is likely that their work with IR will force an extension into other areas including quality control. Thus far, IR analysis has been employed in solving a range of heat transfer problems. Examples are: (1) Emissivity control of an airborne computer to assure proper radiative cooling in the Orbiting Astronomical Observatory (2) Redesign of an integrated circuit to improve thermal characteristics (3) Analytical determination of thermal resistances critical to hybrid circuits. The work has also been applied in at least two somewhat isolated instances as the only possible means of locating a short in a very complex multilayer "mother board", and as a technique for locating hidden nicks in the wires of a memory cell plane.

Current studies are aimed at providing engineering with better design guides for integrated circuits. Thermal transfer in a vacuum environment, maximum allowable current stress in fine wires, and maximum power dissipation capabilities of semiconductor components are among the areas under investigation.

An ability to equalize the emissivity of the many surfaces examined would be a significant breakthrough, as would a more rapid scanning capability and improve spatial resolution.

Philco Corporation
Lansdale, Penna.
W. M. Berger

Areas of current or planned investigation for application of IR techniques include thin film circuits, monolithic integrated circuits, and related micro-circuit units. Tasks are company funded and the Philco Microradiometer is used for the investigations.

The prime objectives are the development of improved design techniques and increased reliability through elimination of hot spots.

Quality control may see application of IR techniques, but it will follow the development of engineering uses and construction of specialized instrumentation for line use. The ideal solution to the problems presented by differences in emissivity would be the development of equipment that would automatically compensate for these differences. Improvements in scan speed, spatial resolution, and low temperature performance of instrumentation are desirable and will likely evolve, but are not considered necessary at present.

Raytheon Company
Norwood, Mass.
Dr. R. Vanzetti, S. Bobo

Three major areas of IR application are currently under investigation: (1) Determining the feasibility of troubleshooting conventional printed circuit boards by scanning them with a radiometer and comparing the results with "standard" IR profiles. This effort is being performed under contract to WADC. The IR equipment is a line scanning radiometer constructed by Raytheon. (2) Developing a high speed, high resolution, scanning radiometer. This effort is being performed under contract to NASA. (3) Investigating the use of fibre optics for remotely monitoring the output of otherwise inaccessible components. This effort is being performed with company funds.

The boards being used for the troubleshooting investigation are available in large quantities from a current production contract, providing an excellent source of data to develop standard profiles. Pattern repeatability of functionally acceptable boards is very good. Once the profile of a particular board type is developed, only those boards failing functional test are subjected to IR examination. The time required for troubleshooting by IR is estimated to be 25 percent of conventional troubleshooting time. Further savings could be made if a completely automated substage were available for Y axis motion (line scanning takes place in the X axis) and if a more rapid system of readout could be substituted for the Polaroid camera pictures of an oscilloscope trace.

Details of the scanning microradiometer system being developed for NASA are not available for publication, but one of the design goals is to scan a 1.5 mm square area in 0.1 second.

The investigation of fibre optics is company classified. The IR instrumentation to be used is not known, but the fibre optics have approximately 70 percent transmission of IR in lengths of over 3 inches.

A coating to provide uniformly high emissivity of all components would significantly speed investigations; NO effort is being expended in this area. Design evaluation is considered to have excellent possibility of future application.

Sylvania Electric Company
Woburn, Mass.
Dr. B. Selikson, J. DiMauro

As a manufacturer of transistors, Sylvania is investigating the feasibility of using the IR radiation levels of energized transistors in cases as the indicator or basis for identifying those units having a short life expectancy. The task is being performed under an RADC contract. The IR instrumentation used is the Baird Atomic Evaporograph.

Approximately 50,000 transistors of a single type (unspecified) have been examined for IR output under identical conditions of load. A frame of 50 units is viewed in each test. A distribution curve has been established and points selected to represent upper and lower acceptable limits. All units (termed "sports") falling outside these limits, in addition to a group of standard units, have been set aside for further tests. All such units have been re-examined for their radiation levels and verified by either Barnes or Philco radiometers. Correlation between short life expectancy and high or low IR radiation levels will be determined on the basis of life tests and/or visual microscopic examination. Life tests are scheduled to begin about June 1965 and terminate about January 1966.

The basis for establishing the upper and lower limits was not revealed nor was the number of units disclosed. Dr. Selikson did state, however, that examination of only a hundred or so transistors might very well turn up no "sports". Uniform emissivity is considered a must, with the development of a universally applicable material highly desirable. Should correlation between radiation level and life develop, the limits would likely become a new specification parameter usable by both manufacturers during acceptance and users during receiving inspection. Some difficulty was experienced in obtaining precisely repeatable results when the Evaporograph diaphragms were replaced.

