# ADVANCED CONTROL SIGNAL PROCESSOR MODULE DESIGN, FABRICATION, AND TEST

Phase V

Final Report

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## MODULE DESIGN

An objective comparison of the relative advantages of encapsulated and nonencapsulated modules led to the conclusion that encapsulated modules are better suited to the requirements of the ACSP system. Several major improvements made in the basic design of ACSP modules should provide better producibility and higher reliability in the future. A description of the new Inverter module design is presented in the report.

## DYNAMIC ENVIRONMENTS

A dynamics analysis of a basic encapsulated module indicated that response of the conformally coated substrate assemblies to anticipated vibration input levels would not be excessive. The first Inverter module constructed with the new back-to-back substrate assembly method was mounted in a special module test fixture and subjected to high level sine and random vibration levels without any functional or structural failures. Relative module pin displacements measured during the tests were considerably lower than those measured during Phase III tests.

## MATERIALS EVALUATION

An evaluation of a variety of available materials resulted in selection of General Electric RTV 615 and RTV 616 silicone rubbers for conformal coating of substrate assemblies and Minnesota Mining and Manufacturing CRP 241 epoxy as the encapsulant for the Inverter test modules built. An evaluation of several materials for use in sealing pinholes in the silicon monoxide coating evaporated over thin film resistors resulted in selection of Dow Corning DC 96-005 for use in the test modules. Both Inverter test modules built were subjected to three complete temperature cycles from -55 to +125°C without adverse effects on circuit operation nor any physical damage to the modules.

## MODULE FABRICATION

A detailed description of thin film circuit fabrication, module assembly, and encapsulation is given in the report.

# INTRODUCTION

The primary objective of this program was to design, construct, and test a microelectronic module using the latest fabrication and interconnection techniques. Substrate assemblies were to consist of thin film substrates mounted back-to-back with printed circuit cards to which would be attached discrete components.

A statement of work accomplished during this phase is outlined below:

1 The Inverter module for the closed loop ACSP system was designed

2 A comparison of encapsulated and nonencapsulated modules was made

3 An evaluation of sealer materials for closing pinholes in the silicon monoxide coating on thin film resistors was performed

4 An evaluation of silicone rubber conformal coating materials and of module encapsulants was conducted

5 A dynamics analysis of the basic module was performed

6 Temperature cycling tests on dummy modules were made to determine the effects of encapsulation stresses on internal structures and components

7 Temperature cycling tests were conducted on two Inverter modules fabricated using the latest techniques

8 High level sine and random vibration tests were conducted on an operating Inverter module to determine the effects on electrical performance, module pin deflections, and structural integrity.

# I. MODULE DESIGN

The objective of this phase of the program was to design a module that is more reliable and more producible than that used in the Phase III ACSP test prototype. In addition, a comparison was to be made between encapsulated and nonencapsulated type modules.

Several design approaches for nonencapsulated modules were reviewed with respect to structural integrity, thermal dissipation, and manufacturing complexity. The most serious drawback of a nonencapsulated module was determined to be the difficulty of providing adequate thermal paths between the substrate assemblies and the module mounting base without the use of an elaborate internal structure that would increase manufacturing complexity. An encapsulated module provides excellent thermal dissipation with a relatively simple internal structure. It is structurally superior, thus providing the capability for withstanding more severe shock and vibration levels. The simpler internal structure makes it easier and thus less expensive to manufacture and provides the module with a higher level of reliability. A nonencapsulated module is easier to repair and lighter (for the same size), although the difference in weight is made less significant by the heavier internal structure required. When the relative advantages of encapsulated and nonencapsulated modules are compared, the superiority of the encapsulated module for space applications is clearly evident. The potential advantage of less weight for a nonencapsulated module can only be practically realized for low power circuits.

Several major improvements have been made in the encapsulated module design used for the Phase III prototype ACSP:

1 Use of a back-to-back thin film substrate and printed circuit component card assembly within the module offers three basic advantages:

   a Elimination of the gap between substrate and printed circuit card in the old "piggyback" method of assembly that allowed contaminants to become entrapped

   b The complete accessibility of both thin film and printed circuit surfaces for effective cleaning and thorough inspection after assembly c Interconnections are now made by short leads connecting pads at the periphery of thin film substrate and printed circuit card surfaces. There is no relative motion between substrate and printed circuit card to fatigue these wires during conditions of environmental stress

2 Use of a sealer coat over thin film resistors has eliminated the possibility of damage to thin film resistor elements by contaminants having passed through pinholes in the protective silicon monoxide layer

3 Use of a screw to secure the plug-in module to the channel printed circuit card has considerably reduced the amount of mechanical stress on the module output pins during periods of shock and vibration.

The closed loop ACSP Inverter was selected as the module to be designed and tested in this program. The module is comprised of three thin film circuit assemblies, a printed circuit card with discrete components, a heat sink mounting bracket with two power transistors, and a base interconnection card. After the three hybrid circuit assemblies and the printed circuit card have been mounted on the base card and interconnections made at the top, the overall assembly is dip-coated with a flexible silicone rubber to protect the electrical components from the mechanical stresses of subsequent encapsulation. After the assembly has been conformally coated, it is encapsulated with a semiflexible epoxy to provide structural support for the internal assembly and the module output pins, and to provide a good thermal path from the electrical components to the module heat sink mounting bracket.

A hybrid circuit assembly consists of a ceramic thin film substrate, the back side of which is bonded with a flexible adhesive to the back side of a printed circuit card with discrete components. Interconnections between the substrate and the printed circuit card are made by means of gold plated OFHC copper wires (0.002 inch in diameter) passing around the edges of the bonded assembly as shown in Figures 1 and 2. The edges of the slightly larger printed circuit card are notched for protection of the interconnection wires. All such interconnections are made between pads located at the periphery of the substrate and the printed circuit card, and relief is provided to allow for the difference in temperature coefficient of expansion of the substrate and the printed circuit card. Discrete components are attached to the printed circuit card (Figure 3) before it is bonded to the thin film substrate to reduce the possibility of damaging the substrate surface through excessive handling. Both surfaces of the completed substrate-printed circuit card assembly are completely exposed for cleaning and inspection prior to module assembly.

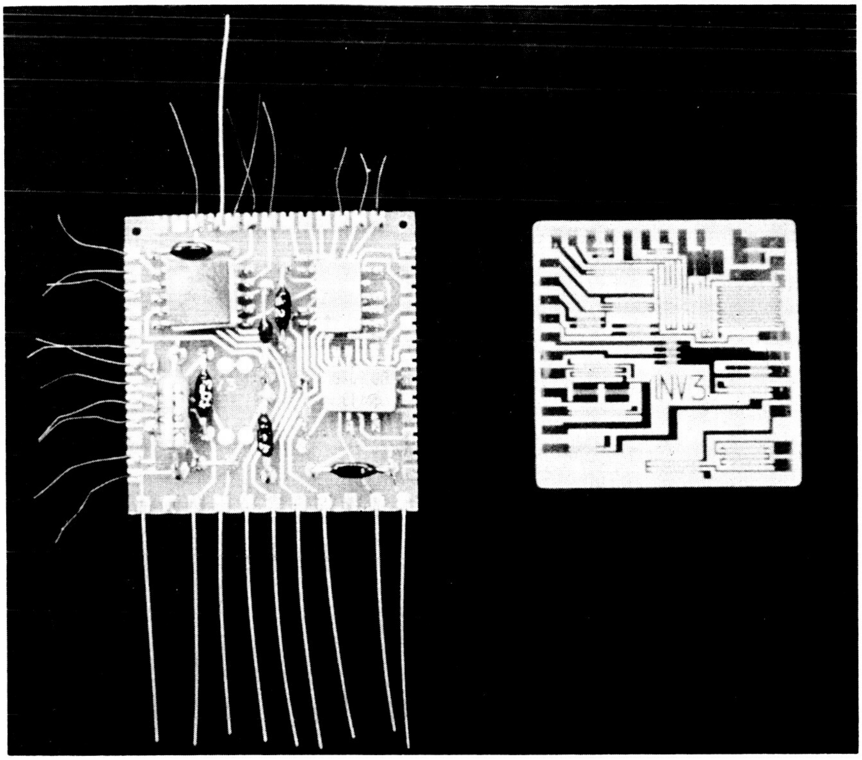


Figure 1. Discrete Component Assembly with Interconnections

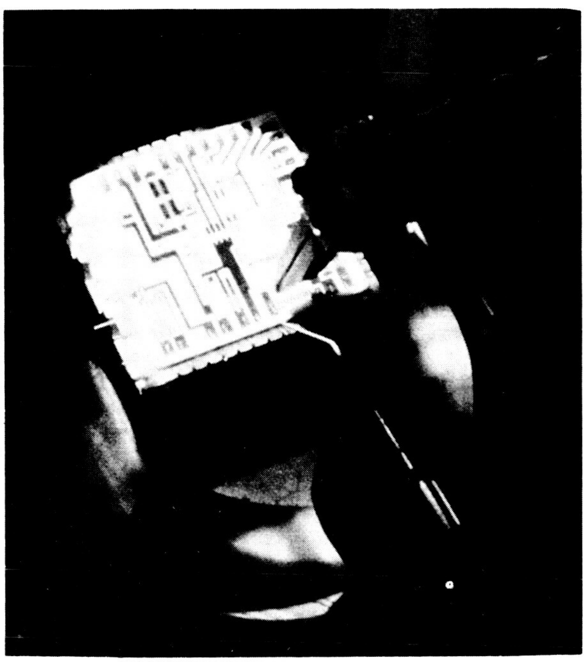

Figure 2. Parallel Gap Welding of Interconnections

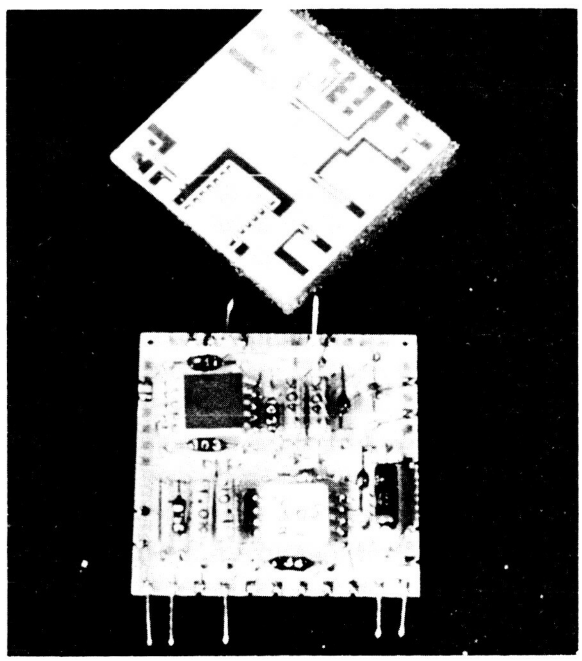

Figure 3. Discrete Components Attached to Printed Circuit Card

The heat sink mounting bracket provides structural support for the module, a heat sink mounting surface for the power transistors, and a thermal path for the hybrid circuits and the printed circuit card components. In Figures 4 and 5 a heat sink bracket is shown with the two mounting holes for attachment of the module to the channel assembly frame and a single mounting hole for attachment of the module to the channel assembly printed circuit card for stress relief of module output pins. The cases of the power transistors are at collector potential and must be isolated from each other as well as from circuit ground. Since pressure cannot be exerted on the cover, but only on the rim of the power transistor, a piece of 0.062 inch G-11 material is prepared with two holes through which the transistor covers protrude. Mica sheet insulation with thermal joint compound are used between the power transistors and the bracket mounting surface. Pressure on each transistor is maintained by two screws located diametrically opposite on the rim of the transistor.

