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MANUFACTURING TECHNOLOGY STUDY ON RADIO FREQUENCY POWER MODULES--ETC(U)
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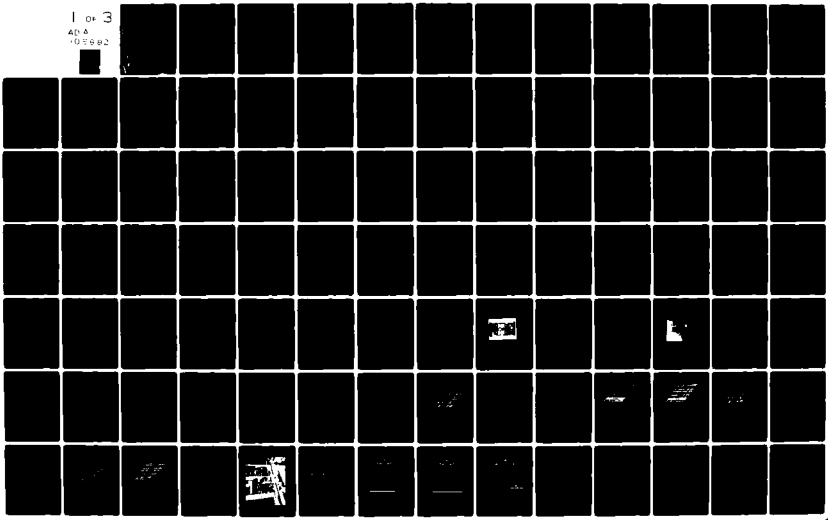

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MANUFACTURING TECHNOLOGY STUDY

ON RADIO FREQUENCY POWER MODULES PACKAGING TECHNIQUES

CONTRACT N-00039-79-C-0378

FINAL REPORT

COVERING THE PERIOD

SEPTEMBER 1979 TO JUNE 1981

PREPARED FOR:

NAVY DEPARTMENT - NAVAL ELECTRONIC SYSTEMS COMMAND

WASHINGTON, D.C. 20360

PREPARED BY:

GENERAL ELECTRIC COMPANY
ELECTRONIC SYSTEMS DIVISION
MILITARY ELECTRONICS SYSTEMS OPERATION
SYRACUSE, NEW YORK 13221

REQUISITION EH-88334

(6) MANUFACTURING TECHNOLOGY STUDY

ON RADIO FREQUENCY POWER MODULES PACKAGING TECHNIQUES.

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ABSTRACT

SCOPE - Program requirements cover manufacturing methods and technology encompassing a determination of materials, processes, and related techniques to improve producibility thereby enhancing manufacturing methods to achieve a significant reduction in production cost of R.F. Power Amplifier Modules. The requirement includes the fabrication and test of proof of process of 25-100 watt R.F. Microwave Hybrid Modules. The foregoing amplifiers featured the enhanced materials, processes, and techniques evolved under this program which achieved reduction of total cost of product.

The achieved design is directly applicable to the production design of the AN/TPS-59 Solid State Radar system with direct benefit to a wide family of other Solid State Radars and other systems which may use similar R.F. Power Modules. Because several hundred of these R.F. power modules are used per system, the cost savings resulting from this program are significantly multiplied and provides a very favorable payback on MM&T investment.

APPROACH/SOLUTIONS - At the outset of the program, the materials, manufacturing and test/tune methods being used for fabricating power modules at that time were reviewed with respect to their yielded final cost. This resulted in identifying the following specific areas for improvement development work: All of the peripheral processes related to the Direct Bond Copper process, the hermetic glass seal between the ceramic frame and the substrate, the lid seal process and the final testing and tuning method.

RESULTS - Many of the improvements resulting from this program have been implemented at the General Electric Company - MESO Hybrid Facility in Syracuse, New York for the present production of AN/TPS-59, SEEK IGLOO, U.K. and Q.M. Solid State Radar Systems. A very favorable payback ratio of 69.9:1 was achieved on the MM&T investment.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES, EXHIBITS AND APPENDICES

LIST OF FIGURES, EXHIBITS AND APPENDICES (Cont'd)

APPENDICES (Cont'd) PAGE

1. SCOPE

Program requirements cover manufacturing methods and technology encompassing a determination of materials, processes, and related techniques to improve producibility thereby enhancing manufacturing methods to achieve a significant reduction in production cost of R.F. power amplifier modules. The requirement includes the fabrication and test of proof of process assemblies as follows:

Quantity 25 each R.F. Power Module (100 watts, minimum) for use in Radar Set AN/TPS-59.

The foregoing amplifiers feature the enhanced materials, processes, and techniques evolved under this program which thereby achieve reduction of total cost of product. The achieved design shall be directly applicable to the production design of the AN/TPS-59 radar set with direct benefit to a wide family of Solid State Radars (SSR) and other systems which may use similar R.F. Power Modules.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect September '79, form a part of this program to the extent applicable:

MIL-STD-490: Specification Practices

MIL-STD-1556: Government/Industry Data Exchange Program, Contractor Participation Requirements

2.2 Dwg. No. 77C716283 Rev. "B" - R.F. Power Module - Appendix "A"
Dwg. No. 77A100244 dated 11 Nov.'80 Specification - Appendix "B"

3. REQUIREMENTS

3.1 Background. The impact of establishing this new technology will be on the acquisition cost of SSR's such as AN/TPS-59, Seek IGLOO, UNITED KINGDOM, QM and others which may be purchased by DOD or its Allies. Of course, systems such as IFF and TACAN which may also use such R.F. power modules may also benefit from the results of this program. Because several hundred R.F. Power Modules are used per system, the derived cost benefits are significantly multiplied providing good payback potential.

3.2 Related Development. We are presently in production on the subject 100 W. R.F. Power Modules and have carried out this MM&T program in parallel. Consequently most of the developed improvements have been implemented on present on-going production product.

3.3 Approach/Solutions. At the outset of the program, the materials, manufacturing and test/tune methods being used for fabricating power modules at that time were reviewed with respect to their yielded final cost. The specific areas identified for improvement development work were:

A. All of the associated peripheral processes related to the General Electric Co. patented Direct Bond Copper (DB Cu) operations. See Appendix "C" for a description of the DB Cu process.

B. The air fired hermetic glass seal between the ceramic frame (or wall) and the substrate; change to a nitrogen fireable glass.

C. The presently used solder clad F-15 Alloy (KOVAR) lid; change to a plain nickel plated F-15 Alloy lid.

D. The manual testing and tuning of the module; change to a semi-automated test/tune system.

To verify the reliability of these improvements build 25 electrical working modules incorporating these improvements and subject them to the full qualification tests to verify that the product has not been compromised by virtue of these changes.

Each of the above five tasks were broken down into subtasks for milestone scheduling and reporting in conjunction with the written monthly reports (Exhibit "A" five sheets, typical set of monthly milestone reports).

The objective of performing all of the tasks described below is to reduce the total cost of producing 100 W. R.F. Power Amplifier Modules thereby reducing the acquisition cost of SSR systems. The approach to reducing costs encompassed a study of the basic materials used for fabricating the modules, looking at the material cost vs the function it performed. Manufacturing methods were also studied with relation to labor cost for achieving desired function. Total manufacturing cost has to include the costs associated with yield losses, level of skill required to perform tasks and other uncontrolled labor variables. As a result of these initial cost studies, the paragraph 3.3.1 MM&T tasks and subtasks were identified for development activity.

3.3.1A DB Cu Peripheral Process Improvement Subtasks

To aid the reader in identifying the tasks a photograph (Fig. 1) of the assembled 2" x 3 1/2" module is shown without its lid. Figure 2 is a sketch more specifically showing the DB Cu elements of the package. Three mil DB Cu is applied in separate operations to the bottom ground plane of the substrate and to the top of the ceramic frame. The DB Cu process is also used for the 16 ground feed through pin connections of the thick film copper microstripline circuit to the ground plane (see Fig. 3).

Additional DB Cu associated work is required for obtaining R.F. shielding along the two 3" long sides of the ceramic frame. This shielding is accomplished by making use of the technique in direct bond copper which permits unbonded sheet copper to overhang the bonded surfaces. Using this feature, the ceramic frame is bonded with overhanging copper along its sides. By using direct bond copper on the bottom of the substrate for the ground plane and allowing it to extend beyond the sides of the substrate, we subsequently (after glass sealing of ceramic frame to substrate) lap-solder join the bent-down unbonded sheet copper from the top of the ceramic frame to join the bent-up unbonded copper sheet from the bottom of the substrate. This technique very effectively provides shielding along two sides of the module.

Although the DB Cu process was implemented on the modules being built at the outset of this program, there was excessive labor and yield cost associated with these processes. The actual bonding operation consumes very little time, the major labor effort was in preparation (cleaning and pre-oxidizing) and trimming after bonding.

Therefore, to meet the program's objective of enhancing the producibility of the module, the DB Cu process steps identified as having potential for improvement were listed and given further study. After performing an initial screening of the many areas identified for possible improvement, five subtasks were selected for development. The below listed subtasks were selected on the basis of technical feasibility of successful implementation within the limits of the time and funds available under the contract.

3.3.1A1 Improve the methods for cleaning and chemically oxidizing copper prior to DB.

3.3.1A2 Pre-blank copper sheet to final size and develop fixturing for proper location to ceramic.

3.3.1A3 Replace cylindrical copper ground feed through pins with spherical copper feed throughs.

3.3.1A4 Improve the method for removing the copper oxide formed after air firing glass seal.

3.3.1A5 Automate feed through pin continuity test.

3.3.1B <u>Change from Air Fired Sealing Glass to Nitrogen Fired Glass</u>

Considerable time was required, and yield loss occurred in the outset process of deoxidizing both the thick film and direct bond copper after glass sealing. Oxides are formed when the metalized ceramic frame is hermetically glass sealed to the metalized substrate with an air-fired crystalized glass at $400^{0}C$ plus (Figure 2). It was proposed and the task defined to develop a class of low-temperature crystalizable glasses which are fireable in nitrogen. If successfully implemented, considerable labor savings would accrue and yield loss would be reduced by virtue of eliminating the chemical etching and mechanical abrasion required to remove the oxides to render the copper solderable. It was recognized that improved control and inspection would be required for this development to assure that losses do not occur later in processing or, more seriously, that they do not occur much later in the field.

To develop an improved glass seal material and process, the task was split into two subtasks:

3.3.1B1 Search literature for possible improved glasses and/or processes and evaluate.

3.3.1B2 Develop test method for evaluating candidate glasses.

3.3.1C Change lid from solder clad Alloy F-15 (KOVAR) to plain plated KOVAR. As previously stated (paragraph 3.3.1A), we have already implemented the process for applying direct bond copper to the top of the ceramic frame, which is later followed by a solder dip operation coating the entire substrate assembly, including the top sealing surface of the ceramic frame, with solder. Our present process uses a KOVAR lid clad with solder on the sealing side for making the final hermetic seal (Figure 2). It is proposed that plain nickel-plated KOVAR alloy lids be used, since there is ample solder on the sealing surface from the solder dip operation. The cost savings which would accrue by this development would be in materials. We presently procure this solder clad KOVAR alloy as a custom-made material at considerable extra cost, plus long lead time. The successful implementation of the plain KOVAR lid approach will reduce material cost and lead time, and provide a seal with greater integrity due to less solder at the seal interface.

3.3.2 Develop improvements in the semi-automated test/tune software and integrate into hardware. The equipment in place at the outset of this program was a manual test station for tuning modules requiring approximately five hours for complete alignment and testing of a module. This total evaluation time consists of:

1. Initial tune and placement of necessary tuning elements.
2. Evaluation of finalized soldered circuit adjustments.
3. Complete preseal data evaluation.
4. IR scan of transistor junctions.
5. Postseal data verification.
6. Signal time delay measurement.