Texas Instruments, Incorporated
Dallas, Texas
Dr. D. A. Peterman

The Thermophysics Section is responsible for investigating and developing uses of IR techniques. All areas of semiconductor device production, from materials and design to final inspection,are open to consideration, but none have been pinpointed and explored in great detail to date. To quote Dr. Peterman: "The real problem is sorting the potentially successful applications from the possible applications and integrating these into the engineering, manufacturing, quality control, or other area indicated." It is expected that any specific area of application will require instrumentation particularly designed for it. Partially for this reason, a microradiometer is under development that will permit the basic exploration to be accomplished. This basic tool will be modified as necessary to cover specific applications as they develop. Some of the applications being considered are: (1) Alteration of processes to permit more rapid heat treatment of materials and devices (2) More precise sorting of transistors for power handling capability (3) Thermal transfer analysis of high power density integrated subsystems.

In general, IR techniques will complement present total analyses in evaluating thermal transfer functions. Equalization of emissivity is essential to interpretation of IR analysis data.

Western Electric Company
Allentown, Penna.
P. R. Young
N. Chaplin

The two general areas under investigation for application of IR techniques are thin films and transistors. The transistors are being examined uncased, mounted on their header. Both tasks are company funded. Infrared instrumentation being employed consists of Philco Microradiometers.

The primary objectives of the thin film effort are to: (1) develop a design evaluation capability, and (2) establish design criteria for optimizing thin film circuits and resistors. A secondary objective, dependent on the success of the others, is the elimination of life tests being performed on samples from each production lot of thin film circuits.

Emissivity equalization employing a coating which may be left on the circuit after IR analysis has been completed would be of significant benefit. Instrumentation with better temperature resolution near ambient would also aid the program.

The objective of the effort concerned with transistors is to develop the capability to analyze such factors as transistor design, performance, and construction, with respect to hot spots of microscopic size. This would lead to development and production of transistors and microcircuits with optimum reliability at optimum power dissipation levels.

Emissivity differences and variations present considerable problems to analysis of data. The development of a coating to overcome the problem does not appear too likely since any such material must be applied in a very thin film which will neither form beads on lead wires or fillets at junctions. Lack of fine spatial resolution and relatively low scanning speed are the major disadvantages of existing microradiometers.

BIBLIOGRAPHY

1962 PAPERS

1. "Component Failures Predicted by Infrared." P. J. Klass (Reporting on work by Dr. R. Vanzetti), Aviation Week and Space Technology Magazine, December 1962.

1963 PAPERS

2. "Recombination Radiation in Semiconductors." Dr. Peter Bratt, Hughes Aircraft Company, Galeta, California.

3. "Infrared Techniques Enhance Electronic Reliability." R. Vanzetti, Raytheon Company, Norwood, Massachusetts. Solid/State/Design Magazine, August 1963.

4. "Infrared, Another Medium of Evaluation, Part I." R. Vanzetti, Raytheon Company, Norwood, Massachusetts. Quality Assurance Magazine, December 1963.

5. "Infrared for Circuit Check-Out." Ruth A. Herman Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Electronic Engineering Magazine, January 1963.

6. "Infrared for Integral Electronics." H. S. Kleiman, ARINC Research Washington 6, D.C., ARINC News Letter, Vol I, No. 4, December 1963.

1964 PAPERS

7. "Infrared, Another Medium of Evaluation, Part II." R. Vanzetti, Raytheon Company, Norwood, Massachusetts. Quality Assurance Magazine, January 1964.

8. "Nondestructive Testing for Microelectronics: An Appraisal." H. S. Kleiman, ARINC Research Corporation, Washington, D.C. 24th Convention Society of Nondestructive Testing, October 1964.

9. "The Testing of Electrical Components and Systems using Thermal Plots." G. Revesz and B. G. Marks, Sierra Electronic Division, Philco, Menlo Park, California. 24th National Convention, Society for Nondestructive Testing, October 1964.

10. "Evaluation of the Resistance Microwelding Process by Infrared Energy Measurements." S. Leonard and J. K. Lee, Lockheed Missiles and Space Company, Sunnyvale, California. Lockheed Report No. 5-73-64-Z dated June 1964.

11. "Comments on the Evaluation of Semiconductors by External Infrared Measurements." S. S. Loomis, Jr., Brown Engineering Company, Huntsville, Alabama. Distributed at 3rd Annual Meeting Infrared Techniques for Electronics Committee, Huntsville, Alabama, February 1964.