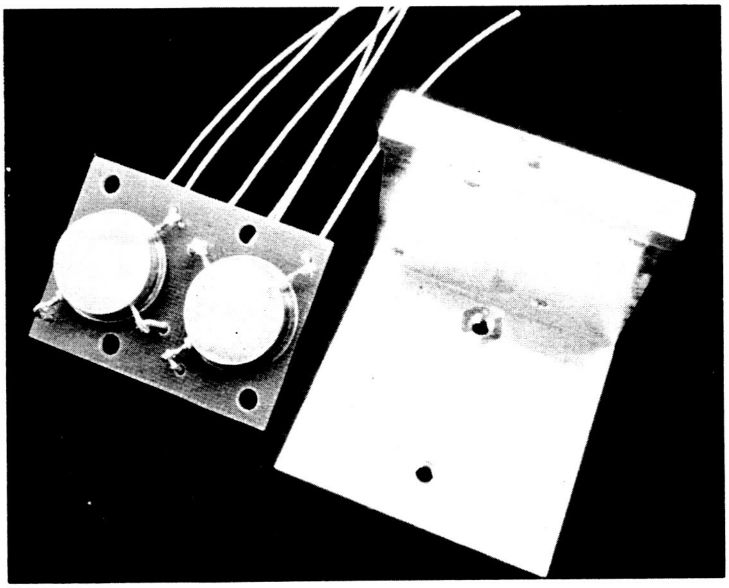

Figure 4. Power Transistor and Heat Sink Assembly, Unassembled

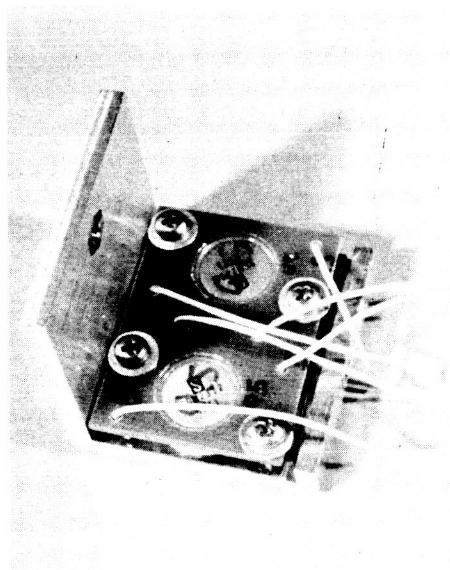

Figure 5. Power Transistor and Heat Sink Assembly, Assembled

The base card, which provides interconnections among the hybrid circuits, printed circuit cards, and output pins, is shown in Figure 6 mounted in a groove on the heat sink bracket. A standard grid pattern is used to determine all hole locations in the base cards for better producibility. The Inverter module assembly coated with General Electric RTV 616 silicon rubber is shown in Figure 7. The finished module encapsulated with Minnesota Mining and Manufacturing CRP 241 epoxy is shown in Figure 8.