This sequence was accomplished by movement of each module through two separate test stations and an IR microscope position. On a large percentage of amplifiers, two tuning iterations had to be accomplished before junction temperature and/or phase performance specifications were met. The movement of modules between test stations and the accompanying multiple set-up operations are large contributing factors to total test time. The set-up used separate analog voltage, current and power measuring instruments. All wiring and cabling was accomplished at the front of the instrumentation and most instrument adjustments were analog. The test method and procedures were not efficient, in that they require many hand movements and visual operations at several points in the overall tuning and testing program. Among these were the setting of five discrete frequencies at several points in the tuning and testing cycle, switching to a swept mode after each step to assess changes on overall circuit performance, switching to various pulse width/ duty cycle templates, multiple instrument settings to determine spectral and harmonic rejection performance and multiple frequency time delay evaluation. In addition to these measurements, the operators had to constantly check their equipment manually to reset for the effect of temperature and instrument drift, and monitor and set analog voltages and current levels.

After data had been collected and recorded manually, it was reduced and certain parameters such as efficiency and junction temperature computed from the raw data. This was done manually using a hand calculator with all data recorded on data sheets.

The task defined under this contract was to utilize the contractor-furnished semi-automated module tuning, testing and data collection system facility to develop methods and processes for use with the R.F. power module. This was to be accomplished in conjunction with the qualification testing and evaluation of mechanical and R.F. module samples specified in paragraph 3.3.3.

The judgment factor and decision making requirements of the tuning procedure will require continuous operator-equipment interface and will probably remain largely a manual operation. The equipment level setting, template selection and data accumulation will be automated whenever possible or reduced to a single pushbutton operation.

The entire tune and test sequence will be controlled by a microprocessor programmed to interact with the station operator. In conjunction with the microprocessor, we will use programmable test equipment controlled and interconnected through a digital bus system. This will allow voltage levels, frequencies, signal levels, pulse widths, repetition rate and other system parameter levels to be pre-set according to software instructions. After initial settings, readings can be monitored by a program subroutine initiated by a pushbutton command of the operator at various time intervals in the test sequence. During the tuning portion of the sequence, small metal tabs are added to various areas of the circuit and the swept power output versus the frequencies monitored to note the effect of these additions. After tuning for power, the frequency response of the input impedance match and the signal time delay are checked to insure that specifications have been achieved.

This sequence is repeated until all specifications have been met. With the proposed method, input match and phase data would be measured and stored in the computer memory and would be called up instantaneously by the operator during tuning. Each time a tuning operation was performed, all parameters would be remeasured at the command of an operator pushbutton, and the up-to-date information restored. The stored information can then be displayed on a CRT data terminal, continuously or at pushbutton command. The operator can thus measure and monitor all affected parameters as he tunes and will not have to monitor these parameters sequentially. When tuning is complete, the operator can, by a pushbutton, start a complete data sequence and the information will be stored after comparison with previously programmed go/no-go limits. Minimal data will be printed out for daily update of station output. The IR scan procedure will remain a manual operation, since placement of the microscope cross-hairs and position of the instrumentation at the proper cell location are essential to accurate readings. Once the position of the hottest cell and the frequency at which the cell temperature peaks are located, a pushbutton command will store data.

At the conclusion of all data collection, the software can be used to compute the module efficiency versus frequency and convert the IR microscope voltage output to temperature readings.

To accomplish the above test/tune improvement objectives, the following subtasks were identified:

3.3.2.1 Complete individual software modules.

3.3.2.2 Interface each software module with instruments.

3.3.2.3 Perform partial systems test of software/hardware.

3.3.2.4 Test complete system using all instruments and software.

3.3.3 Verification of Program Goals - The final activity of this program was to demonstrate that the reliability of the product was not compromised by virtue of the developed changes. This was accomplished initially by appropriately excess stress testing mechanical samples of the modules at each subtask development phase. At the end of all the development work, 25 operating modules were constructed and subjected to the full qualification tests per "Qualification Procedure - R.F. Power Amp #77D609955" attached as Appendix "D". Paragraph 3.3.4.3 details results of the qualification testing.

3.3.4 Solution, Results and Benefits

3.3.4.1A DB Cu Peripheral Process Improvements Subtasks.

3.3.4.1A1 Improve the Methods for Cleaning and Oxidizing Copper Prior to DB.

The method employed, at the outset of this program, for cleaning and oxidizing copper comprised using 8 successive wet chemical process steps. Standard laboratory ware was used which limited the batch size and caused the 3 mil copper sheet to lose its initial flat shape. The method was basically still at a chemical laboratory stage.

In order to improve the producibility of this processing method, several options were considered and investigated. First, we considered and ruled out the feasibility of using less than 8 wet chemical process steps. The necessity to remove finger soil and/or machining/rolling oils then activating the surface for subsequent uniform chemical oxide formation together with associated rinses precluded the reduction of process steps.

Another investigation was made into the improvement possibilities of forming an oxide on copper thermally. Various thermal equipments were evaluated; hotplate, carbon block heater, belt furnace and box oven using many thermal profiles. The oxides formed were unacceptable for DB Cu application, they were too brittle flaking off in handling and/or too non-uniform. No further work was done in this area.

Work was now concentrated in improving the efficiency of the wet chemical process. Initially stainless steel wire teflon coated baskets were designed and built for holding 60 - 3" x 4" sheets of copper. Special tanks to accommodate these baskets were procured. This effort proved that the batch size could be increased without adverse effect. At this time, we undertook the development of a semi-automatic wet chemical processing equipment. The resulting equipment (Fig. 4) provides a microprocessor controlled programmable trolley mounted over a row of tanks to automatically perform the successive wet chemical clean and oxidize operations. The tanks provide heat and control the temperature of solutions as required. The automatic machine removes possible operator variables resulting in more reproducible product also resulting in higher DB Cu process yields.

At the time of this writing, the machine has not been proven out in production although satisfactory dry runs have been made. This extreme delay has been caused by the need to completely revamp our hybrid chemical area and provide a safe exhaust facility to accommodate this new equipment. We have high confidence that all the manual labor will be reduced for performing the copper clean and oxide operation outside of the load and unload operation. Shortly, when the equipment is implemented for on-going production, all the operator will have to do is load the large batch basket with copper blanks, push the start button and unload baskets when the equipment signals completion of the cycle. The operator will be free to perform other work during the interval between load and unload.

3.3.4.1A2 Pre-blank Copper Sheet to Final Size and Develop Fixturing for Proper Location to Ceramic.

The need to develop a means of accurately pre-blanking the 3 mil copper sheet used on top of the ceramic wall and on the bottom of the substrate arose from the high level of manual labor required to trim to size the excess copper extending from the ceramic after the DB Cu operations. The approach to reduce this labor factor was to pre-cut the copper to its exact size prior to bonding when either a high speed punch press or multiple pattern etching means can be used. Then develop locating fixturing for precisely placing these copper blanks with respect to ceramic features. The following work was done to complete this task.

The correct blank size had to be developed allowing for the growth of the copper sheet after DB. No previous data could be used for this correction factor and a basic data base had to be accumulated from a series of experiments. Eventually the correct size was established and verified using etched blanks having a correction factor of 10 mils per inch for the ground plane copper (see Appendix "E" and "F"). The correction factor required was found to be less for the ceramic wall blanks (see Appendix "G" and "H"). Hundreds of verification DB Cu trial runs plus many artwork iterations were required to obtain the required design information. Having this information, quotes were requested for 5000 each blanked copper parts made either by punch and dies or by multiple pattern etching. The most favorable priced part was the punched part at $0.08/ea ($4,000 tooling) vs etched part at $2.83/ea ($600 tooling). The punched part was purchased and is now being used in production.

In parallel, fixturing work went on to develop a means for locating the copper blank with respect to certain features in the ceramics. The location of the ceramic wall copper blank with relation to its features is not critical and is accomplished rapidly visually by sighting the four corners. Substrate relative location is more critical and required locating fixture development. The final implemented fixture was comprised of a steel plate with 3 pins picking up the location of the transistor holes in the substrate and also co-locating the matching 3 holes in the copper blank. This locating is done on top of a fire brick carrier which is lifted off the steel plate and loaded into the belt furnace for the DB operation.

Another punch and die was developed for blanking out the inside portion of the copper bonded to the top of the ceramic wall. First, a hand operated soft punch and die was made to verify feasibility and size. Special precautions were required to assure that the ceramic walls are not stressed and/or cracked during this blanking operation. Size and feasibility was verified and an air operated bench press equipped with hard dies was purchased and is now implemented in production.

Other small tools also have been implemented which were developed to reduce labor and enhance producibility. These aids consist of a custom shear for trimming the excess copper off the ends of the substrates and the ceramic walls. The specified ceramic substrate tolerance permits variations in length in excess of 30 mils which does not permit specifying a copper blank length dimension such that it is exactly flush with the substrate ends as required for proper grounding. This need for post bond trimming precludes the complete elimination of trimming after bonding. However, the simple tooling expedites this operation while the major trim operations are completely eliminated. Another small tool which tightly folds the DB Cu along the sides of the ceramic wall was also developed and implemented.

3.3.4.1A3 Replace Cylindrical Copper Ground Feed Through Pins with Spherical Copper Feed Throughs.

The R.F. Power Module design makes use of 16 very low impedance grounding pins interposed between the thick filmed copper microstripline circuit and the 3 mil DB Cu ground plane. The holes in the 25 mil thick ceramic substrate are 60 mils in diameter and it is desirable to fill these holes with copper (at least 75%). From the outset, copper cylinders 55 mils in diameter by 30 mils long were used for this purpose using the DB Cu for fusing the pins to the ground plane. Subsequently, the R.F. topside circuit is connected to the flushed pin top via the thick film copper printing process. This procedure for making extremely low impedance ground connections has proven to be reliable and superior to the alternate conventional wraparounds. Like many desirable things, the cost can sometimes be high. The machined cylindrical pins cost $0.31/ea in thousand piece quantities and the manual labor for individually placing 16 pins in holes is also high. As a result of this program, an improved method for accomplishing this function was developed and implemented as follows:

It was agreed that copper spheres could be most easily handled for mass placement of 16 feed throughs at a time by vibratory or vacuum pick and place equipment. In parallel, tooling and sphere source activity was commenced. Finding a source for copper spheres and determining correct diameter was more difficult than expected. The first two sources evaluated produced non-uniform, non-spherical and non-solid spheres which yielded, as would be expected, non-uniform results. Finally, a third source was found which could produce solid copper spheres to precise diameters (Lucas Milhaupt Co.) using a coining and grinding process rather than a "shot" process.

Both 0.055" and 0.065" diameter spheres were evaluated for our use as a feed through replacement. The automatic vacuum pick-up placement tooling for rapidly placing all 16 feed throughs simultaneously worked very well. However, developing the technique for direct bonding was difficult and slow. The following was observed. When an 0.055" D sphere is placed in the 0.060" D hole in our 0.025" thick alumina substrate, it does not completely fill the hole (we calculate that the hole volume is equivalent to a 0.052" D sphere - Fig. 5). Instead, the spheres project out of the top and bottom surfaces of the substrate which will require the labor of a lapping operation for further use. It appears that the sphere has to be in initial contact with sides of the substrate hole in order to wet and fill the hole. This is proven when the 0.065" D spheres (Fig. 6) are placed in the holes, we get complete fill but some projection from the surfaces since the sphere volume is greater than the hole volume. Work on reconciling these observations towards developing an optimum feed through process was done weighing the producibility effects of the various options open to us.

It was decided to use a 0.063" diameter sphere for making feed through connections (see Appendix "I"). Lapping off excess feed through copper will be required with this size sphere, but it was also required for the cylindrical feed throughs it replaces. Therefore, no extra cost for lapping is involved with spheres. The trade-offs favoring the use of the 0.063" diameter copper spheres are as follows:

a. The hole is 100% filled.
b. Spheres are automatically placed.
c. Using smaller spheres to eliminate lapping requires special pressing operation to squeeze out spheres to contact sides of holes.
d. Present cylindrical pins do not fill hole completely, they require lapping and cost $0.31 ea. (spheres cost less than $0.02 ea.).

The DB Cu sphere feed through process is now implemented in our production R.F. Power Module build using the developed vacuum pick and place tool for applying 16 spheres in one operation. To further improve the producibility of the sphere feed through process, a separate study was made to improve the manually performed operation of lapping the excess portion of the copper sphere protruding from the substrate surface. Techniques investigated and ruled out as not applicable were electrical discharge machining (EDM), surface grinding and machining with a milling machine.