12. "Fiber Optics, Infrared Region." N. S. Kapany and R. J. Simms, Optics Technology, Belmont, California. Spring Meeting Optical Society of America, Washington, D.C., 1964.

13. * "Preliminary Report on the Development of a Nondestructive Test for Bridgewires." D. W. Ballard and co-authored by L. J. Klamerus and J. D. Stewart, Sandia Laboratory, Albuquerque, New Mexico.

14. "Infrared Fiber Optics." R. J. Simms, Optics Technology, Incorporated, Palo Alto, California.

15. "Reliability Screening Using Infrared Radiation." Anthony J. Feduccia, Rome Air Development Center, Griffiss Air Force Base, New York.

16. "Infrared Technique for Electronic Testing and a Plan for its Implementation." L. R. Judd and J. F. Pina, Boeing Company, Huntsville, Alabama.

17. "The Thermal Plotter and its Uses in Microcircuit Analysis and Testing." G. Revesz, B. G. Marks, and M. Walker, Philco Corporation, Lansdale, Pennsylvania.

18. "An Aperture for IR Temperature Measurements of Small Areas." Fred Arnold, IBM, Endicott, New York.

19. "Infrared Emissivity Equalization via Use of Special Coatings." Neville Burrowes, United States Naval Applied Science Laboratory, Brooklyn, New York.

20. "Recent Developments in Infrared Thermography." Richard Yoder, Barnes Engineering Company, Stamford, Connecticut.

* Subject material not applicable to the scope of the current NASA Contract.

21. "Infrared Nondestructive Testing for Improvement of Integral Electronic Circuits." James D. Reese and Herbert S. Kleiman, ARINC, Washington, D.C.

22. "Latest Progress in Application of Infrared Techniques to Electronics." Dr. Riccardo Vanzetti, Raytheon Company, Norwood, Massachusetts.

23. "Cryogenic Methods Applicable to the Use of Long Wavelength Photo-Conductive Infrared Detectors." George Giggey, Raytheon Company, Waltham, Massachusetts.

24. "A High Speed Infrared Mapping System for Reliability Assessment of Miniature Electronic Circuits and Examples of its Use." H. F. Dean and R. M. Fraser, United States Navy Electronics Laboratory, San Diego 52, California.

25. * "Use of Infrared Testing Technique Grows." P. J. Klass (Reporting on work by Dr. R. Vanzetti), Aviation Week and Space Technology Magazine, May 1964.

1965 PAPERS

26. "Tolerance Studies for Infrared Production Testing of Electronics." L. R. Judd and T. J. Magee, Boeing Company, Huntsville, Alabama.

27. "Infrared Fiber Optics and Infrared Nondestructive Testing." John Simms, Optics Technology Incorporated, Palo Alto, California.

28. "Application of Infrared Technology Development of Thin Film Resistor," P. R. Young, Western Electric Company, Allentown, Pennsylvania. Spring Convention, Society for Nondestructive Testing, February 1965.

29. "Emissivity Independent Infrared Thermal Testing Method." D. R. Green, Batelle-Northwest, Pacific Northwest Laboratories, a Division of Battelle Memorial Institute. Materials Evaluation Magazine, February 1965.

---

* Subject material not applicable to the scope of the current NASA Contract.

30. "The Relative Contributions of Emissivity and Thermal Conductivity in Infrared Nondestructive Testing." F. E. Alzofon, Lockheed Missiles and Space Company, Sunnyvale, California. Spring Convention, Society for Nondestructive Testing, February 1965.

31. "Two Thermal Nondestructive Testing Techniques." D. R. Maley, Research Division, Automation Industries, Incorporated, Boulder, Colorado. Spring Convention, Society for Nondestructive Testing Febryary 1965.

32. "A High Speed Infrared Mapping System for Reliability Assessment of Miniature Electronic Circuits." H. F. Dean and R. M. Fraser, Research and Development, U.S. Navy Electronics Laboratory, San Diego, California. March 15, 1965.

33. "A Review of RADC Research Efforts in Infrared Radiation." Anthony J. Feduccia and William E. Dulac, Reliability Branch, Rome Air Development Center, Griffiss Air Force Base, New York. Spring Convention, Society of Nondestructive Testing February 1965.

34. "Emissivity Equalization by Thermosetting Coatings." Neville R. Burrowes, U.S. Naval Applied Science Laboratory, Brooklyn, New York. Spring Convention, Society of Nondestructive Testing February 1965.