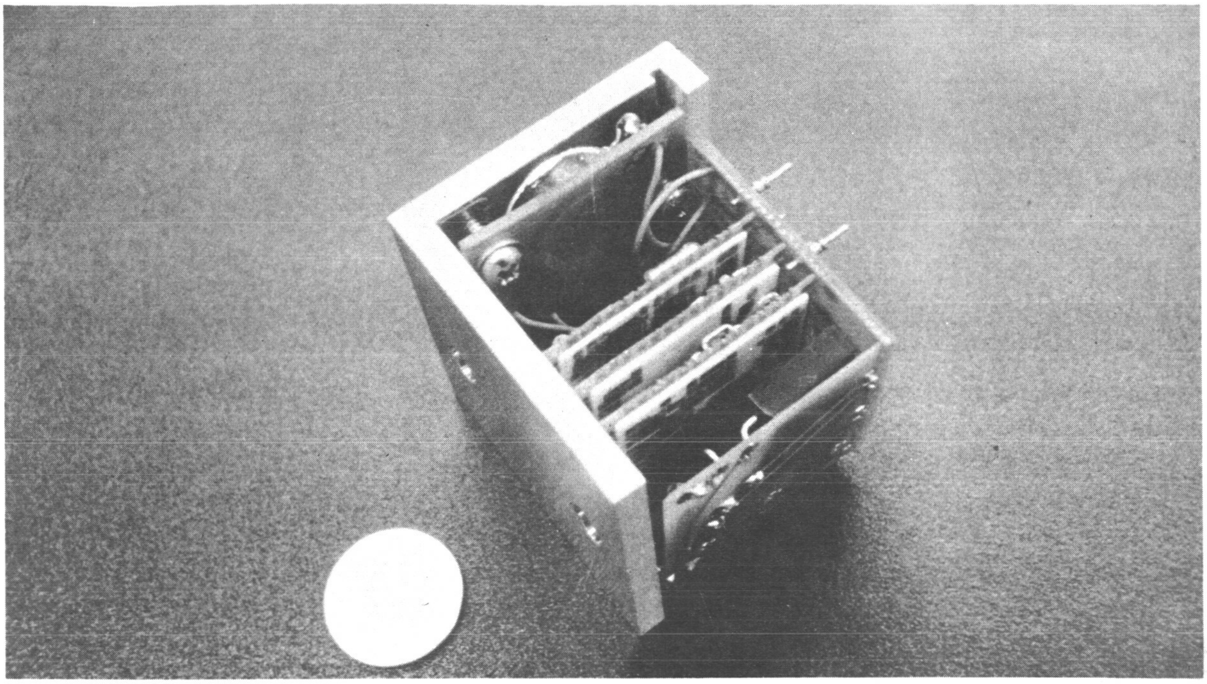

Figure 6. Hybrid Inverter Module Assembly Before Conformal Coating

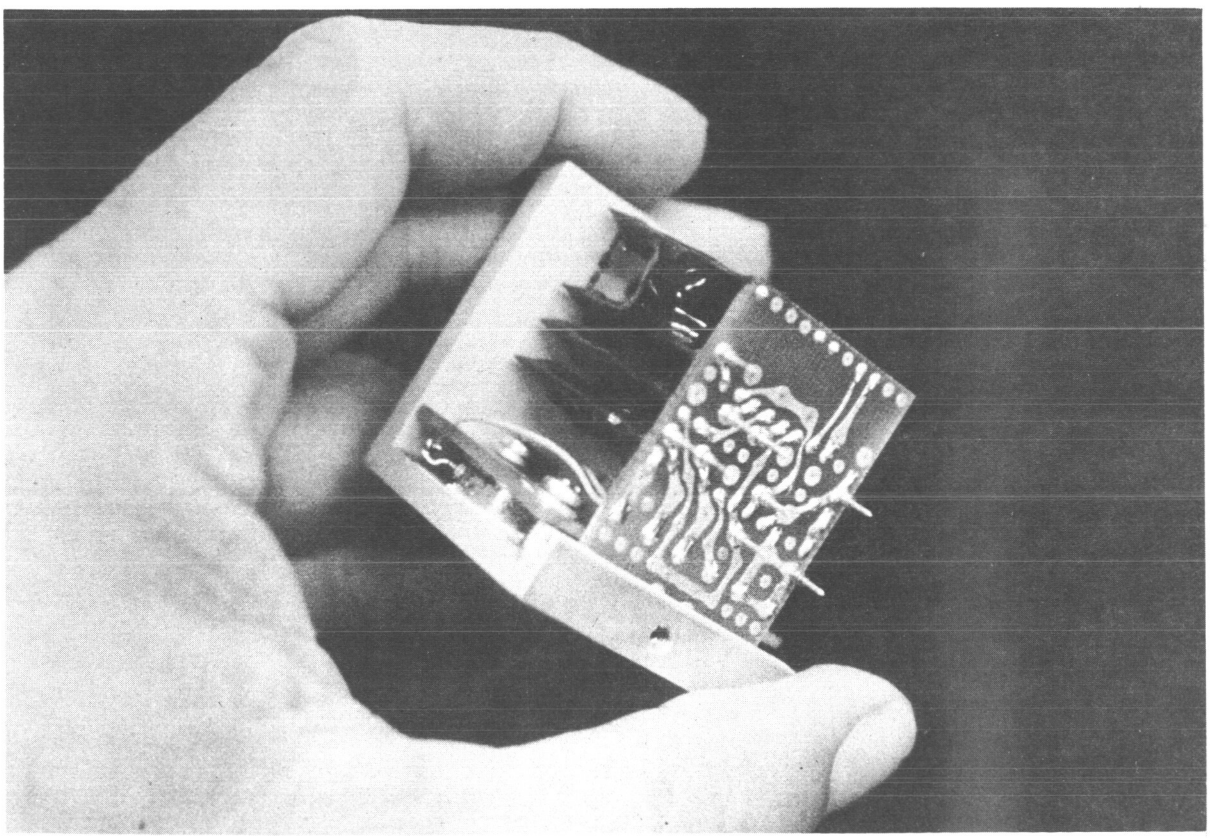

Figure 7. Hybrid Inverter Module Assembly After Conformal Coating

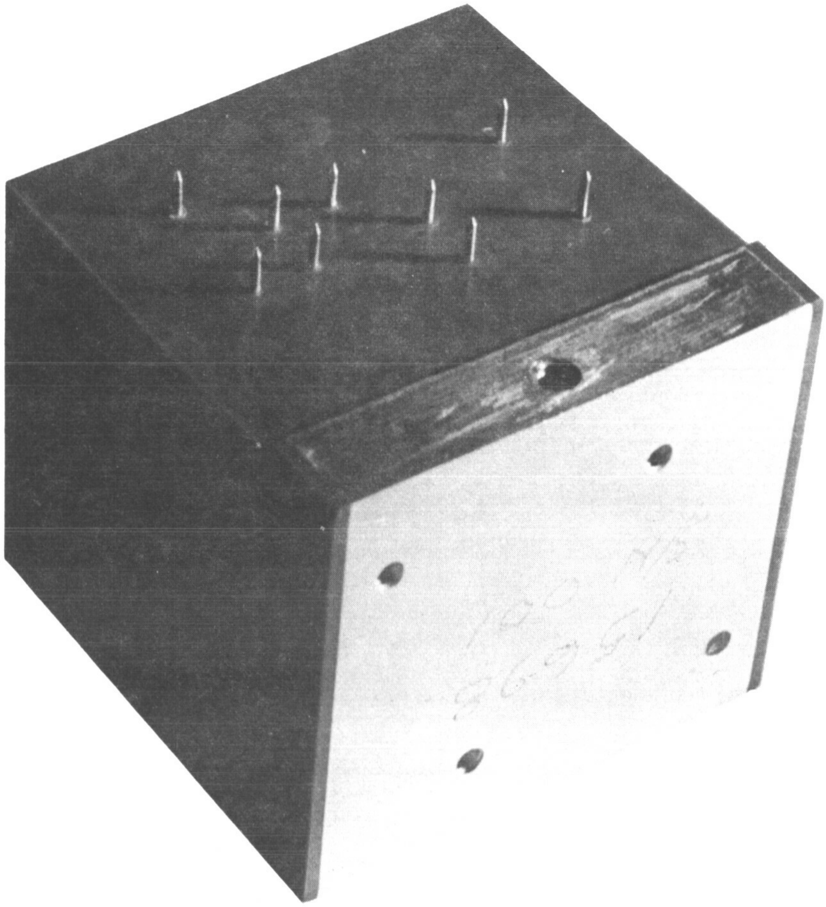

Figure 8. Encapsulated Module

## II. DYNAMIC ENVIRONMENTS

The module vibration test levels were arrived at by combining the dynamic packaging characteristics and the contractual requirements for Phase V (Figures 9 and 10). The dynamic packaging characteristics were derived from data recorded during Phase III vibration tests and from projected control of the design parameters of Phase V packaging. The test data indicated the principal modes of vibration response which would be encountered and the frequency ranges in which the modes occur. The dynamic response at each particular mode was calculated assuming decoupling of resonant frequencies and incorporation of designs with increased damping. A reasonable confidence level in the derived module vibration levels was attained because the high acceleration levels anticipated at the resonant peaks were extended over a broad frequency range (200 c/s or greater) to cover possible shifts in resonant frequencies. The derived vibration spectra for each axis are presented in Figures 9 and 10. The axes specified are those designated in the Advanced Control Signal Processor Phase III Completion Report (Reference 1).

### A. DESIGN AND DEVELOPMENT

One of the first tasks was to evaluate the possibility of using an unpotted module configuration. Initial dynamic analysis was made on the module base card and the substrates of the unpotted module. This analysis showed that if the substrates were attached on opposite sides rather than cantilevered from the module base card, the unpotted module would be dynamically satisfactory (see Appendix). The unpotted module was discarded from further consideration for reasons other than dynamics.

The primary analytical concern of the potted module was the spring mass system consisting of a substrate completely coated with silicone rubber. This analysis required the compressional spring constant of completely encapculated silicone rubber (General Electric RTV 616). An experimental test was conducted on two samples to determine the static load versus deflection characteristics of the material. The results of this test showed a static spring constant of 2200 lb/in for completely encapsulated RTV616, 0.050 inch thick. Elastomeric materials, such as the RTV616, have dynamic characteristics which are higher than the corresponding static characteristics. For a material with a Shore A durometer reading