The approach which showed most promise makes use of a lapping machine wherein multiple quantities of substrates could be lapped to some pre-set level. The operators duty would then be to load and unload the machine with the abrasive material automatically fed and a built-in timer to shut down the operation and signal completion. A machine meeting these requirements is made by P.R. Hoffman Co. Arrangements were made for trials at their plant which proved feasibility. An appropriate machine model was selected and recommendations made for abrasives and tooling to be used for best results. A "PR-1" Hoffman planetary lapping machine with the recommended abrasive and tooling was procured recognizing the need for additional application work when the machine was installed in our Facility.

Initial results of lapping work done in our Facility showed a labor reduction of 50% vs manual lapping. However, as larger lots of substrates were run on the machine with production operators, results were found to be very inconsistent. We also realized the need for improved work holders necessitated by the overhanging 3 mil DB Cu ground plane. Several different abrasives which appear to cut copper more rapidly have been evaluated with no final selection made. Development activity still continues in this area since we strongly believe that implementing this lapping method will improve the producibility of the process.

3.3.4.1A4 Improve the Method for Removing the Copper Oxide Formed After Air Firing Glass Seals.

The development work reported below was considered a back-up parallel effort with the work in developing a nitrogen fireable glass seal (results reported in section 3.3.4.1B) since the successful implementation of a nitrogen fireable glass seal would obviate the need for removing the heavy copper oxides formed when the glass is air fired. We recognized at the outset that the probability of successfully developing a nitrogen glass was low, thus the back-up effort.

The work in improving the copper oxide removal process was approached with extreme care because of the possible interaction effects that any new process may have on all the other materials used in the module, i.e., efficiency of removing copper oxide alone cannot be the criteria. The resulting effects of any proposed new process had to be weighed with respect to the influence they might have on copper film adhesion, conductivity, solderability; the effect on printed thick film resistor values and their life stability; the effect on glass seal strength and alumina substrate and wall.

The copper oxide cleaning process in place at the start of this program and which was to be improved comprised: several cleaning processes and rinses for removing greases followed by a mild copper etch to undercut the oxide, then rinses and finally careful manual abrasion to remove whatever loosened oxide remains. This process was time consuming and subjective on the part of the operator. Too much etching and too active abraiding results in defective products which often were not detected until completion of final assembly when considerably more labor was expended. Accordingly, improvements in this process were sought through many exploratory paths as follows:

a. Ultrasonic cleaning - Representative oxidized parts were sent to various equipment companies for their application laboratory evaluation. All reported that their equipment would not do the job.

b. Vapor blast - shot blast - sand blast - Same as (a).

c. Plasma etching - Using the facilities in place at our semiconductor operation in Syracuse, feasibility experiments were run with help of a well experienced process engineer to establish whether this relatively new technique could advantageously be used. Results were poor even with the use of hydrogen. After several attempts using different gases and gas mixtures, we concluded that plasma etching was not the way to go.

d. Hydrogen reduction - Considerable work was done with this approach in view of the very promising results achieved in our first trial. Using an available belt furnace with a forming gas atmosphere (30% H_2 - 70% N_2) set at a peak temperature 420^oC and belt speed 4.75 inches/min. we were able to effectively clean up a group of 5 extremely oxidized modules in one pass. They readily wetted with 62/36/2 (tin/lead/silver) solder and did not exhibit any evidence of attack by the hydrogen. There was evidence though that the adhesion of the thick film copper was diminished and that the thick film printed resistors shifted in value after hydrogen reduction. In view of the simplicity of this process, work was continued in trying to overcome these two problem areas (adhesion and resistor shift). Experiments were conducted to determine whether the furnace temperature profile could be reduced to diminish hydrogen attack and yet adequately clean (de-oxidize) the copper. Additionally, we investigated another paste vendor's copper conductor and resistor paste materials to determine their hydrogen affects. To quantify this effect, we first looked at the bond strength by performing pull tests on DuPont 9922 thick film copper pads printed with a standard pull test pattern. Substrates which had not been subjected to a hydrogen atmosphere showed an average bond strength of 3.5 pounds whereas specimens subjected to a reducing hydrogen atmosphere degraded to an unacceptable bond strength of less than 1 pound.

In an effort to reduce this degradation, we next tried reducing the temperature from the original 420°C to 365°C and also reducing exposure time by increasing belt speed from 5 inches per minute to 10 inches per minute. These parameters were shifted in six steps. The resulting pull test data for the range of parameters (18 test points per temperature/speed parameter) did not show any dramatic change. The temperature/speed change also did not diminish the effectiveness of copper oxide removal. All specimens were readily wetted by mild fluxing and dipping in a 62 Sn/36 Pb/2 Ag solder pot. Later, more work was done at lower temperatures and/or higher speeds to determine the lower limits of the hydrogen reduction process for removing copper oxide without degrading bond strength.

To expedite this investigation, a belt furnace in our facility was modified to handle forming gas (mixed Nitrogen and Hydrogen) to enable us to complete this development. After several iterations a gas mixture, temperature and belt speed was developed to minimize the affects on the thick film copper and resistors but it was also found that these process conditions did not result in fully removing the oxides from the DB Cu. More development work was done resulting in a process having the parameters: 350°C peak temperature, 15% hydrogen - 85% nitrogen reducing gas, belt speed of 1 1/2 inches per minute and requiring two passes in the furnace.

A similar investigation was made for copper compatible nitrogen fired 10 ohm and 1,000 ohm resistor pastes made by Dupont and Cermalloy. These types of pastes are used on the subject R.F. Power Module and accordingly investigated for effects. The effect on the four resistor materials of hydrogen reduction at 420°C and 4.75 inches per minute are acceptable for our process and can easily be laser trimmed to value. The data shows that after a severe two firings that the DuPont 1,000 ohm paste shifts by +0.5 and 0.57% and the 10 ohm paste shifts +7.5 and 8.1%.

Thus, the end result of the hydrogen reduction process development program was a process using an extremely slow belt speed which consumes a large amount of forming gas per module to be cleaned. Essentially, what was accomplished at this point was to establish that it was feasible to use hydrogen for cleaning without significantly affecting thick film copper, resistors and DB Cu. It now remained to see how cost effective this changeover would be. In this connection, we investigated the use of a reducing atmosphere box oven in lieu of a belt furnace. The assumption being that gas consumption would be lower and that large batches could be handled at one time only requiring load and unload labor. We were not successful in finding a commercially available reducing atmosphere box oven with a 350°C temperature capability leaving us only the belt furnace for performing copper oxide cleaning. For a brief period, the belt furnace was implemented in production to gain operating data and experience. This resulted in a clear indication that the process was not cost effective, gas cost was prohibitively high as was labor.

e. Chemical oxide reduction - In parallel, we investigated an alternate chemical oxide removal process. This process uses phosphoric acid with surfactants and easily removes the oxide by a simple dip operation requiring no manual abrasion. Preliminary tests indicated that the thick film copper had better conductivity after cleaning with the phosphoric acid solution than with the old chemical cleaning process. A negative aspect of the phosphoric acid is that is destroys the thick film resistors. However, a resist coating over the printed resistors did protect them during cleaning. Further evaluation trials revealed that the phosphoric acid solution (OAKITE-31) was an excellent low cost means of removing copper oxide. Further testing of this process indicated that the bond strength of the thick film copper is not compromised; in most cases, it was found to be higher than our original process. An accelerated high temperature aging test was performed to attain assurance of process realibility. Results of these tests confirmed that OAKITE-31 was an acceptable improved process and was implemented in production replacing the hydrogen reduction process.

Several other proprietary chemical oxide strippers were tested and quickly ruled out for further evaluation. One material labeled "TARNEX" did show initial promise and was further evaluated. This material is a widely advertised consumer product sold as a silver tarnish remover and copper brightener. The attractive feature of "TARNEX" was that it did not require solution heating as OAKITE-31 requires and that it stripped the oxide very rapidly. Unfortunately, when we applied our standard adhesion and solderability tests we found that the results were entirely too variable to recommend it as a standard oxide removal process. As a result of the above described work, we concluded that the process which uses OAKITE-31 (a proprietary phosphoric acid compound) as a copper oxide remover offered the most producible process and significantly reduced the labor content of this operation. The Oakite process is now documented and implemented into our R.F. Power Module production.

3.3.4.1A5 Automate Feed Through Pin Continuity Testing.

At the start of this MM&T program, cylindrical copper feed through pins (Fig. 3) were used for connecting the top side micro-stripline circuit to the DB Cu ground plane. From time to time one of the 16 pins would not bond to the ground plane largely due to the pin hanging up on the side of the hole in the ceramic substrate. To detect this defect, prior to doing additional work, manual electrical testing for continuity was performed on each of the 16 pins. To detect this type of fault more cost effectively, our existing Company owned Everett-Charles circuit verifier was fixtured to simultaneously test all 16 pins for continuity. A probe fixture was designed and ordered from the Pylon Co. Upon receipt of the fixture, it was cabled to the tester and programmed to perform the simple required test. With very little difficulty this automatic test procedure was implemented and is in use on our present production of R.F. Power Amplifiers.

3.3.4.1B Change From Air Fired Sealing Glass to Nitrogen Fired Glass.

3.3.4.1B1 Search Literature for Possible Improved Glasses and/or Processes and Evaluate.

An initial literature search did not identify possible contender glasses for the application of making seals between alumina and alumina in a nitrogen atmosphere. Private communications with basic glass producers and compounders plus other glass experts indicated that there was no way of crystalizing the lead or zinc borosilicate sealing glasses without some oxygen. Alternatively, there are many high temperature amorphous type glasses which satisfactorily fire in nitrogen but are generally characterized as being less desirable structurally than the crystalizable glasses. The possibility of mixing the two glasses exists to achieve some degree of crystalization when fired at high temperature. In using the high temperatures (900°C range) the effect on the previously printed resistors has to be evaluated. Another possibility is to mix only a small amount of oxygen into the predominent nitrogen and thus reduce the level of copper oxide formation. This latter possibility does not accomplish the full objectives of this effort but will make it easier to remove the light copper oxide formed with the reduced oxygen level and will also diminish copper degradation resulting from heavy copper oxide formations.

These initial observations set the stage for our development work. In broad terms, we would first try to develop a glass which can be fired in 100% nitrogen. Failing to achieve success with this approach, we would then revert to the low temperature crystalizable glass in use at the outset of the program using the minimum amount of oxygen. To narrow down the development, the below listed materials were selected for initial evaluation and processing. Following the material list are comments on the results of first evaluations plus comments on techniques which may be investigated if time and funds are available.

Some possible compositions which would melt at lower temperatures (500°C to 700°C) would do so because of added Fluoride content. Such additives provide corrosive by-products upon processing and are unsuitable. Other glasses, primarily Boro Silicate types such as Corning 7070 electronic glass are amorphous and require high processing temperatures (850°C-950°C). It is generally believed that amorphous glass sealing compositions are unreliable for use in alumina to alumina electronic packaging and is the reason for the industries development of devitrifying sealing glasses.

Even so, there were several glasses selected which seemed to be capable of providing a nitrogen sealing glass either by modifying processing conditions of blend glass composition types. The list is as follows:

G64	Barium Boro-Silicate	Owens-Illinois Inc.
G80	Lead Boro-Silicate	Owens-Illinois Inc.
SG 67	Lead-Copper Boro-Silicate	Owens-Illinois Inc.
EJ 3	Composition not available	Hommel
M 3040	Composition not available	Electro Science Labs, Inc.
G 201	Composition not available	Electro Oxide Corp.
7583	Zinc-Lead Borate	Corning Glass Co.

o The G64 glass is known to be a devitrifying composition processing between 835°C and 950°C. Various peak temperatures and rise times were used since these parameters determine the time to melting and degree of devitrification. Indeed, the glass processes well in nitrogen and adheres well to alumina. However, the sealing step for the electronic package requires both a glazing and a sealing step. In each processing condition tested, the glazing step rendered the G 64 glass to a processed condition where sufficient devitrification always occurred during the glazing step, the two glazed surfaces would not flow enough to seal during the subsequent sealing step. Devitrification increases the viscosity of the melting glass. An attempt was made to mate the substrate and frame using dried but not glazed parts (by-passing the glazing step) but intimate surface to surface contact of the sealing glass surfaces was still not obtained. The desired seal reaction was limited to about 5% of the seal area.

o The G80 glass is low temperature melting (430°C) lead (80% wt) - Boro (10% wt) - Silicate (10% wt) which will provide a light to dark gray glassy finish under nitrogen. The darkish color is a result of free lead nucleation well distributed in the glass. The glazed parts (substrate and frame), appear to be an excellent opportunity to provide a seal but the results of sealing at 550°C include an unacceptable void content.

o The G80 was thought to be useful as a melting temperature modifier of the G64 Barium glass so as to allow this glass to melt and flow yet retain some devitrifying characteristic. G80/G64 ratios of (1/10, 2/10) and (5/10) were fired out for evaluation. The 1/10 ratio did not significantly change the G64 melting characteristics and the 2/10 and 5/10 ratios would not permit devitrification. Also, the higher G80 containing mixtures exhibited excessive void content.

o The SG67 is a low melting lead-copper-boro-silicate glass sometimes used in air fired sealing applications. This composition does not produce a smooth glaze and is not reliable as a seal glass when processed under nitrogen. No further work was done to evaluate this glass.

o The EJ3 glass composition is not known by us at this time. It is sealing glass developed to mate copper metal parts. The initial nitrogen atmosphere sealing steps produced a seal which had a high void content. This glass was not totally eliminated as a possible nitrogen sealing glass because the first materials and process compatibility test was not refined relative to controlled film deposition. More specific deposition control of the dried film and its drying was done which did not greatly improve results.

o The Electro Science Labs M3040 low temperature composition, when fired out in nitrogen, produced a film which is too porous and has insufficient mechanical strength.

o The Electro Oxides G201 is of the same family composition as the G64 with a somewhat lower melting temperature. They do perform similarly. However, the results are unacceptable. High viscosity at melting stage and some bubbling make this glass undesirable for sealing.

o Corning 7583 and Owens-Illinois CV-111 sealing glasses are very similar zinc-boro-lead-silicate materials and were not expected to make strong hermetic seals when fired in a 100% nitrogen atmosphere furnace. Experiemnts were performed to determine the limits of oxygen required for good glass flow and crystalization without excessive oxidation of the thick film copper. The results of these experiments showed that neither of these glasses would process adequately until so much oxygen was present that atmosphere must be considered an air firing atmosphere. For reference, the glass seal process used on these experiments comprised printing glass on both the ceramic wall and the substrate; separately glazing wall and substrate; joining the two for final hermetic glass seal.

o Some efforts were made to determine if cupric oxide powder could be used as a source of oxygen internally available to the glass. It is known that the poor melting characteristics of low melting glasses is often due to the reduction of easily reducible metal oxides like zinc oxide and lead oxide in the absence of oxygen. Up to 10% of copper oxide was added to 7583 and two different firing schedules used. The melting characteristics were improved in nitrogen but increased outgassing caused high void content in the seal.

o The addition of SG67, a low melting glass, to 7583 provided similar results as reported above but air glazing and nitrogen sealing yielded impressive results in terms of apparent good seals. This approach was scheduled to be further evaluated later since the process of fabricating the circuit package permitted air glazing the ceramic wall which would contain all the sealing glass and nitrogen sealing wall to the unglazed substrate.

o Investigate the feasibility and possible advantages of a multi-layer glass seal structure wherein different glasses are used for each layer. A configuration which may offer advantages would consist of, first, air glaze 7583 glass onto the ceramic wall with the intention of later reducing the oxidized DB Cu on top of the wall. Then, nitrogen firing a very thin layer of G80 and SG67 seal print on the substrate. This print would serve primarily to encourage the 7583 to wet the opposite surface during the sealing process and the G80 or SG67 would essentially disappear into the 7583 bulk. The 7583 is resistant to nitrogen processing after first being glazed over (glassy smooth finish) and the low melt composition is already known to be compatible with the 7583. The primary disadvantage would come if the amorphous component of the seal did not become displaced by the 7583. This combination was also scheduled for further evaluation.

A summary of the results of our preliminary investigation is presented below. Those areas requiring further investigation are identified.

Glass Tested	Results	Conclusion
G64	Does not flow during sealing	NG
G80	Void content too high	NG
SG67	Does not melt correctly in N_2	NG
EJ3	Void content too high. Evidence that thinner seal film deposition may look better	NG but some further evaluation is required
M3040	Too porous - low mechanical strength	NG
G-201	Does not flow during sealing - some voids	NG
G64 & G80	Void content too high	NG
CuO_2 & 7583	Void content too high	NG
SG67 &7583	Void content too high	NG but air glaze Cu N_2 sealing should be evaluated
G80 then 7583 2 separate layers	Not yet evaluated	Should evaluate

Second phase investigation was started with a thorough evaluation of the Corning 7583 and Owens-Illinois CV-111 low temperature crystalizing glasses. The initial objective being to compare the new 7583 glass with what was our standard glass (CV-111) and not introduce nitrogen firing perturbations at this time. Accordingly, a variety of thermal furnace profiles were investigated to determine their effect on the glaze and seal characteristics of CV111 and 7583 glasses. Two different paste vehicle systems were compounded and tested for clean burn out of organics in the drying and firing process. Hot surface heating at 300°C for 15 min. was found to be adequate in all cases. Slow drying was used at first to avoid blistering. The peak glazing temperature required for both glass frit products is fairly insensitive at 500°C. Recommended profile is 5"/min. through 36" heated length (zone 1 - 200°C, zone 2 - 320°C, zone 3 - 320°C, zone 4 - 500°C) so the profile is pushed up rapidly just before the parts exit the furnace. The presence of air is essential.

Results: Excellent seals with good fillet characteristics, low void content and size were obtained. The 7583 was considerably more crystallized than the CV111. The completion of crystal formation indicates maximum seal strength. Thus, for an air fired seal, 7583 glass is recommended using the same sealing profile as the glaze profile except that the sealing profile will have the third zone set at 500°C.

Dry	300°C	15 min. Slow initial drying			
Glaze	5 IPM	36" heated length	Zone 1	200	
			Zone 2	320	°C
			Zone 3	320	
			Zone 4	500	
Seal	"	"	Zone 1	200	
			Zone 2	320	°C
			Zone 3	500	
			Zone 4	500	

Unsuccessful seal results were obtained when the combination of air glazing and nitrogen sealing was done with both the CV111 and 7583 glasses. An optimum profile was developed for glazing 7583 parts which yielded very well glazed-over surfaces. That is, the glaze finish was very glassy and therefore less susceptible to the influence of inert or reducing components in the atmosphere of the Nitrogen firing sealing process. The following zone settings and belt speeds were used:

Air Glaze	Zone 1	200	Nitrogen Seal	Zone 1	200
	Zone 2	200		Zone 2	320
	Zone 3	320 °C		Zone 3	320 °C
	Zone 4	300		Zone 4	550
	Zone 5	550		Zone 5	550

Belt Speed 5 IPM 36" heated length

Observation of the results showed that weak seals were produced by virtue of the high void content through the cross section of the seal and poor filleting. It should be noted that most of the seals were hermetic but still not acceptable from a strength requirement criteria.

Further experiments using various combinations of multilayered glasses also were unsuccessful. Attempts at making nitrogen seals with G80 and SG67 fired in nitrogen on the substrate and 7583 air glazed on the wall were not acceptable. Both the G80 and SG67 exhibited outgassing and resulting bubbling which precluded the accomplishment of acceptable seals.

An ESL low temperature overglaze #4775 paste was reduced in viscosity by a factor of two by thinning with Butyl-Carbitol-Acetate. This provided a thin fired out glass film in Nitrogen which has good properties. On sealing the air fired wall member (7583 deposition) to the substrate having Nitrogen fired 4775, a good seal was produced. Examination of the broken apart package members showed that the amorphous layer was the "weakest link" and there was considerable voiding present. The voids were present mostly in the 4775 at the 7583 interface.

Work on attempting to develop a nitrogen fireable sealing glass under this program was completed at this point. Our tests, trial runs, experiments and evaluations did not reveal a glass or combination of glasses which would permit us to make strong glass seals in nitrogen. Had we been successful in this development the work in copper oxide removal described in para. 3.3.4.1A4 would not be required. However, on a more positive note, we did improve our air fired glass seal process and have qualified a second source glass (Corning-7583). As a post script item, promising glass seal work has been continued with Company funds. It comprises applying all the glass (7583 or CV111) to the wall and air glazing; removing the copper oxide from the rugged DB Cu previously applied to the top of the wall and then making the final hermetic seal in a predominantly nitrogen rich atmosphere. The results of such a seal is the formation of a light oxide on the substrate thick film copper which was found to be easily removed.

At the '80 ERADCOM Symposia at Ft. Monmouth, we presented a status report on the work being performed on this program. As a result of our presentation relative to glass seals, EARL RIGGS of NAFI told us in a private discussion that RAYTHEON was presently using on the TRIDENT program, a glass which they sealed in 100% nitrogen. EARL gave us the name of the individual for follow-up on the details. We called RAYTHEON and found that the glass was the same glass we evaluated and use, Corning #7583. They, however, glaze the glass in air and do the final seal in nitrogen. They do not use any oxygen to devitrify the glass to achieve its maximum strength in the final seal operation. Their strength requirements are minimum since the ceramic leadless chip carrier package they are sealing is very small. This process is not directly applicable to the subject MM&T program for two reasons. First, the glaze operation performed in air at 350-500^{o}C is sufficient to thoroughly oxidize the copper. And secondly, because of the extremely large size of our package we require the full strength provided by crystalized glass which can only be accomplished by using some level of oxygen at seal. The glass work which we are now pursuing is somewhat similar to the Raytheon approach except that a small amount of air (oxygen) is used so that full crystalization strength is achieved. We can tolerate this small amount of air since the final hermetic seal is made at a later stage whereas Raytheon uses their glass seal as a final seal and cannot allow air to be sealed within their chip carrier enclosure.

3.3.4.1B2 Develop Glass Seal QC Procedures and Test Methods.

To our knowledge, the basic need exists in the ceramic hybrid package industry for a quantitative glass seal strength test. The need is of particular importance for the subject R.F. Power Amplifier package where the large 2 in. x 3 in. glass seal performs a structural function in addition to providing hermeticity. In the parallel para. 3.3.4.1B1 glass seal development effort the ability to quantitatively discriminate attributes of the various glasses under evaluation is extremely relevant. The typical QC visual criteria of void free well filleted glass seals plus hermeticity do not directly relate to strength of the seal. Thus, the need existed to develop an improved test method. In addition, the need existed to determine the strength required in the glass seal so that is survives the stresses the package is designed to meet in its storage and operating life. It also must be strong enough to survive the considerable stresses induced in the hybrid assembly operations.

Having expressed the above concerns, we hasten to add that we have built tens of thousands of these type of integral substrate packages over the past ten years which have met all levels of military requirements. Their reliability has been proven with the QC visual and hermetic criteria used in fabrication. However, when attempting to "fine tune" the selection of a new glass and associated processes more basic knowledge is required. Accordingly, the following work was undertaken; (a) describes test methods investigated, (b) describes the stress analysis work performed.

(a) Prior to this program, attempts were made to obtain glass seal shear strength data. Packages having substrates with ceramic walls glass sealed to them were sawed so that only a 1" long section of a wall sealed to the substrate remained (Fig. 7). This section was positioned vertically in an Instron tester and force applied to the wall to the point of destruction (Fig. 8). Data was collected on at least 20 units which were made with the same materials and processes. The data spread was much too eratic to be meaningful. Ruptures of substrates as well as seals occurred with about equal frequency. In retrospect, we rationalized that the substrates were subjected to bending stresses and breaking. Additionally, the sawing operation can easily induce micro-cracks in either the glass seal and/or the substrate which weakens the structure under test. We believe either of these two conditions caused the observed eratic results. This test method was abandoned for the above stated reasons and the absence of a solution.

In order to further evaluate the strength of a glass seal and be able to distinguish and characterize one glass seal paste from another, a technique of centrifuge testing was investigated. The centrifuge set up is shown on Fig. 9. Eighteen seals were made with the Owens-Illinois CV111 glass and 18 seals made with Corning 7583 glass and tested, the data is reported below.