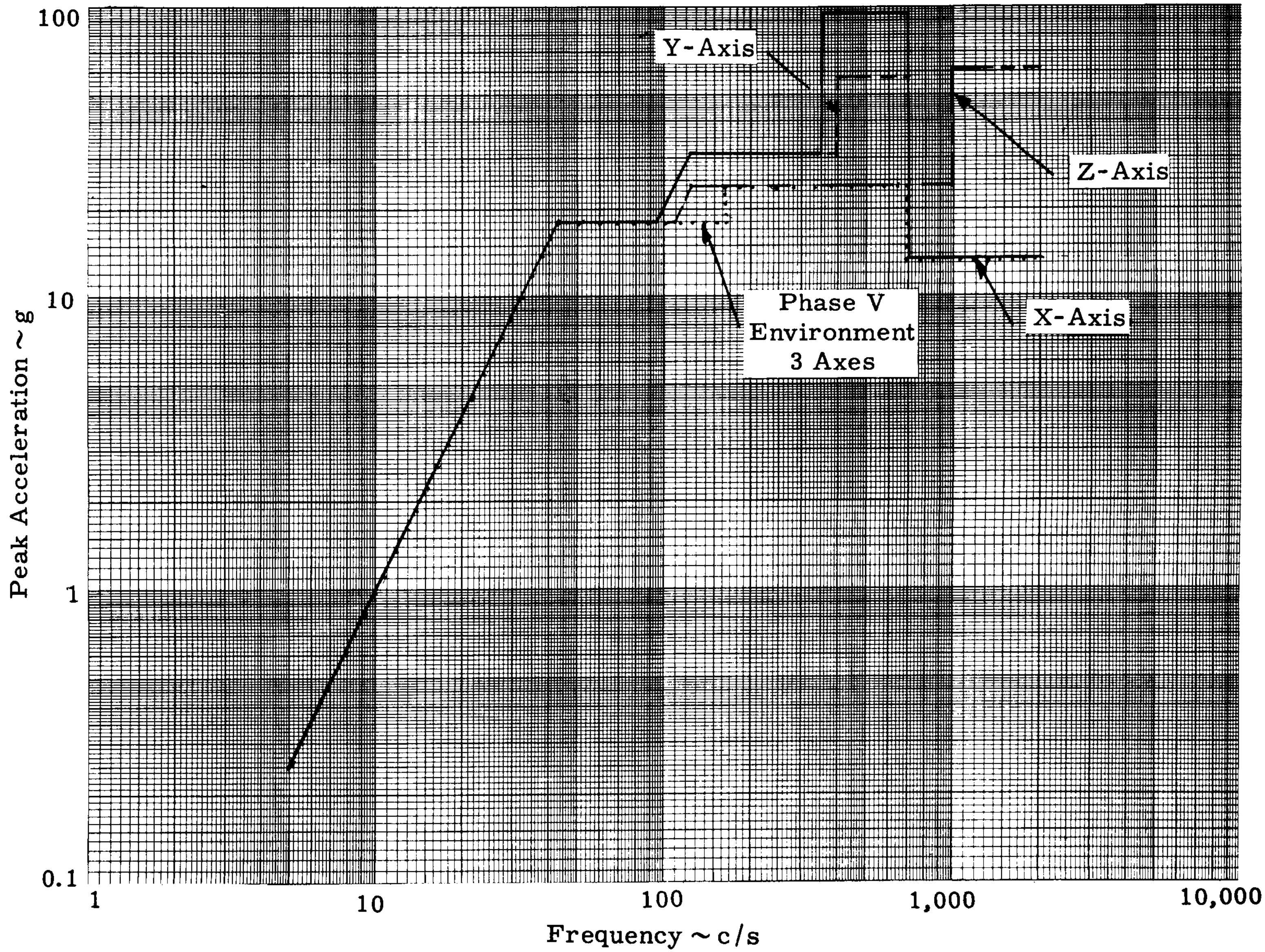


Figure 9. ACSP Module Sinusoidal Input Vibration Spectra

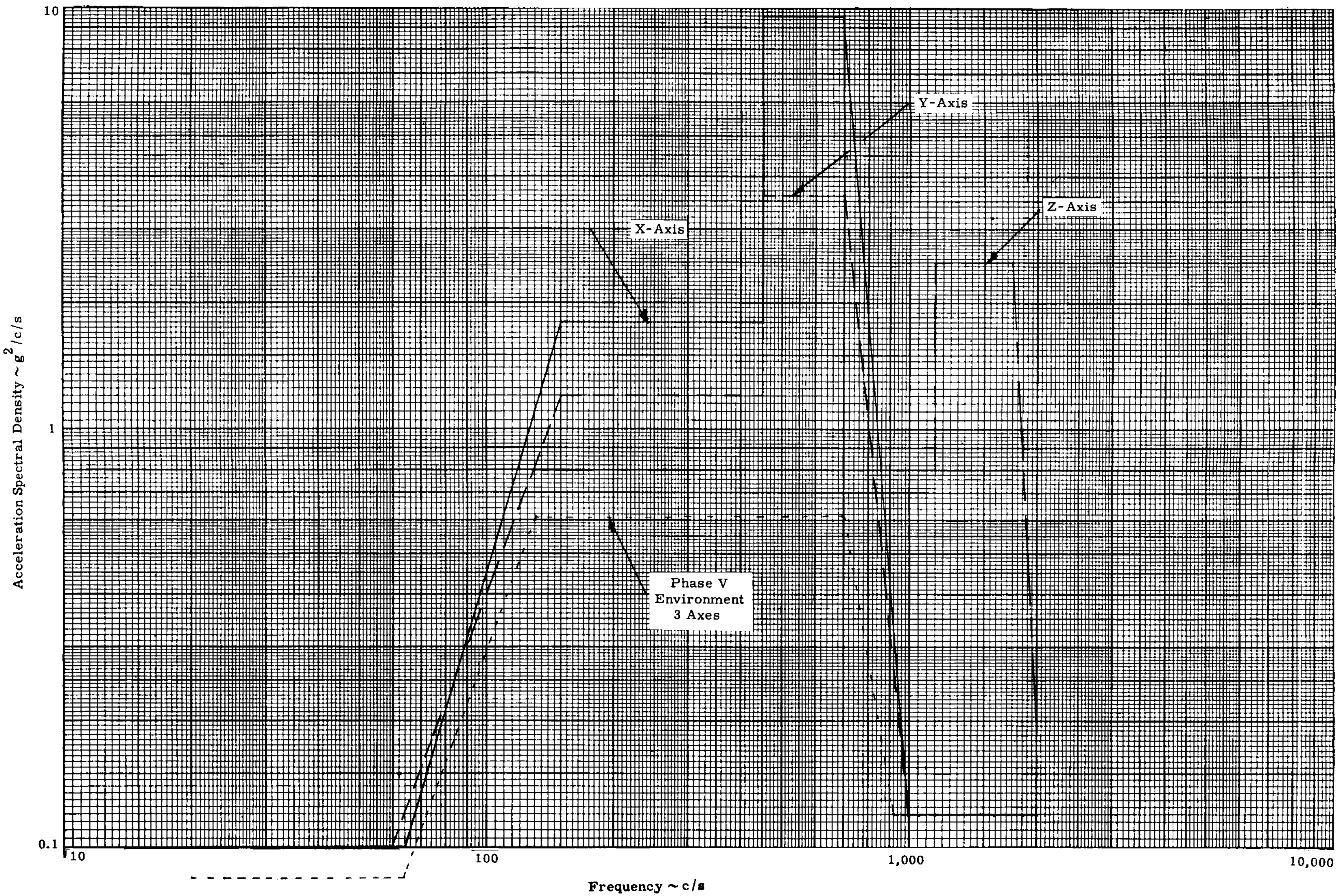


Figure 10. ACSP Module Random Vibration Spectra

of 45 (such as GE RTV616), the ratio of dynamic modulus to static modulus is 1.4. Applying this factor, the static spring constant yields a dynamic spring constant of 3080 lb/in. Using this spring constant, the calculated resonant frequency of the substrate coated with a 0.050 inch thickness of RTV 616 is 1655 c/s. The response of the substrate to the anticipated vibration levels yields deflections and stresses which are within tolerable limits since they are less than the deflections and stresses predicted in the "unpotted-module" analysis which was deemed acceptable.

## B. DEVELOPMENTAL VIBRATION TESTING

A vibration test was conducted on the ACSP Inverter module to determine if the module could satisfactorily sustain the random and sinusoidal vibration environment anticipated in testing of the module in the Phase V enclosure. The test levels were those described in Figures 9 and 10, and the test times were the same as those used in Phase III testing (one octave per minute per axis sine sweep, and a 3 minute random test per axis). The purpose of the test was to determine the relative deflections of the module pins as compared to the pin deflections encountered in Phase III testing, and to demonstrate proper module operation under the imposed vibration environment.

The Inverter module was rigidly fastened to a specially built module test fixture with two mounting screws as in a typical module installation. The module pins were plugged into a printed circuit card that was rigidly attached to the test fixture. The base of the module was also secured to the printed circuit card with a screw. The size of the card was minimized to offer as high a mechanical impedance as possible to the module.

Three response accelerometers were used on the test assembly to verify the rigidity of the fixture and to measure relative deflections of the module pins.

An analysis of the input random vibration environment, recorded during testing in each axis, is presented in Figures 11 through 13. The maximum relative pin deflections measured during sinusoidal testing are presented in Table I.