G-FORCE	CORNING #7583 NUMBER OF UNITS FAILED		OWENS-ILLINOIS CV111 NUMBER OF UNITS FAILED	
	SUBSTRATE CRACKED	WALL SEPARATED ONLY	SUBSTRATE CRACKED	WALL SEPARATED ONLY
7,000 G's	1	--	--	--
8,000	--	--	1	1
9,000	1	1	--	--
10,000	1	4	--	1
11,000	--	4	--	2
12,000	--	2	2	4
13,000	--	--	--	1
14,000	--	1	--	1
15,000	--	2	--	2
16,000	--	--	1	1
17,000	--	1	--	1
TOTAL	3	15	4	14

Discussion of Data - Since it was impossible with our test set up to see whether the substrate cracking occurred before the wall separates or the wall separates causing the substrate to crack, and since we are only interested in glass seal strength, i.e., the wall separation, we will not consider the data points related to substrate cracks. Thus, considering only the wall separation data there is no clear indication of one glass being better than the other. The Owens Ill. CV 111 does appear only slightly stronger. We conclude from this test that the strength of the two glasses are about equal. In the visual observation, we found that they were equal visually, hermetically and in printability. We then can say that the two glasses can be used interchangeably and they should qualify as materials available from dual sources.

This test method was also abandoned because of the time consumed in performing the tests and the fact that about 20% of the samples tested resulted in broken substrate. We believe that the allowable substrate camber of 3 mils per inch is sufficient to cause the substrate to bend when under sufficient centrifugal force causing the substrates to break. This bending stress may also start a fracture of the glass seal diminishing confidence in the resulting data which was supposed to strictly relate to glass seal strength.

A third glass seal test method was investigated which makes use of the technology being developed in acoustic/ultrasonic non-destructive test equipment and methods. As a first step, we presented the problem to our Acoustic Section of our Electronics Lab. for their suggestions and recommendations. The "Pulse Echo Method" was recommended and they agreed to perform feasibility studies using their existing laboratory equipment. Results of the first feasibility efforts were positive. A second phase effort was performed wherein 5 glass seals were made with known defects. The object being to calibrate the sensitivity of the equipment. The final Electronics Lab. report is attached as Appendix "D". We conclude that the technique described in the report represents a feasible means for detecting flaws in glass seals. Further work, under this program, was stopped since further work related to producibility or cost effect of implementation could not be completed in the available time and budget. For instance, this technique should be compared with X-ray techniques in terms of efficacy of finding flaws. And even if ultrasonics should be more effective the task of productizing the laboratory equipment would be impossible to accomplish in the remaining time. Since the ending of the Electronics Lab. work, we have sought out vendors of ultrasonic test equipment to interest them in making or adapting an equipment which could meet our needs. We have not been successful to date.

It should be pointed out that a non-destructive ultrasonic test will not directly indicate the quantitative strength of a glass seal. However, a relationship of strength vs void defects probably can be established and correlated to glass strength.

More work in this area has been continuing with Company funding. Initial results are very promising and the test method is very simple. The test data is quantitative and appears rational, always breaking the glass seal only. The test comprises applying the glass and process under test to a 1" long section of ceramic wall and a 1" x 1" ceramic substrate such that the wall section is cantilevered off the substrate to a fixed constant dimension. The test is performed by applying a vertical force to the top of the wall section of the horizontally supported wall/substrate glass seal. More work is going on to establish confidence in this test method and subsequent implementation for the continuing glass seal development work.

(b) To deal with the opposite side of the equation, a knowledge of the stresses the package is required to endure is essential, i.e., is the package (particularly the glass seal) strong enough to withstand the imposed stress? Accordingly, a finite element stress analysis was performed with the aid of the "ANSYS" program (see Appendix "K" for description of program). A finite element model of the subject R.F. Power Amplifier module was made as shown in Figures 10 through 18. These figures show the nodal points and elements for each of the eight layers. The model contains 349 nodes and 174 three dimensional solid elements. Finite element analyses using the "ANSYS" computer code will be made to determine stress distribution associated with the numerous external load conditions. The loading conditions include shock, vibration, centrifuge and temperature extremes plus the interim stresses generated in assembly. The following list describes the materials used the module, the temperatures used in the various fabrication steps and the environmental stresses the completed module is expected to endure.

MATERIALS

Ceramic Substrate 2" x 3 1/2" x 0.025" 96% Alumina
Ceramic Wall Frame 2" x 3" (O.D.) x 0.150" High Alumina (0.100" wide)
0.003" thick Copper
Kovar Lid (2" x 3" x .023" thick)
62% Sn/36% Pb/2% Ag Solder Throughout
Molybdenum (moly) base/heatsink 2" x 3 1/2" x 0.050"

PROCESS AND TEMP

1. DB Cu (.003") to Substrate (.025" thick) for ground plane.
   Peak Temp 1075°C - Total ramp up & down - 20 min.

2. 16 Feed Through Cu Spheres - 0.063" D. - Same as #1 process.

3. Thick Film Print and Fire Cu Microstripline on top of Substrate
   Fire 3 times @ 900°C Peak - 3 min - ramp up & down - 25 min
   Laser trim resistors
   Wall Sub-Assembly
   A - DB Cu on top of wall - same as #1 process.
   B - Glaze glass seal on bottom of wall - 525°C
   Peak with 20 min ramp up & down - Screen Printed

4. Screen Print glazed glass on Substrate - 20 min @ 400°C.

5. Form Glass Seal between Substrate and Wall - Belt Furnace
   20 min. - up/down @ 525°C peak (3-5 min).

6. Leak check glass seal - vacuum pulled on interior of wall.

7. Solder Dip entire assembly (wall and substrate) at 225°C with preheat in 4 stages, 75, 100, 150, 200°C. Same temperature staging for post heat.
   Moly base pre-processing - Solder dip coat one side @225°C.

8. On controlled hot plate, gradually bring temp up for the assembly of moly to the substrate for solder reflow attachment of moly to substrate at 225°C. Cool down with 5 lb. weight on top of wall.

9. Assemble devices to module - hot plate at 150°C; IR spot heat (1/2" dia.) thru bottom, i.e., thru moly to melt solder for component reflow assembly (3 places). About 10 small caps attached with soldering iron when hot plate still at 150°C.

10. Pre-cap cleaning includes ultra-sonic cleaning.

11. Kovar lid seal comprises vacuum bake for 2 hrs at 125°C, then into N_2 dry box for solder seam seal (no heat).

12. Tests Qualification and Screen

a. Leak - He Bomb 1 ATM for 1 HR then
Exterior Vacuum - 1 min approx (Fine Leak Test)
Then, 125°C - 2 min liquid immersion (Gross Leak Test)

b. Stab. Bake - 24 Hrs @ 125°C

c. Temp. Cycle - -55°C to +125°C (10 times)
-50°C to +85°C (100 times)
Burn-in 75°C - 160 Hrs under power
Cold Turn-on @ -56°C, 10 cycles

d. 30G max shock, vib. - 20G PK - Simple Harmonic, Acc. - 1500 G - Y1 Plane Only

Computer simulation runs were made in-putting the loads and forces listed above. The computed output of resultant stresses in various sections of the modeled elements are presented and discussed.

Details of the module displacement (strain) and stress data, are given in Figures 19 through 29. Figure 10 shows a section of the module and the eight layers of six different materials plus thickness which comprise the assembly. Figures 19, 20 and 21 are the ANSYS geometry plots.

<u>Temperature extremes simulation</u> - An analysis was performed to determine the stress distribution within the module due to a temperature change from an ambient of 20°C to 125°C. The displacement and stress plots for this case are shown in Figures 22, 23 and 24. The plotted output data for this case only displays the alumina

substrate along with the 3.0 mil DB Cu layer on its top surface and a 3.0 mil glass seal attached to the lower surface. Figure 22 basically shows the warpage of the substrate. A 0.00126 inch maximum displacement occurs in the width direction. Figure 23 shows a plot of maximum principal stress. A stress of 21,315 psi exists at node 181 in the alumina substrate. Figure 24 is a similar plot but shows minimum principal stress. A compressive stress of 33,653 psi is found at node 133 in the substrate. It should be noted that this stress level occurs at the cut-out in this ceramic material. Within the glass seal, the maximum principal stress is 5,107 psi and the maximum shear stress is 2,708 psi.

<u>30-G Shock simulation</u> - In general, the stress components within the module for this level of shock loading are extremely small. For example, within the glass seal elements (127 - 136) the maximum stresses are as follows:

Max. principal stress = 43.0 psi
Max. shear stress = 46.0 psi

<u>1500-G Centrifuge simulation</u> - Details of this finite element model together with its displacement strain and stress data are graphically displayed in Figures 25 through 29. Figures 25 through 29 are plotted for the alumina substrate and mating 3-mil DB Cu elements. A summary of maximum and minimum stress values for SMAX (maximum principal stress), SMIN (minimum principal stress) and TMAX (maximum shear stress) are given in Table 1.

TABLE 1

STRESS	SMAX (PSI)	NODE NUMBER	SMIN (PSI)	NODE NUMBER	TMAX (PSI)	NODE NUMBER
(Maximum)	4891.	225	147.	215	2422.	225
(Minimum)	-521.	195	-4321.	223	68.	104

The maximum principal stress and maximum shear stress occur at node 225 and are located in figures 27 and 29. These stress levels are considerably lower than those for the thermal stress case. The greatest stress levels in the glass seal at centrifuge are found in element 136 where SMAX = 116 psi, SMIN = -1036 psi and TMAX = 576 psi. These data can be compared with the temperature extreme case where SMAX = 5107 psi and TMAX = 2708 psi.

Summarizing our finite element work with respect to the glass seal: Centrifuging at the 1500-G level produces stresses in the glass seal of 116 psi, -1036 psi and 576 psi; stresses from a 30G drop shock are 43-46 psi and the stresses resulting from a temperature excursion of $100^{o}C$ are 5107 psi and 2708 psi. This data indicates that temperature cycling and/or temperature shock produces the most severe stress on the glass seal and suggests that it may be used as a simple screening test for glass seal strength.

Full stress analysis of all the elements of the module for all the load conditions has not been done. Our interests under this MM&T program were simply to find out how strong the glass seal had to be to safely withstand the stresses resulting from subjecting the module to the specified environmental tests. Verification of our stress analysis data has not been accomplished because of our inability to develop a reliable quantitative glass seal test method as reported in (a) of this section above. At this time we are confident that a glass seal test method can eventually be developed which we believe will verify our stress analysis data.

Lest the above analytical and test development work appear too academic, we restate our objective in doing this work. Considerable cost can be saved and yields can be improved by developing a glass seal which can be fired in nitrogen. This would eliminate the severe copper oxidation which occurs when the glass is fired in air as required with our presently used glass. However, to accomplish this glass change complete knowledge of all the physical attributes of the presently used reliable glass seal are required. It is also helpful to know what safety margin exists in the presently used material and process. With the sought after knowledge available simple quantitative testing of new candidate seal glasses using a variety of glaze and seal processes can be objectively evaluated. The bottom line being to develop and implement a new seal glass and process which reduces processing costs and increases production yield saving even more cost.

3.3.4.1C Develop Lower Cost Lid Seal Material and Improve Seal Design and Process.

The objectives of this task were planned to be met by procuring plain Kovar (ASTM A-15 Alloy) lids, then developing suitable non-noble metal plating for the Kovar lids which would permit reliable solder wetting of the lid to assure the integrity of the final hermetic seam seal. Initial activity dealt with finding a responsive source for the flat 0.023" thick 2" x 3" Kovar lids. After several iterations 200 chemically etched blanked out lids were received having a minimum of 100 microinches (u") of electrolytic nickel plate. Subsequently, another 200 lids with no plating were procured. Many plating variations and power settings on our "SSEC" Seam Sealer were evaluated. Dummy modules were used for first trial runs using destructive analysis for seal evaluations and feedback. When results looked promising, hermetic module packages were used for final seal process verification. The combinations evaluated are listed and discussed below:

<u>1st Trial Run</u> (10 Modules)

Using mechanical samples, a preliminary seam seal process was developed comprising the following:

1. Kovar lid as received with electrolytic nickel - no preparation work required.
2. Plate approximately 200 microinches of tin to the seal side only of Kovar lid.
3. Prepare MIC package ceramic wall by our standard solder dip process.

4. Seam seal lid to ceramic wall with following settings and conditions.
   a. Used standard established fixturing.
   b. Power for long side set at 900 amps, speed at 13.
   c. Power for short side set at 800 amps, speed at 13.

This process produced extremely strong solder seals often pulling the DB Cu off the ceramic when package broken for seal joint inspection. Wide, 0.050" or more, solder joints were produced by this process which appeared hermetic.

2nd Trial Run (15 Modules)

Fifty hermetically tight mechanical modules were made for the pre-proof of process run to verify the process reported in the 1st Trial. The new Kovar lids under development were tin plated (200 microinches) as before except that the plating was done 2-4 weeks earlier and the packages and lids were vacuum baked (150^{O}C - 2 hours) in the oven built into the seam sealer. The seal process used was identical to our standard solder sealing process whereas in our preliminary tests where we had very good results the vacuum bake was not used and the tin plating was done only hours before. These differences between our first and second trials we believe are the reasons for the poor results obtained in the pre-proof of process run. We ran 15 packages out of the 50 and found the hermeticity yield to be unacceptable. We rationalize that the time between applying the electroplated tin, wherein the underlying nickel is activated, and the time of use in sealing was sufficient to cause the nickel to become passivated and difficult to solder wet. Other experience has shown that electroplated tin is porous and does not protect the underlying nickel from forming hard to solder wet nickel oxides. To remedy this situation the tin plate was hot reflowed immediately after plating to eliminate porosity.

3rd Trial Run

New lids having only the vendors electrolytic nickel plating were electro-chemically activated and immediately tin plated and hot reflowed. In the hot reflow operation, they initially wet the nickel very uniformly but beginning after 90 seconds, the wetting began to deteriorate. Lids from the 2nd Trial Run lot were also hot reflowed and found to not wet the nickel at all. We interpret these observations to confirm our belief that hot reflow of the electroplated tin is required to maintain the activation (wettability) of the nickel. The ability to wet the nickel is critical to a good solder seal since the thin tin coating rapidly goes into solution with the eutectic solder which must then wet the nickel plate on the Kovar lid to product the final hermetic seal.

To establish further confirmation, two lids having freshly electroplated nickel over the base Kovar metal were made and immediately electroplated with 200-300 microinches of tin. These were hot reflowed hours later at 250^{o}C on a hot plate using a mild flux. About a week later, they were used for sealing 2 packages using our previously developed sealing process, vacuum bake etc. Hermetic seals were produced. Mechanically removing the lid to examine the solder seal revealed good solder joints with separation occurring within the solder.

Further work was done in investigating and evaluating the relative merits of several different electroless and electrolytic nickels in terms of their durability of wetting properties when protected by hot reflowed tin. We also prepared samples of lids plated with nickel boron which is reported to be an extremely solder wettable nickel. These samples comprised:

1. Sample quantities of Kovar lids were replated with electrolytic nickel plus 200 microinches of "Schlotter" Process tin.
2. The same as #1 except that electroless nickel was used.

3. The same as #1 (Electrolytic Nickel) except that "Harston" Process tin is used.
4. The same as #2 (Electroless Nickel) except that "Harston" Process tin is used.
5. Same as #1 except that the "Allied Kelite" Process for electroless plating Nickel Boron was used.

All the samples were hot reflowed to melt the tin and create a non-porous plate over the nickel. All samples wetted the nickel plated (electrolytic and electroless) kovar equally well. These sample lids were then used for hermetic sealing packages on the seam sealer using our standard sealing process. Seal results were again unacceptably low regardless of the plating process used to prepare the lid. After examining some of the defective seal joints, we have concluded that our problem may be the fact that we are mixing pure tin (M.P. 232^{o}C) on the lid with 62% tin/36% lead/2% silver solder (M.P. 187^{o}C) which is used for pre-tinning the top of the ceramic wall. There probably is not enough heat created at the electrode contacts to attain a thorough mix of the tin and solder. This results in a weak solder matrix wherein a tin rich zone interfaces with a eutectic zone.

A final attempt was made to try to make this new lid concept work. 50 Kovar electroplated nickel lids (as purchased) were prepared by first chemically activating the nickel plate then immediately plating with 500 u" of 60/40 solder on one side followed by hot reflowing the solder. Ten of these lids having reflowed electroplated 60/40 solder on the seal surface were seam sealed to dummy module packages. The results of this trial run were promising; visually the lids appeared well wetted to the packages and upon mechanically removing the lid a wide solder seam was evident. Based on these results, another group of 16 lids were sealed to hermetic packages for a final evaluation. Hermetic seal yield results were as good as the yields achieved with our present solder clad Kovar lid sealing process (close to 100%).

Thus, at the conclusion of this program, we have demonstrated that we can effectively use a non-solder clad Kovar lid for high yield seals. However, upon considering all the producibility factors and their impact on labor and material costs, we conclude that no advantage can be gained by making a change from our original solder clad Kovar material and seal process. Our rationale for this decision is based on the following weighted factors chart.

FACTOR	PRESENTLY USED SOLDER CLAD KOVAR LID*	NEW NON-SOLDER CLAD KOVAR LID*
1. Cost of lid, ready to use	9	10
2. Time required for preparing lid prior to seal	10	10
3. Time required to make the seam seal	10	10
4. Seal yield	10	10
5. Experience, Maturity of Process	10	6
6. Technical factors (solder thickness, seal joint strength)	10	10
* 10 Represents Most Favorable TOTAL	59	56

Discussion of Factors:

1. Our present base cost for purchasing solder clad lids is $2.27 per each as compared to a quote for $2.04 per each for a non-solder clad lid. Higher material cost savings were expected but not realized because it was found necessary to nickel and solder plate the non-solder clad lids to achieve acceptable seal yields.

2. Savings of labor in lid preparation did not accrue as expected because of the necessity of solder plating the non-solder clad lids. The solder plating was found to creep around the edges of the Kovar to the top so that is interfered with the seam sealer electrodes. To eliminate this solder creeping action, the edges of Kovar lid had to be abraided prior to sealing just as we have to do with our present solder clad lid.

3. In the area of machine time for performing the seam seal operation, the times should be equivalent after the operator comes to the top of the learning curve.

4. As reported above, nickel/solder plating of the bare Kovar did result in equivalent yields.

5. The maturity/experience factor is the most compelling reason for staying with our original process especially when it is not outweighed by the other factors. Perhaps even more compelling is the fact that many other similar packages are made in this Facility and use similar solder clad Kovar lids which are sealed in the same seam sealer. Thus, the operator is highly experienced and skilled in making high quality hermetic seals essentially using the same processing techniques for a broad spectrum of hybrid products. The new lids will require a change of processing technique and have the potential for loss of quality.

6. All other factors being equal, it is desirable, from a joining strength point of view, to obtain a minimum thickness solder joint for the lid seal. The non-solder clad lid does meet this objective. However, subjective pull tests wherein the lid is destructively removed from the package does not verify that the thinner solder joint is in fact stronger. In any case, the present lid seal using solder clad Kovar does meet all of the mechanical qualification requirements of the module, thus obviating the need to enhance the strength of the present solder seal. Our lid seal development did have a positive

result in that it demonstrated that alternate lid materials can be used for high yield seals. This factor may be of value in the event that our present sole source solder clad Kovar lid supplier is not able to make deliveries as required.

3.3.4.2 Results of Developments in Improving Semi-Automated Test/Tune Software and Integration into Hardware.

The broad objective of this task was to reduce the labor content and skill level required for testing and tuning R.F. Power Modules plus simplifying the data collection and data reduction. Specifically:

a. Tune amplifiers with CRT display of corrected parameters such as power output, return loss and efficiency vs frequency.
b. Incorporation of junction temperature and amplifier time delay measurements into the basic system.
c. All tuning done in one test station in order to observe and correct any performance deviation.
d. Once the amplifier is tuned, all important data to be recorded on magnetic disk and with a printer for hard copy.

To accomplish these objectives, the semi-automatic test station requires the capability to test/tune 3 types of solid state modules; Pre-drivers, Drivers and Power Amplifiers; four transistor types - Classes A and C; and temperature evaluations from -55°C to +80°C. Measurements must be made under varying load and temperature conditions with minimal operator attendance.

The functions which this test station must perform include: Module tuning (pre-seal, post seal and post burn-in), parameter calculations, parameter/data display, data transfer, design aid and transistor test.

Considerations involved in developing the improved test station comprised the following:

PREVIOUS METHOD	SEMI-AUTOMATIC STATION
Completely manual	Computer controlled
High skill level operator	Lower skill operator
- Technical Specialist	- Technician
High labor content	50 to 75 percent reduction
5 Frequencies	20 Frequencies
2 Power levels	4 Power levels
5 Manual measurements	4 Manual measurements
2 Off Line calculations	All calculations done in computer
Hand written data	Disk, tape and hard printed data

The parameters to be measured in the modules and transistors are:

Input Power	Harmonic Output
Return Loss	Junction Temperature
Collector Current	Pulse Droop
Collector Voltage	Saturated Power
Phase Shift	Spurious Output
Stability	Efficiency

Figure 30 shows the block diagram of the test station and Figure 31 shows a photo of one of the stations now in place and operating full time. Two separate programs were developed under this Contract, one which emphasizes man machine interaction and the other applying where cost effective, full automation for data collection. In use, the pre-tuning steps are:

- Visual inspection by tester
- Input transistor IR data
  - o Measurement of lot emissivity
  - o Enter emissivity number
- Module serial number/revision
- Testers initials/test station
- DC and RF runup

The tuning steps are:

Manual sweep processing	Sweep processing
Raw data	System characteristics removed
Oscilloscope Presentation	Graphics display
Real time	Delayed presentation
Preliminary tuning	Machine language programming

General Options

Regular or special parameters

Special IR scan routine

Figure 32 shows the module layout follower used on each module for locating the tuning pads which are required to be used for tuning the module to specification.

The sequence followed for tuning is:

Switch between return loss and power ouput vs frequency
- o Special purpose keys on computer

RF and DC power to module controlled by special keys
- o Off for tab insertion
- o On for performance check

Selection of phase/frequency display
- o Use of module phase trim
- o Note phase tab requirement

Hard copy plot of each parameter set
- o Special purpose keys
- o Automatic data storage

Figures 33 and 34 show hard copies of the oscilloscope displays of reflected input power (33) and delta phase (34) vs frequency/output power.

A summary of the performance capability of the station is listed:

Automatic except for:

- Harmonic, spurious, IR scan, pulse breakup test which are not cost effective

Program has four options:

- Regular module or phase calibration
- Room temperature or range of extremes
- Single or multiple temperature cycles
- Attended or unattended operation

The test stations capability for data collection is:

Phase calibration twice/shift - more frequent if required

standard module check twice per shift

- Select temperature profile
- Enter module data
- Computer data search, check
  - o Option for changes
- Data collection
  - o P_{OUT}, $P_{REFLECTED}$, I_{CC}, V_{CC}, DROOP, PHASE
- H, S, B Options
- IR Scan
  - o 32^{o}C
  - o Nominal power input
  - o Computer interactive
- Storage file indicated
- Extended temp ranges
  - o IR scan option, each temperature

A typical computer print-out data sheet is shown in Figure 35.

3.3.4.3 Proof of Process Verification - Qualification Test Results

Qualification testing per Appendix "D" was performed on the group of 25 R.F. Power Modules produced to verify the reliability of modules incorporating improvements developed under this program. These tests will assure that quality has not been compromised by virtue of these changes. See Appendix "L" for test description and results.

3.3.4.4 Benefits - In paragraphs #3.3.4.1 to #3.3.4.2 inclusive, we discussed the MM&T work done under this program and the results achieved in the eleven identified tasks. The tasks dealt with our efforts under this contract to improve the producibility (lower the cost) of the 100 W. R.F. Power Amplifier Module which is used in a wide family of SSR's including the AN/TPS-59 systems. In summary, the tasks covered improvement work in the following areas:

1. The cleaning and oxidizing of copper prior to the DB Cu operation.
*2. Developing copper blanks to reduce trimming after DB.
*3. Feedthroughs, using copper spheres to replace expensive copper cylinders.
4. Lapping of feedthrough tops using a machine to replace the manual method.
*5. Copper oxide removal.
*6. Feedthrough continuity test automation.
7. Glass sealing, attempt to find a nitrogen fireable glass.
8. Glass seal QC and strength measurement.
9. Establishing strength requirements for the module structure.
10. Lid material and seal process.
*11. Testing and tuning the module.