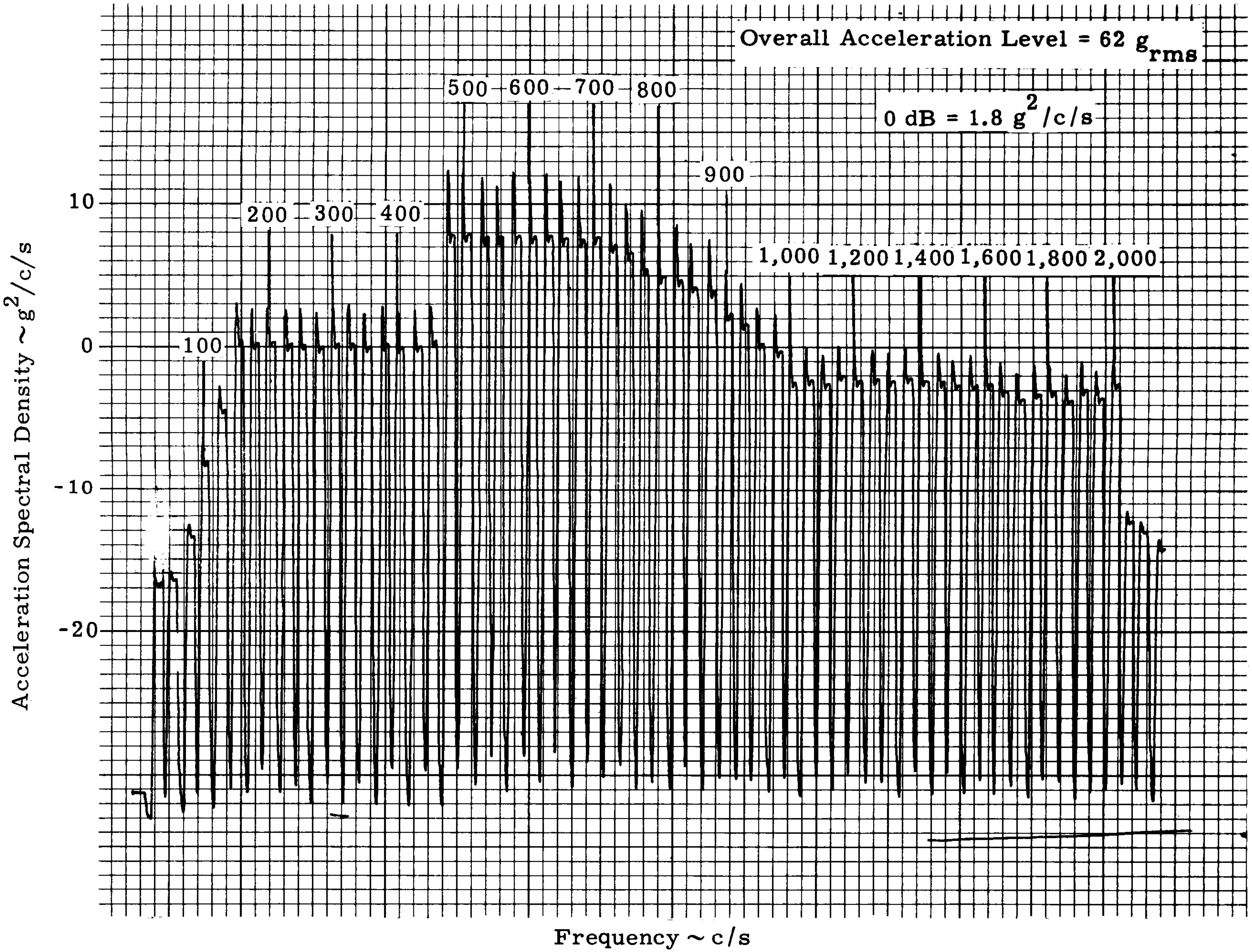


Figure 11. ACSP Module Input Random Vibration, X Axis

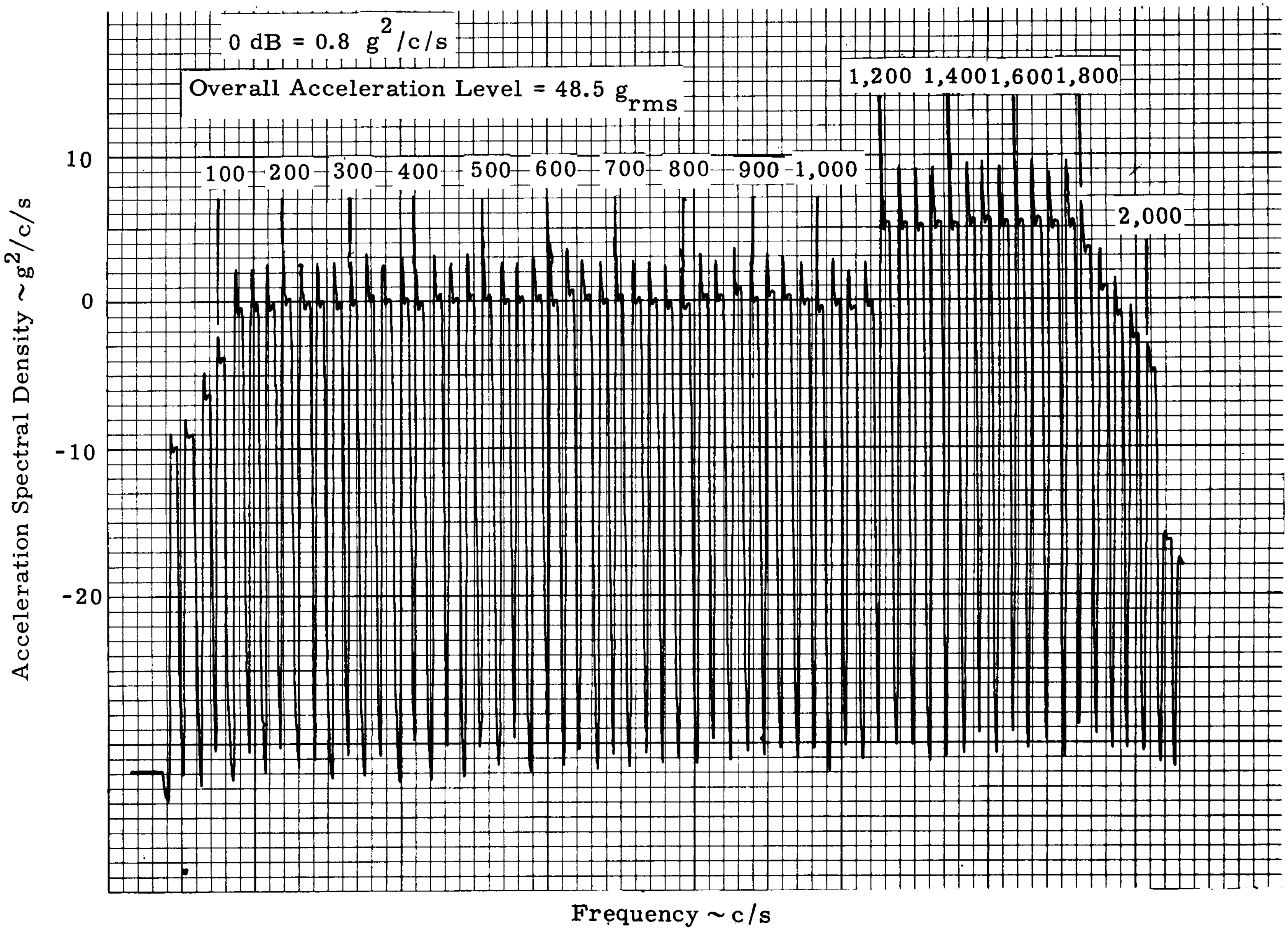


Figure 12. ACSP Module Input Random Vibration, Z Axis

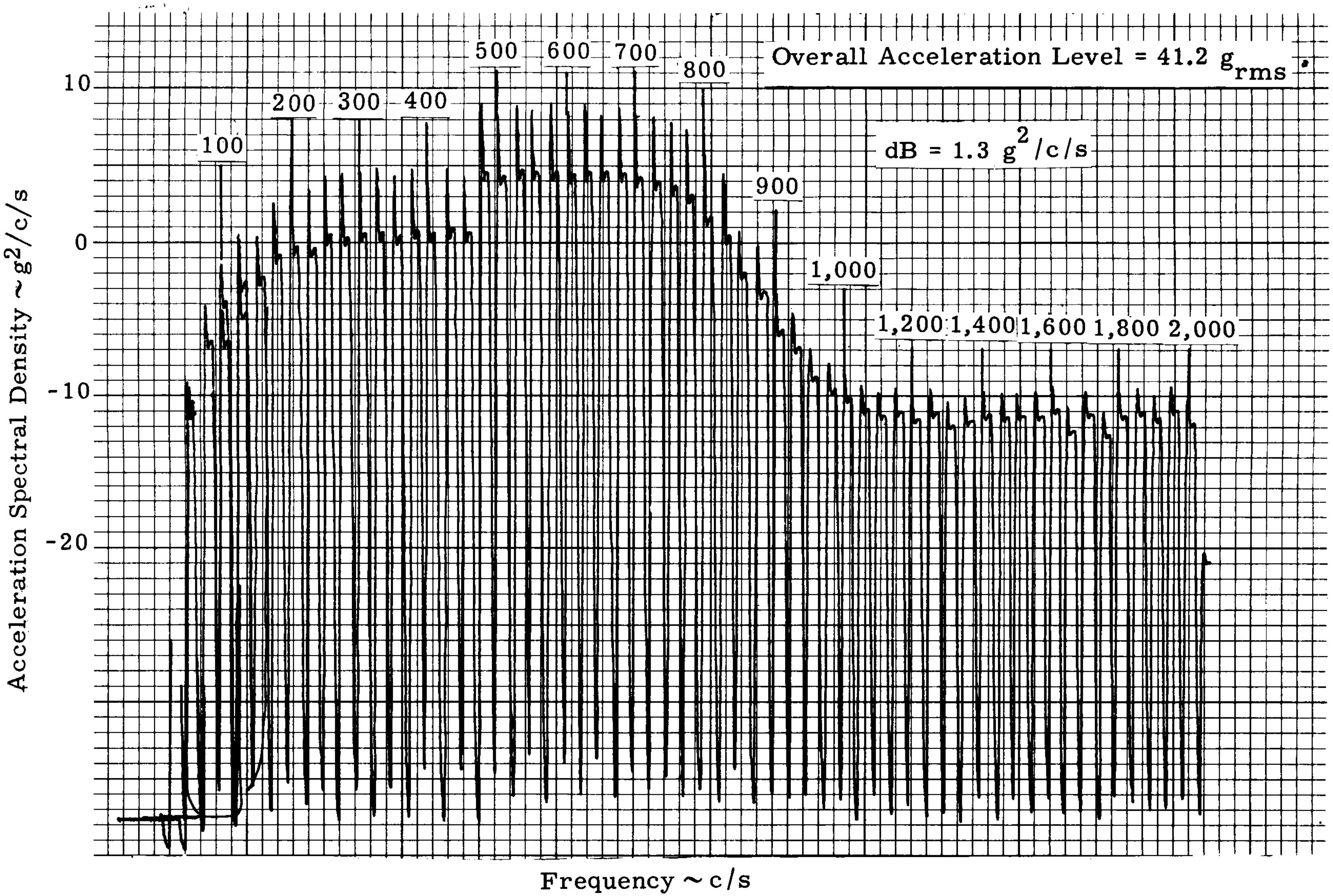


Figure 13. ACSP Module Input Random Vibration, Y Axis

TABLE I

Maximum Relative Pin Deflections

| Direction of Excitation | Frequency (c/s) | Input Level (g peak) | Maximum Relative Single Amplitude Deflection (inches) |
|---|---|---|---|
| X | 2000 | 13.5 | 0.000013 |
| Z | 1700 | 61 | 0.000177 |
| Y | 2000 | 13.5 | 0.000055 |

The maximum relative pin displacement encountered during Phase III testing was 0.0004 inch, while the worst case in this test was 0.00018 inch.

The module sustained the imposed vibration environment without functional or structural failure.

## III. MATERIALS EVALUATION

### A. MODULE ENCAPSULANT AND CONFORMAL COATING MATERIALS

A number of types of silicone rubber materials for conformal coating applications were reviewed before selecting some for actual test. Several manufacturers of such products were contacted and asked for their recommendations for our specific application. Among the materials considered were General Electric RTV 615, RTV 616, RTV 630, RTV 60, and Dow Corning RTV 3110, and RTV 3116 (replacement for RTV 503). General Electric RTV 615, RTV 616, RTV 630 and Dow Corning RTV 3110 and RTV 503 were actually tested. All of these materials appeared to provide comparable performance for the application. General Electric RTV 616 (black) and RTV 615 (clear) were selected for use in subsequently built dummy and working modules.

The encapsulants considered for evaluation on this program included Minnesota Mining and Manufacturing CRP 241, CRP 244, CRP 281; Emerson and Cuming 2850 FT, 2850 GT; Hysol 4169; and Furane EF 221. Hard epoxies such as Hysol 4169 and Emerson and Cuming 2850 GT were excluded from further consideration because of the difficulty of disassembling modules encapsulated with these materials for purposes of repair or failure analysis. Repairability of modules must remain an essential consideration until such time as these modules are declared to be throw-away items. Several dummy modules were fabricated to obtain information relating to internal stresses on components during encapsulation and subsequent temperature cycling prior to testing working modules. The dummy modules built had the same size and shape as the Inverter module designed for Phase V, including the use of an aluminum bracket to form two sides of the module. Electrical continuity on encapsulated substrates and printed circuit cards was monitored throughout temperature cycling tests on all dummy modules. One of the several dummy modules built contained an internal structure consisting of only two printed circuit cards mounted on a base printed circuit card. The internal assembly was dip-coated with RTV 616 silicone rubber and encapsulated with Minnesota Mining and Manufacturing CRP 241. Electrical continuity on the circuit cards was monitored while the module was temperature cycled between -55 and +125°C. The module cracked (Figure 14) during the first cycle when the temperature was rapidly changed

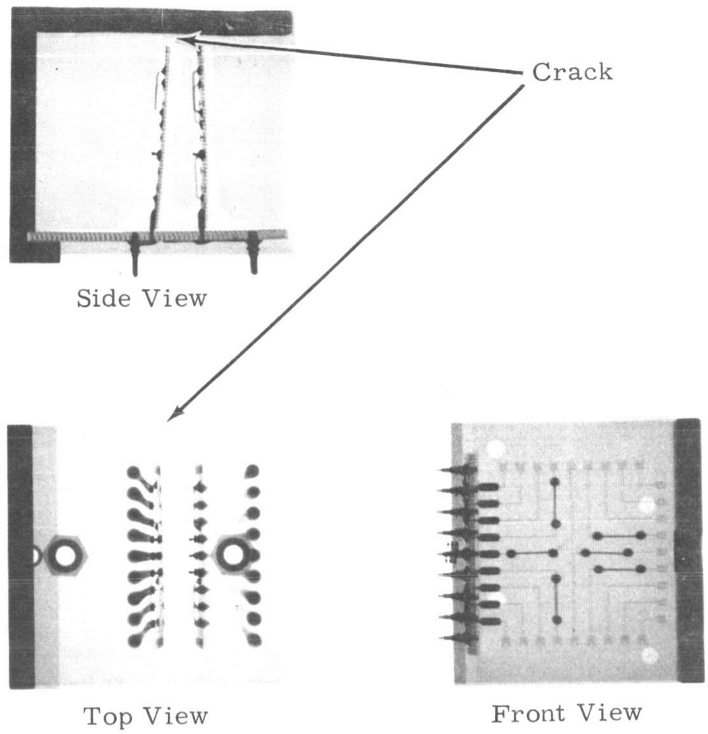


Figure 14. Dummy Inverter Module with Two Component Cards

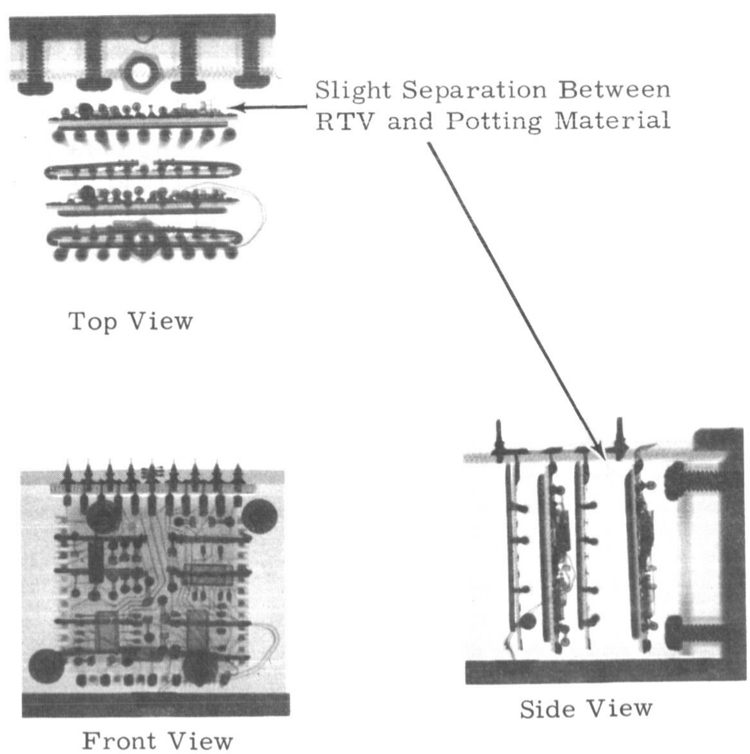


Figure 15. Dummy Inverter Module with Three Substrate-Card Assemblies and One Component Card

from +125 to -55°C, although electrical continuity was never broken. Subsequent controlled tests on a similar module using encapsulated thermocouples revealed that the failure occurred as a result of unequal rates of heat removal from different parts of the module. The use of only two cards in a module large enough for three substrate-card assemblies, a separate printed circuit card, and two power transistors left large volumes of encapsulant from which heat could not be removed as rapidly as from those portions of the module near the heat sink bracket. When three substrate-card assemblies and a printed circuit card were included in the next dummy modules built to simulate more closely the internal structure of an actual Inverter module, no signs of cracking were observed even after several rapid temperature cycles between -55 to +125°C. Such a module is shown in Figure 15. The additional substrate assemblies not only helped to remove heat from all parts of the module more evenly but also broke up the encapsulant into thinner sections. Since the encapsulant does not bond to the silicone rubber conformal coating, individual sections of encapsulant were able to contract separately, thus relieving stress concentrations considerably. At no time during any of the dummy module temperature cycling tests was electrical continuity broken or were components damaged in any way.

The first Inverter test module built was conformally coated with General Electric RTV 616 silicone rubber and encapsulated with Minnesota Mining and Manufacturing CRP 241 epoxy. The choice of encapsulant was made on the basis of the results of dummy module tests and considerable experience with the material during Phase III environmental tests.

The module was subjected to sinusoidal and random vibration tests with the following peak levels:

Sinusoidal (5-2000-5Hz, 1 Octave per Minute)

| | |
|---|---|
| X-axis | ±96g peak |
| Y-axis | ±58g peak |
| Z-axis | ±61g peak |

Random (3 minutes duration for each axis)

| | |
|---|---|
| X-axis | 60.55g rms |
| Y-axis | 41.2g rms |
| Z-axis | 47.8g rms |

The module operated without any problems throughout the vibration tests, as shown by a continuous record of amplitude and frequency for microsyn and spin motor drive outputs.

The Inverter module was then subjected to three complete temperature cycles from -55 to +125°C during which it operated within specifications and was not physically damaged in any way by the rapid temperature changes.

A second Inverter module was built in the same way as the first with the exception that General Electric RTV 615 (a clear conformal coating) was used. The module was also subjected to three temperature cycles without any problems.

## B. EVALUATION OF SEALER COATINGS FOR THIN FILM SUBSTRATES

As reported earlier, a problem had developed when modules began failing because contaminants were reaching and attacking the thin film circuitry through voids in a silicon monoxide coating deposited over the circuitry. A sealer coating was deemed necessary to protect the system from solvents, solder fluxes, moisture, and other contaminants. The program was divided into rough screening and final tests. The following items were selected as major requirements:

1 Withstand thermal shock, air - air, -55 to +125°C

2 Good adhesion to glazed ceramic and metal surfaces

3 Withstand normal flux remover solvents and solder fluxes

4 Cause resistor change no greater than ±1 percent

5 Be 0.010 inch thick or less.

### 1. Screening Tests

Vendors known to be reliable in this field were contacted and asked to supply coatings suitable for sealing the vapor deposited circuits. All were asked for a one-component system if possible. The following vendors responded:

| Vendor | Material |
|---|---|
| John C. Dolph Co.<br>Monmouth Junction, N. J. | Hi-Therm Varnish BC 340 |
| Harton Conrad and Assoc.<br>Boca Raton, Fla. | Duricon Dielectric Fluid |

| | |
|---|---|
| Emerson and Cuming, Inc.<br>Canton, Mass. | Eccosil SC 71<br>Eccocoat EC 200 |
| Dow Corning, Corp.<br>Midland, Mich. | DC 1377 Varnish<br>DC 991 Varnish |
| Product Techniques, Inc.<br>Downey, Calif. | PT 207 |

Several other vendors were contacted but did not respond.

Test substrates were prepared from substrates made earlier. They were reworked so that two sets of conductor pads were made on each piece. Each set comprised a gap of 5/16 inch length by 1/8 inch wide. The substrate material was glazed Al-Si-Mag 614 made by American Lava Corp., Chattanooga, Tenn. Leads were attached to each pad and the specimens were cleaned as follows:

1 Alcohol wash to remove gross soil

2 Ultrasonic clean in Bruhling's solution

3 Wash with absolute alcohol

4 Vapor soak in hot alcohol vapors.

Each specimen was then brush coated with a candidate material and cured according to vendor instructions. Four pieces for a total of eight test areas were made for each sealant. After cure, the wafers were checked for thickness to ensure that none was thicker than the 0.010 inch maximum allowed. The resistance between the pads was measured using 250 Vac. Then the following environmental tests were performed:

1 Thermal shock, air-to-air, -55 to +125°C, 5 cycles (1 cycle = 20 minutes at each temperature)

2 Two 1/2 hour periods at 110°F and 95 percent RH.

3 Three hours at 95°F and 95 percent RH of 10 percent salt fog.

4 3/4 hour at 180°F in water.

After these tests, the specimens were again electrically measured and visually inspected. The most promising were then chosen for coating actual test circuits.

In addition, common flux removal solvents were applied to each coating and the coatings observed for deleterious effects. A further reduction in number of test materials resulted.

2. Final Tests

As a result of previous testing the materials chosen for final testing were Eccosil SC 71, Eccocoat EC 200, Dow Corning DC 96-005, and Electro-Sciences Laboratories ESL 22H. The latter material has had some previous evaluation at the Orlando Division for this purpose and has showed promising results. Each material was coated on an actual double resistor thin film circuit and cured and then tested as follows:

1 Test resistors as coated for value

2 Bake at +125°C for 8 hours under load

3 Thermal shock -55 to +125°C with solder flux (Alpha 611) on one set of resistors, five cycles air-to-air

4 Bake 24 hours at +125°C under load with flux still present

5 Recheck for electrical values.

3. Results

Results of the final tests are shown in Table II. An increase in resistance values indicates pores or voids in the sealant which allowed contaminants to come into contact with the circuit. Under load and temperature, the contaminants attack the resistor, thus tending to open the circuit.

As a matter of curiosity, one marginal material (EC 200) and one good material (DC 96-005) were completely processed a second time. The EC 200 was badly broken down in the fluxed area, while the DC 96-005 was not changed to any great degree.

4. Conclusions

Based upon these test results, and other handling properties, the following materials were found to be suitable for use on Advanced Control Signal Processor substrates:

| | |
|---|---|
| Emerson and Cuming, Inc. | Eccosil SC 71 |
| Dow Corning | DC 96-005 |

TABLE II

Final Test Results

| Resistor No. | Eccosil SC 71 | | | Eccocoat EC 200 | | | DC 96-005 | | | ESL 22 H | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial Value (ohms) | After Test (ohms) | Percent Change | Initial Value (ohms) | After Test (ohms) | Percent Change | Initial Value (ohms) | After Test (ohms) | Percent Change | Initial Value (ohms) | After Test (ohms) | Percent Change |
| 1 | 121 | 121 | 0 | 99 | 100 | +1 Digit | 99 | 100 | +1 Digit | 94 | 95 | +1 Digit |
| 2 | 1001 | 1001 | 0 | 9919 | 9919 | 0 | 991 | 994 | +0.3 | 979 | 983 | +0.4 |
| 3 | 99 | 99 | 0 | 9919 | 9929 | +0.1 | 9869 | 9880 | +0.1 | 9891 | 9914 | +0.2 |
| 4 | | | | 981 | 990 | +0.9 | 9869 | 9882 | +0.1 | 9881 | 9911 | +0.3 |
| 5 | | | | 99 | 99 | 0 | 991 | 994 | +0.3 | 979 | 982 | +0.3 |
| 6 | | | | | | | 99 | 99 | 0 | 99 | 99 | 0 |
| 7F | 99 | 99 | 0 | 99 | 99 | 0 | 999 | 1001 | +0.2 | 99 | 98 | -1 Digit |
| 8F | 999 | 1001 | +0.2 | 991 | 1079 | +8.9 | 9969 | 9978 | +0.1 | 999 | 1009 | +1.0 |
| 9F | 10430 | 10420 | -0.1 | 10010 | 10010 | 0 | 10040 | 10050 | +0.1 | 10030 | 10050 | +0.2 |
| 10F | 10020 | 10020 | 0 | 10060 | 10070 | +0.1 | 991 | 992 | +0.1 | 10030 | 10050 | +0.2 |
| 11F | 1001 | 1002 | +0.1 | 999 | 1010 | 1.1 | 99 | 99 | 0 | 999 | 1059 | +6.0 |
| 12F | 99 | 99 | 0 | | | | | | | 99 | 99 | 0 |

F = With flux present

# IV. MODULE FABRICATION

The major steps in the fabrication and assembly of the microelectronic module and the sequence of each step as it occurs are shown in Figure 16. This chart will be used in the following discussion in describing the hardware fabrication, processes, techniques, and the assembly operations, used to successfully produce the module.

## A. THIN FILM CIRCUIT FABRICATION

Steps 1-6 pertain to the fabrication of the thin film circuits used in the microelectronic module design. These steps are performed in a clean, dust-free, humidity-controlled area.

### Step 1

The substrates used in this design are American Lava Corporation Al-Si-Mag 614 ceramic with 743 glaze. The ceramic substrate is polished prior to glazing in order to control camber and flatness to very close tolerances and to minimize the size of the edge meniscus formed by the glaze. Substrate size is 1.0 ± 0.010 inch by 1.0 ± 0.010 inch by 0.030 ± 0.005 inch in thickness. A resistance layer (Chromel-C) is first vacuum deposited on the glazed ceramic substrate to a thickness that will result in a resistance per square of 500 ohms after further processing. The deposited value of resistance per square is approximately 25 percent below the final value. This is done to allow a thermal passivation of the resistor material and to provide the means by which individual resistors are adjusted to within ±1 percent of their design value. The layer of Chromel-C is followed by a protective vacuum-deposited layer of pure gold.