As previously reported, not all task efforts resulted in successful implementation at the conclusion of contract supported work. Resulting improvements from five of the eleven tasks are now fully implemented in our production of R.F. Power Amplifier Modules and are identified with an asterisk as 2, 3, 5, 6 and 11. The cost benefits which may result from completing the remaining six tasks are not included in the payback calculations of cost savings accruing from work done under this MM&T Contract.

Cost Savings - Payback Calculation (1980 Dollars)

Total cost per module (less u-wave transistors) at outset of contract	= $612.12
Total cost per module (less u-wave transistors) at end of contract	= $303.73
Total cost savings per module after MM&T	= $318.39

Conservative estimate of number of SSR systems to be produced over the next ten years is 167 and on the average each system will use 400 modules including spares; therefore, 66,800 modules are to be produced over a ten year payback period on MM&T investment.

Ten year gross savings - 66,800 x $318.39	= $21,268,452.
Less MM&T investment	300,000.
Net Savings	$20,968,452

MM&T Payback Ratio $\frac{20,968,452}{300,000}$ = 69.9 to 1

3.3.5 Implementation

The 5 improvements identified in Para. 3.3.4.4 which have been listed as successful developments are now fully implemented in the G.E. Co. Hybrid Facility in Syracuse for the production of R.F. Power Amplifier products. These modules are used in SSR systems presently being built for the Government and its Allies. Systems now in production are identified as AN/TPS-59, SEEK IGLOO, U.K. and Q.M. Work on the remaining 6 incompleted tasks will be continued as funds and resources become available. The benefits which may result from completion of these tasks will be applied to on-going future production.

3.3.6 System Safety and Hazard Analysis - Final Report

A system safety program in accordance with MIL-STD-882, with certain customer approved exceptions, was conducted. Preliminary hazard analysis in accordance with MIL-STD-882 were also performed on the processes, assembly techniques and all materials related to the subject R.F. Power Amplifier module. The final Safety Statement (Appendix "M") prepared by our Safety Engineer is appended to this final report.

3.4 Drawings and Data Requirements per CDRL-DD-1423

The drawings, specifications and manufacturing control documents applicable to this program are appended to this final report and comprise the below list. The last items listed are the Product Introduction Authorizations (PIA) sheets which follow the product through manufacturing/test and call out the appropriate manufacturing and quality instructions (MPI/ESI/QCI).

APPENDIX	DOCUMENT DESCRIPTION
A-1	Spec. Control Dwg. #77C716283-Sh.1 Power Mod.
A-2	Spec. Control Dwg. #77C716283-Sh.2 Power Mod.
B	Elec. Spec. Dwg. #77A100244 Power Mod.
D	Qual. Test Procedure #85-47-10-1-0
E	Ground Plane Blank #7248571
F	Ground Plane Sub-Assembly #77C720004
G	Ceramic Wall Blank #7248543
H	Ceramic Wall Sub-Assembly #7248542
I	Copper Sphere Feedthrough #7244612
N	Product Introduction Authorization (PIA) Dwg. #77D609398
	Note Step #110 calling out New Oxide Removal Process
O	PIA #7244612P1 - New Copper Sphere Process
P	PIA #7248543P1 - New Ceramic Wall Blank Process

4. INDUSTRY/GOVERNMENT DEBRIEFING

On our 18 March 1981 Industry/Government debriefing meeting held at our hybrid facility in Syracuse, NY, we had 3 Industry and 5 Government representatives in attendance. Presentations on the activities and status of work performed under this contract were given followed by a tour of the facility. Demonstrations showing the contracted work were also given in the course of the tour.

5. GIDEP PROGRAM

We have and continue to have procedures in place to fully participate in the Government/Industry Data Exchange Program in accordance with MIL-STD-1556A. Our representative has been made aware of the work being done under this MM&T program. He will be furnished a copy of this final report for inclusion in the data exchange program.

There has not been any subcontractor participation in GIDEP since no subcontracts in excess of $100,000 have been awarded under this program.

We have additionally participated in the exchange of data with Government and Industry by presenting a paper on 4 June 1980 at ERADCOM on the subject and status of this MM&T program. The paper has been published in the 1980 ERADCOM Hybrid Microcircuit Symposium Proceedings, Ike Pratt Editor.

6. CONFERENCES

Three conferences were convened with NAVELEX program manager/technical representatives. The first was held in our Syracuse, NY Facility on 19 November 1979 with Messrs. Bicoff, Brown and Rigdon, Navelex representatives, and our key program personnel. A detailed program plan with status was presented together with a tour of our hybrid facility. The second conference was held at NAVELEX on 21 April 1980 with Navelex representatives Brown and Stender and GEC personnel. A complete status update was presented and discussed. The third and final conference was held in Syracuse following the 18 March 1981 GIDEP debriefing.

7. DISPOSITION

The 25 proof of process modules (Item No. 0002) which have been subjected to the qualification tests indicated in Para. 3.3.4.3 are being held at the GE Co., MESO Hybrid Facility pending NAVELEX, Code 5402, instructions for shipping or other disposition.

8. CONCLUSION AND RECOMMENDATIONS

We conclude that the work done under this contract was successful providing an excellent payback of 69.9:1 on the MM&T investment. Five of the eleven initially identified improvement tasks have been implemented on R.F. Power Modules now in production for use on Solid State Radar Systems. This rapid implementation into production products has provided quick payback and at the same time this improvement work was done early enough to benefit long term future production. Two more improvement tasks are expected to be completed in the near future and implemented into production for additional cost benefits. The development task dealing with improving lid sealing was completed but did not offer enough advantage to be worth implementing. The remaining three non-implemented tasks require additional funds to complete.

We recommend that development and verification work continue on the three non-implemented tasks dealing with the glass seal materials, means of testing glass seal strength and package stress analysis to ascertain glass strength requirements. We also recommend the approval and funding of five additional new Manufacturing Technology Projects which were recently submitted to the NAVY for consideration. These projects also deal with the subject R.F. Power Module and upon successful implementation can additionally reduce the Government and its' Allies acquisition cost of SSR Systems. For reference, we list the Navy M.T. Project Briefs (Form NAVMAT 4800/2) presented for consideration.

TITLE	SUBMITTED TO THESE NAVY ORGANIZATIONS	EST. BENEFITS
Unattended RF Power Module Testing	Naval Weapons Support Center-Crane, Indiana Earl W. Riggs (Code 6062) Also, Naval Electronics Systems Command Washington, D.C. Carl Rigdon-Elex 813412	18:1
Computer Defined Tuning of Power Modules	"	33:1
Machine Language Graphics	"	28:1
*Nitrogen Fireable Sealing Glass Application Development	"	15:1
Improved Large Area R.F. Power Module Heatsink	"	7:1
Mechanized Assembly of R.F. Power Modules	" Plus, Naval Weapons Center, China Lake, CA Jim D. Raby (Code 3681)	11:1

*This project carries forward to completion work started under this MM&T Program.

Early funding of these projects will yield maximum payback in view of the fact that we are at the beginning phase of SSR Systems production. The reliability of these systems has been demonstrated creating solid long term production requirements. Considering the large quantities of R.F. Power Modules used per system the cost benefits per module which may be derived from the proposed MM&T projects will have very significant favorable total system cost impact.

9. PERSONNEL

The following General Electric Co. personnel have been closely associated with this program and have made important contributions to its' success.

John Balko	-System Safety Engineer
Howard Burris	-Program Mgr. AN/TPS-59 Systems
Jack Chervenic	-R.F. Power Module Product Engineer-Hybrid Facility
William Conger	-Test/Tune Equipment Design and Programming
James Conley	-Mgr. of Mfg. Eng'g. - Hybrid Facility
Rudolph Delisio	-Mfg. Assembly Process Engineer - Hybrid Facility
Joseph Dickson	-Mfg. Process Specialist - Hybrid Facility
Terry Furhovden	-Mgr. of Hybrid Facility
Charles Gioia	-MM&T Program Mgr. - Hybrid Facility
John Grier	-Consultant on Glass Technology - Hybrid Facility
Robert Jones	-Mgr. of Product Eng'g - Hybrid Facility
Robert Kelly	-QC Engineer
Donald Kortkamp	-Mfg. Assembly Process Engineer - Hybrid Facility
Richard Loew	-MM&T Contract Administration
Ronald Mann, PhD	-Mgr. Mechanical Engineering Analysis
Steven Tehon, PhD	-Electronics Laboratory - Ultrasonic Systems

We extend our thanks to the Department of the NAVY, NAVAL Electronics System Command for their support of this program and to Messrs. Walter Stender and Carl Rigdon for their valuable comments and guidance provided during the course of the Program.