An engineering design requirement that the conductor shall have maximum resistance per square of 0.03 ohm is met by electroplating a relatively thick layer of gold over the vacuum deposited gold. This is accomplished in a cyanide gold electroplating bath and is controlled by Martin Standard Process P31001F (MIL-G-14548 Grade III). This gold layer is approximately 40,000 Angstroms thick.

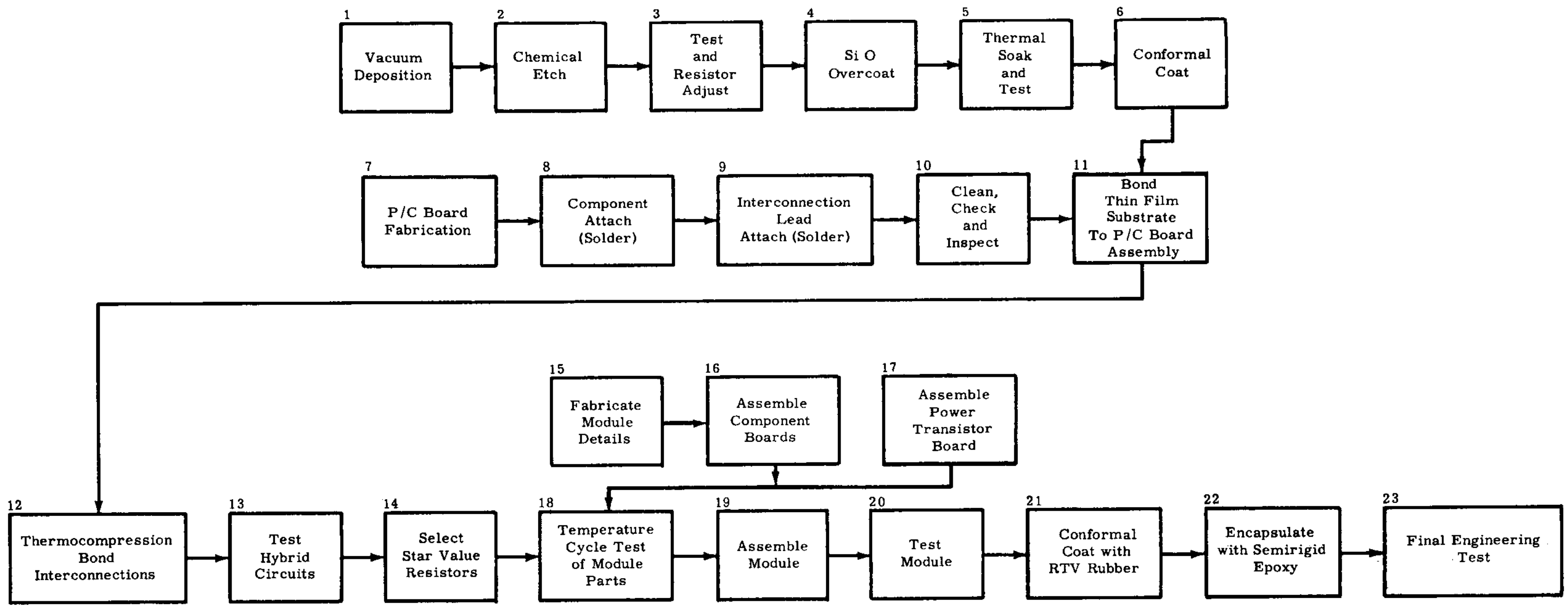


Figure 16. Manufacturing Flow Chart

Step 2

Chemical etching is accomplished in a two-step operation generally referred to as the substractive process.

1 The composite circuit is photoetched down to the glaze on the substrate to establish conductor patterns and resistor widths

2 The resistor areas are exposed by selectively etching the gold and thus establishing resistor lengths.

Step 3

Immediately after etching, the thin film circuits are tested. As mentioned previously, the resistors are deposited so that they have a nominal value 25 percent below design value. The resistors are then adjusted to within approximately 0.5 percent of design value by a thermal and electrical passivation process. The resistors are also stabilized at this time for operation at +150°C. The temperature coefficient of resistance is checked for ±50 parts per million per °C.

Step 4

A silicon monoxide overcoat, approximately 10,000 Angstroms thick, is vacuum deposited through stainless steel masks over all resistors for protection and sealing. Six green (wratten 74) interference color filters are used to monitor SiO thickness.

Step 5

After SiO sealing, the circuits are thermally soaked for 20 hours at 150°C. The circuit is retested for resistor tolerance and temperature coefficient of resistance.

Step 6

A final conformal coating of Dow Corning 96-005 silicone compound, approximately 0.005 inch thick, is then applied over the complete circuit except for the interconnection pads. The three thin film circuits that were fabricated for the Inverter test module are shown in Figure 17.

## B. HYBRID CIRCUIT ASSEMBLY

Steps 7-12 pertain to the assembly of the hybrid circuits. Figure 18 shows a typical hybrid circuit during one stage of assembly. These hybrid

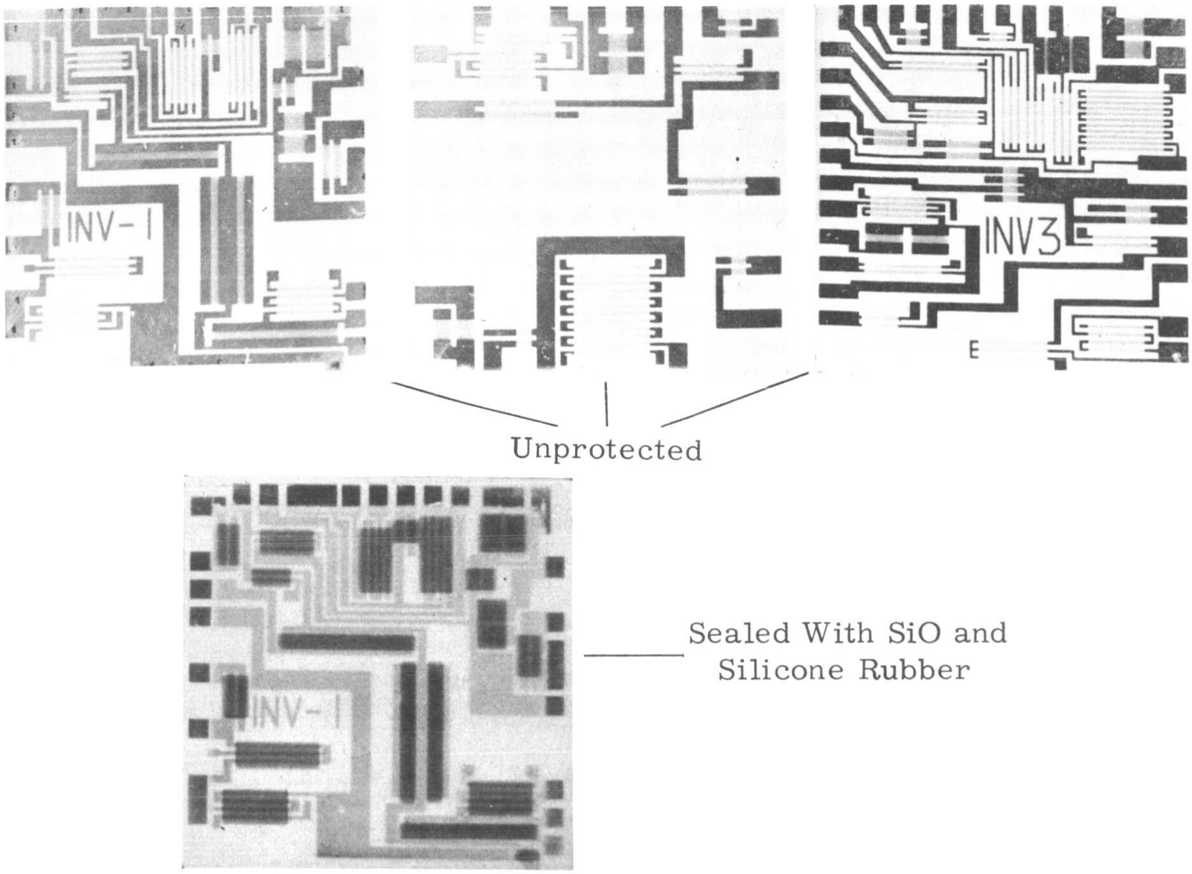


Figure 17. Thin Film Circuits

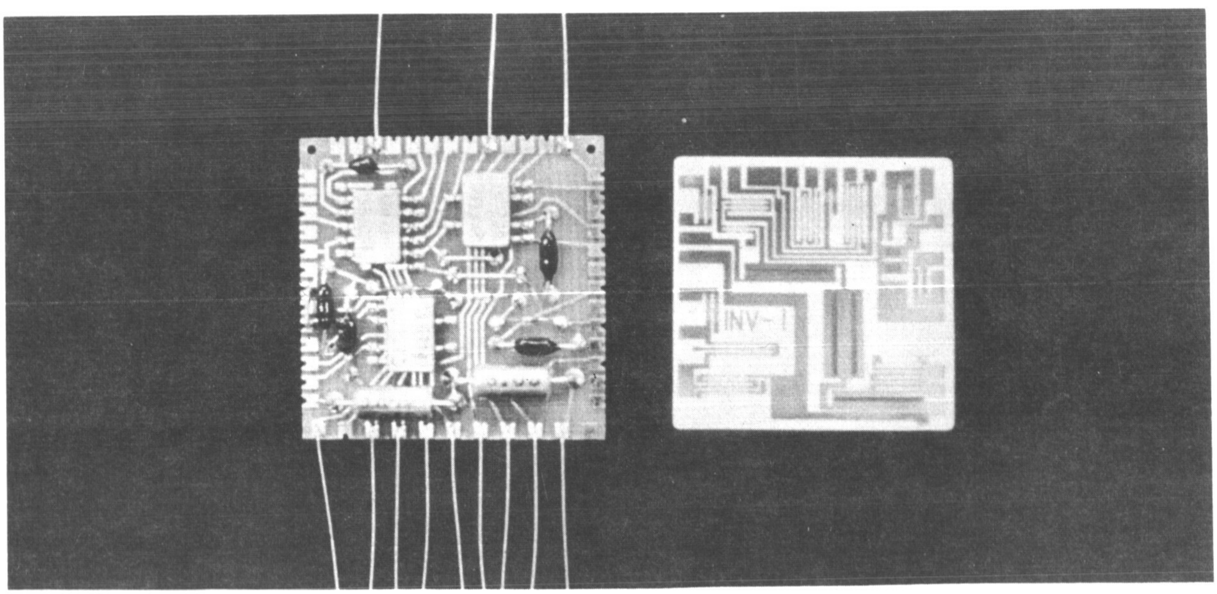


Figure 18. Two Parts of Hybrid Circuit: Printed Circuit Board and Thin Film

circuits are a portion of the Inverter circuit and will be interconnected along with a discrete component board and power transistor assembly to form the complete Inverter module.

Printed circuit boards are fabricated using conventional techniques. The copper circuitry is hot tin dip coated to improve solderability and to protect the circuits against oxidation.

All discrete components are either butt soldered or lap soldered to the printed circuit boards. Interconnection leads, 0.012 inch in diameter gold plated Dumet and 0.002 inch diameter gold plated OFHC copper, are also soldered to the printed circuit board prior to attachment of the thin film circuit. This assembly technique has the advantage that all soldering may be done before attachment of the thin film circuit and no solvents, flux, or contaminants come in contact with the thin film surface.

The thin film substrate and printed circuit assembly are then bonded together in back-to-back fashion using a silastic adhesive (Dow Corning-140). This material was selected for its stability over a wide temperature range. The small interconnection leads (0.002 inch gold plated OFHC copper) are then formed through the protective notches at the edge of the printed circuit board and bonded by thermal compression to the thin film circuit pads to complete the hybrid assembly (Figure 2). A longitudinal and transverse cross section of this bond is shown in Figure 19.

## C. MODULE TEST AND ASSEMBLY

Steps 13-19 pertain to the discrete component board assembly and to the module assembly. This module contains a power transistor assembly which is mounted directly to the heat sink. This assembly, a printed circuit component board, and the three hybrid assemblies, are tested prior to interconnecting in the module. The select value resistors are determined and installed along with select value capacitors. The circuits are electrically tested at room temperature and then temperature cycled over the range of -55 to +125°C. After completion of module test, the hybrid circuits and component boards are assembled on the module base board. Interconnections are made through the printed circuit base board at the bottom and cross wire welded with nickel wire at the top.

## D. CONFORMAL COATING AND ENCAPSULATION

The section of the module containing the hybrid circuits and discrete component boards is dip coated with RTV silicone rubber (Figure 20). This RTV silicone rubber provides a conformal coating for the leads and components. This dipping operation is repeated until sufficient coating thick-

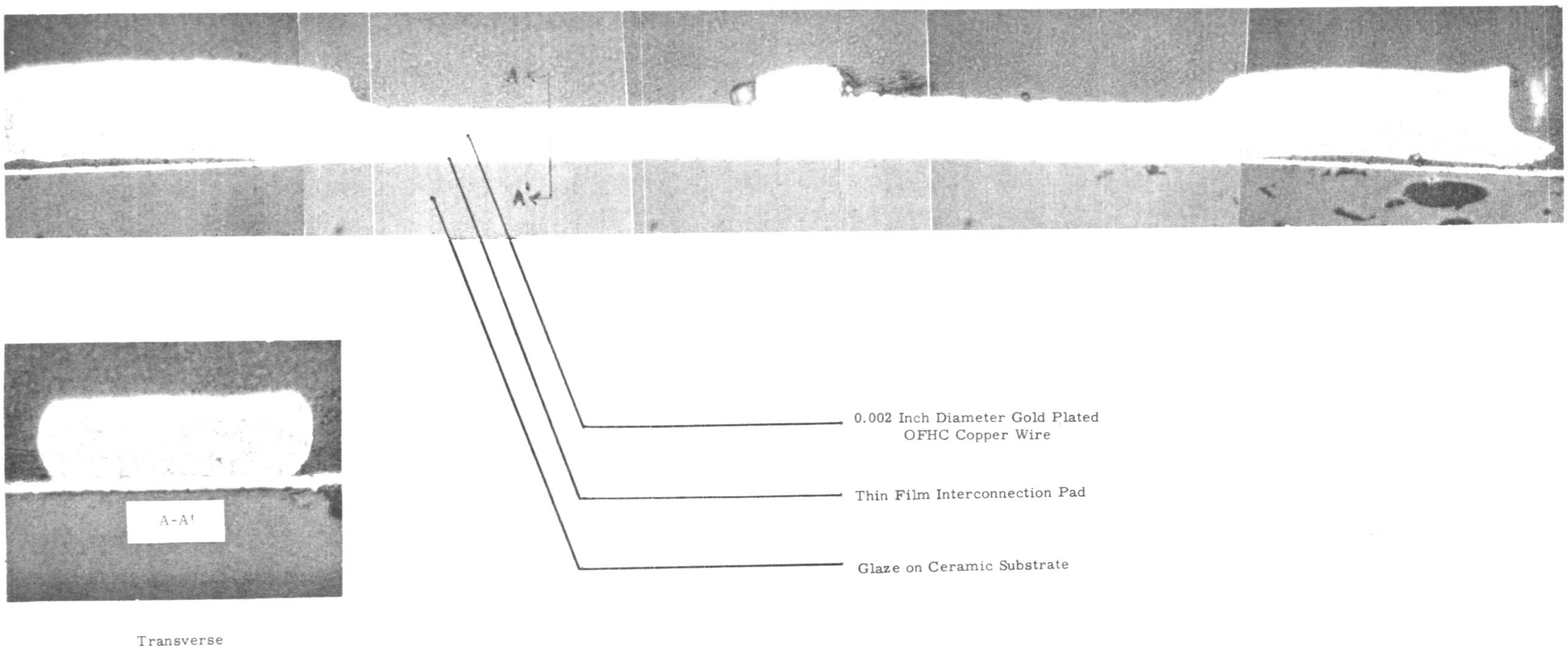


Figure 19. Microsection of 0.002 Inch Diameter Wire Bonded to Thin Film Circuit

Dup.

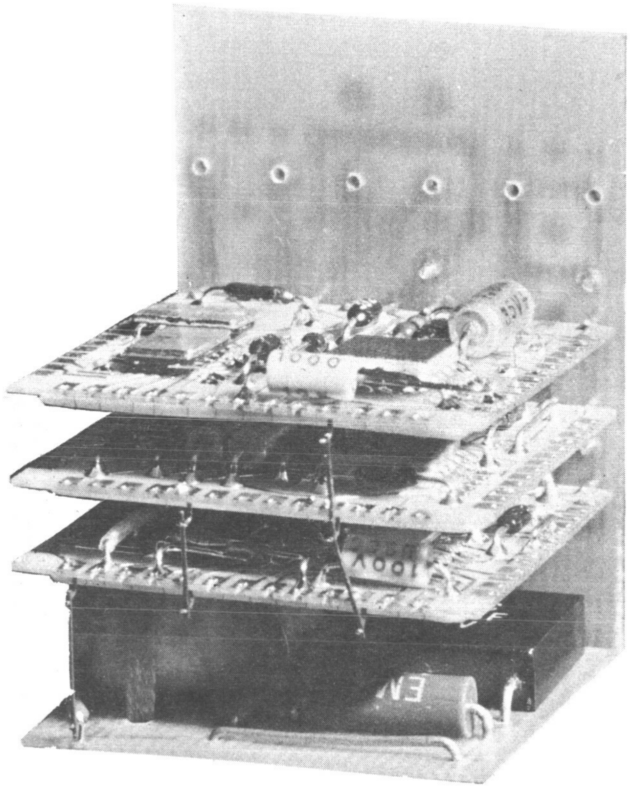

Figure 20. Hybrid Module Assembly Showing Three Interconnected Hybrid Circuits and Discrete Component Board

ness is obtained. General Electric RTV 616 silicone rubber is used for this conformal coating. General Electric RTV 615 is also acceptable, the main difference being that it is clear while RTV 616 is opaque. After conformal coating, the power transistor-heat sink assembly is attached to the module and the complete circuit is then retested. This test is performed to ensure proper operation of the module just prior to encapsulation. The module is then encapsulated with Minnesota Mining and Manufacturing "Scotchcast CRP 241 semi-rigid epoxy.

## APPENDIX

A dynamic analysis was conducted on the ACSP Inverter module. The main concern was to check the feasibility of using a nonencapsulated module.

## ANALYSIS

All transfer functions used in deriving the environment for the module have been assumed through use of the data collected during the vibration tests of the Phase IV ACSP unit.

| Transfer Function | Axis |
|---|---|
| 8 | X |
| 4 | Y |
| 8 | Z |

Natural frequencies have been calculated for the miniature motherboard and the printed circuit boards. A frequency range is shown below for the three major axes. See Figure 8 for orientation.

| Specimen | Axis | Frequency Range (c/s) |
|---|---|---|
| Inverter module | X | 450 - 475 |
| Miniature motherboard | X | 400 - 425 |
| Miniature motherboard | Y | Out of test range |
| Miniature motherboard | Z | 950 - 1050 |
| Printed circuit boards | X | Out of test range |
| Printed circuit boards | Y | 1500 - 1600 |
| Printed circuit boards | Z | Out of test range |

The dynamic deflections are shown on the following page. All of these deflections are for the beam or plate modes of the miniature motherboard and printed circuit boards.

| Specimen | Axis | Deflection (in. DA) |
|---|---|---|
| Miniature motherboard | X | 0.022 |
| Miniature motherboard | Z | 0.035 |
| Printed circuit board | Y | 0.035 |

The predominate stiffness of the module has been calculated to be 7830 lb/in. in the X axis. The classic spring/mass technique was used from which a natural frequency of 464 c/s was calculated.

In calculating the shear across the pins in the bottom of the module a pinned-clamped beam model was used. The shear across the No. 6 screws holding the module to the channel was also calculated using the same model. The shear across the leads of the printed circuit boards was calculated using a pinned-pinned beam model. For results of shear calculations, see below.

| Specimen | Static Shear (psi) | Dynamic Shear (psi) |
|---|---|---|
| Pins module - motherboard | 13.65 | 2620 |
| Leads PC board - miniature motherboard | 7.52 | 1625 |
| No. 6 screws through channel | 7.69 | 738 |

## CONCLUSION

The tops of the printed circuit boards should be stabilized. This could be accomplished by routing a groove in the aluminum for each board and using some form of adhesive. Similarly the bottoms of the printed circuit boards should be mounted in such a manner as to be considered a hinged end condition. The deflections in the suggested system would be minimal.