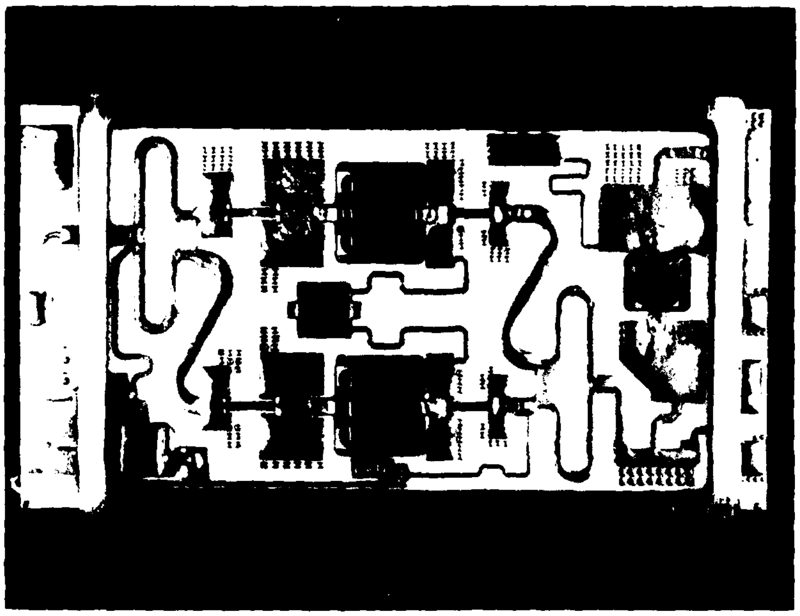


Figure 1. Open 100 W RF Power Module

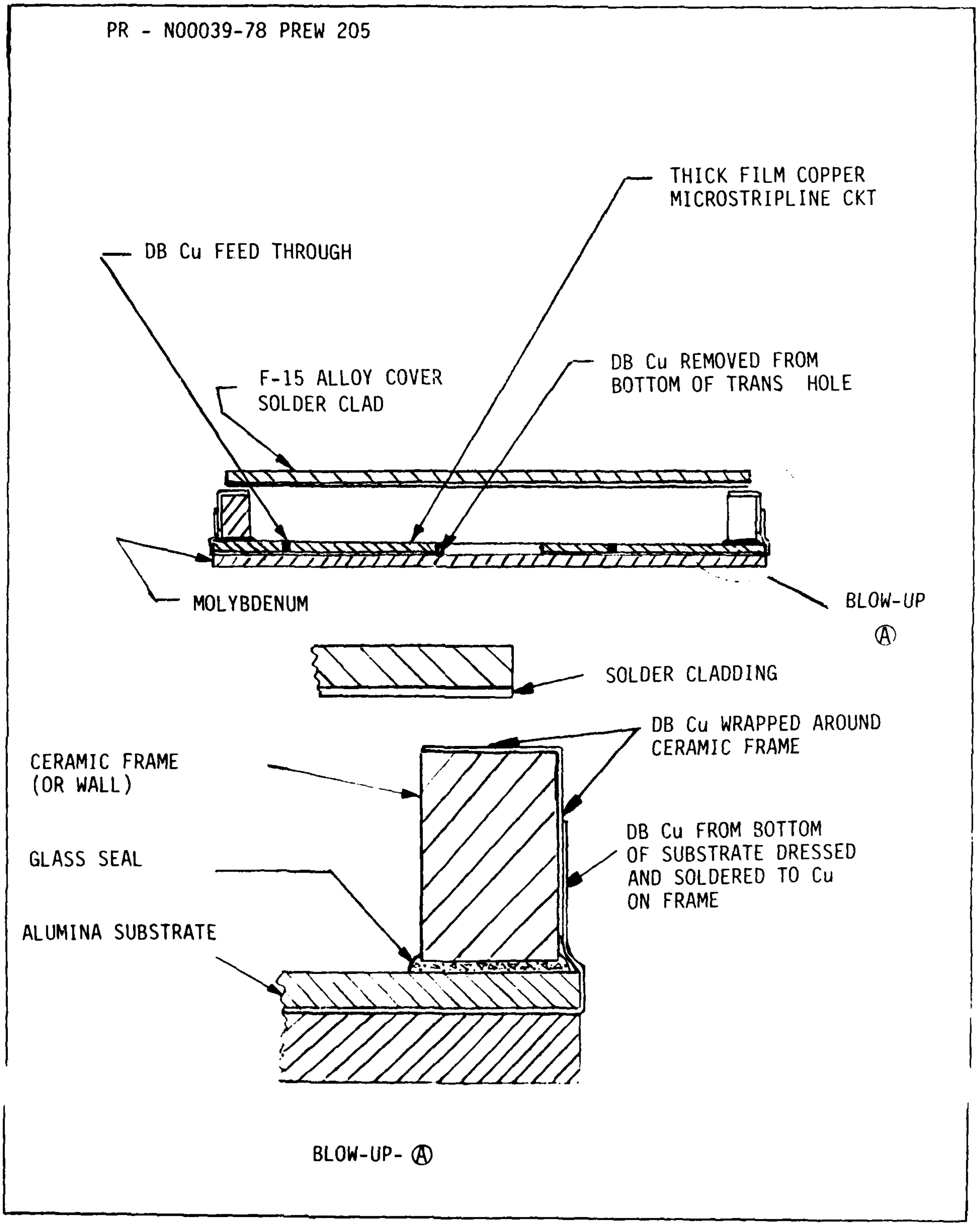


Figure 2. Cross-Section RF 100 W Power Module

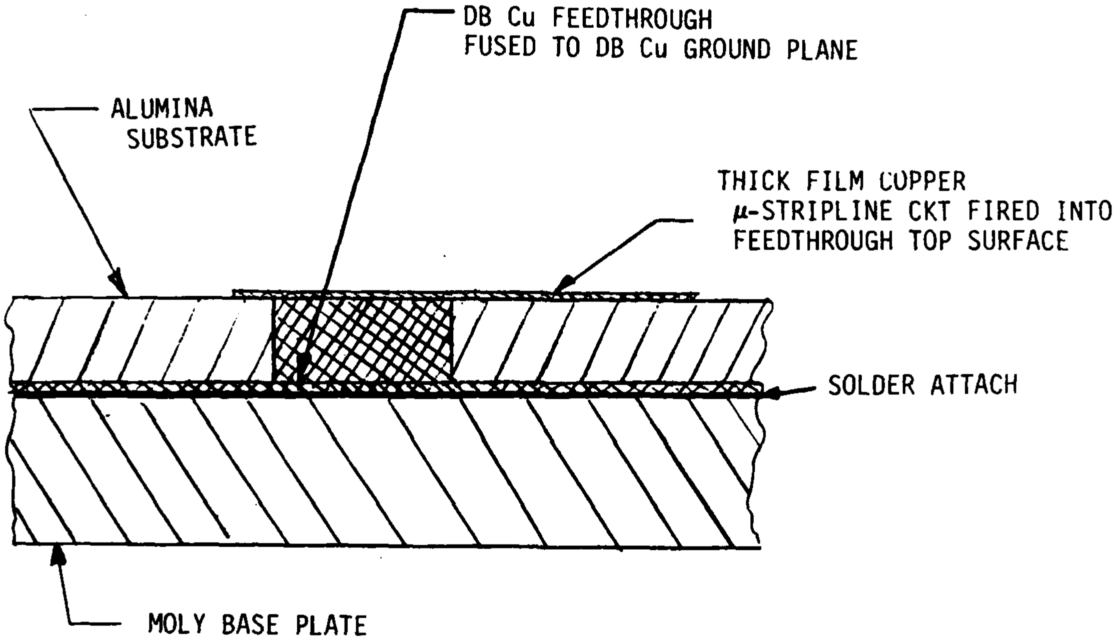


Figure 3. DB Cu Feed Through Section

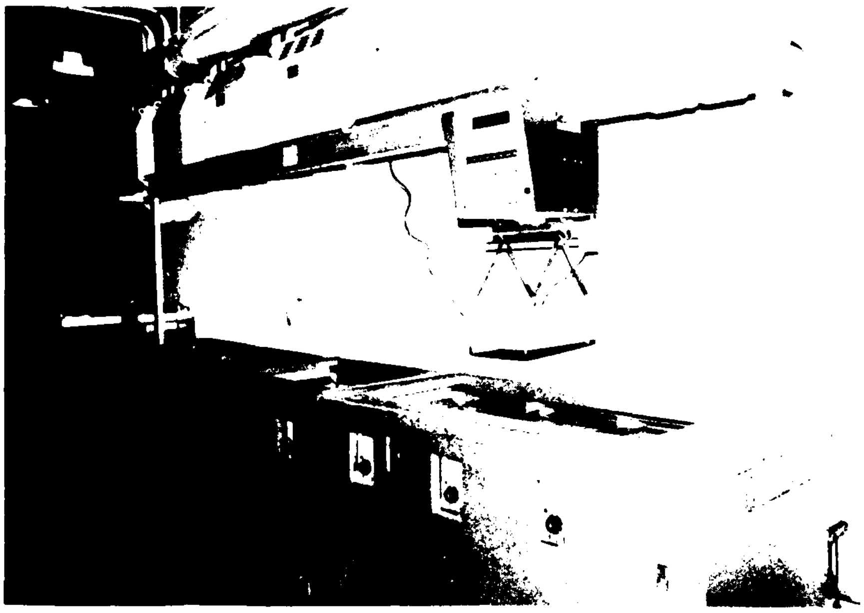


Figure 4. Automatic Copper Oxidizing Machine

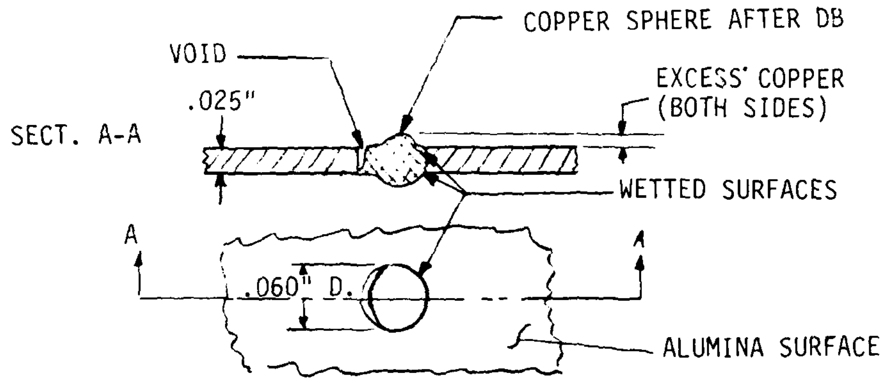


Figure 5. 0.055 In. Diam. Copper Sphere - Void Free Fill

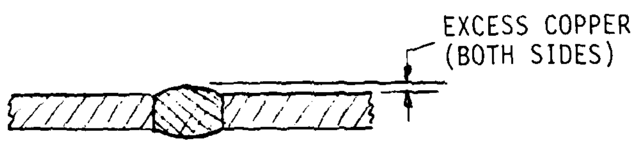


Figure 6. 0.065 in. Diam Copper Sphere - Void Free Fill

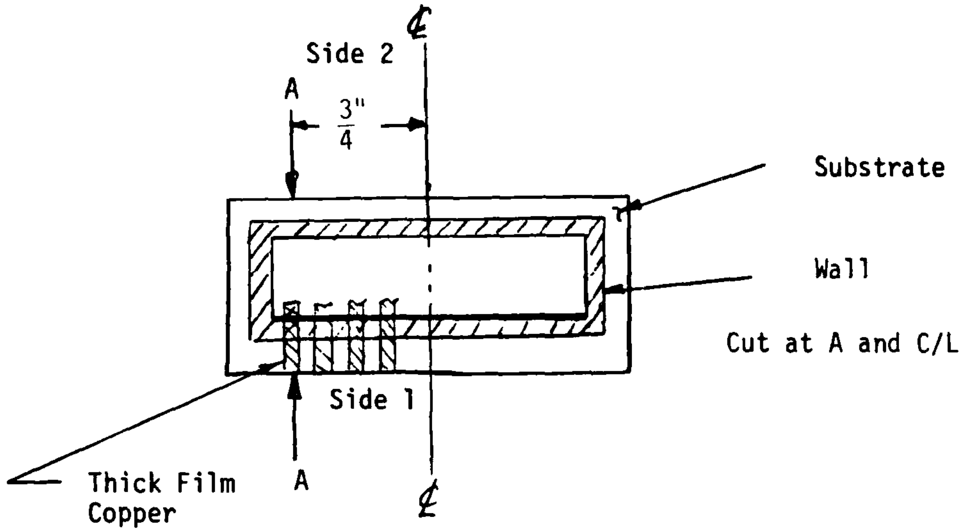


Figure 7. Shear Test Specimen

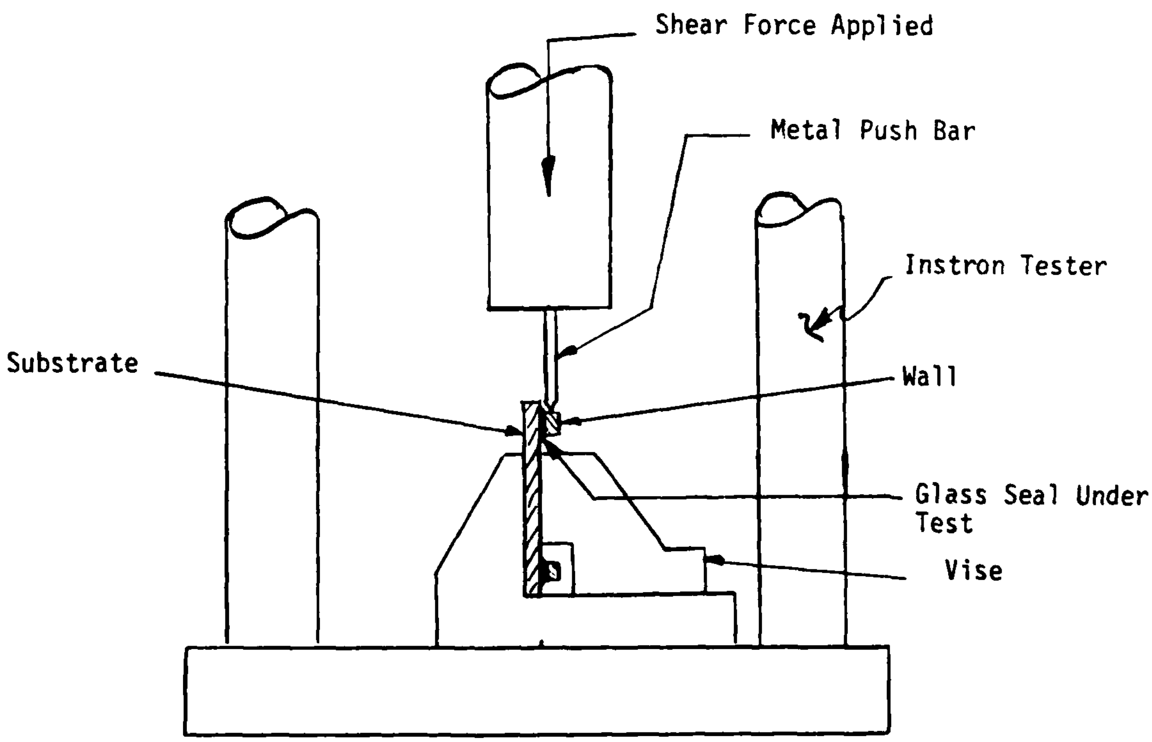


Figure 8. Test Set-Up

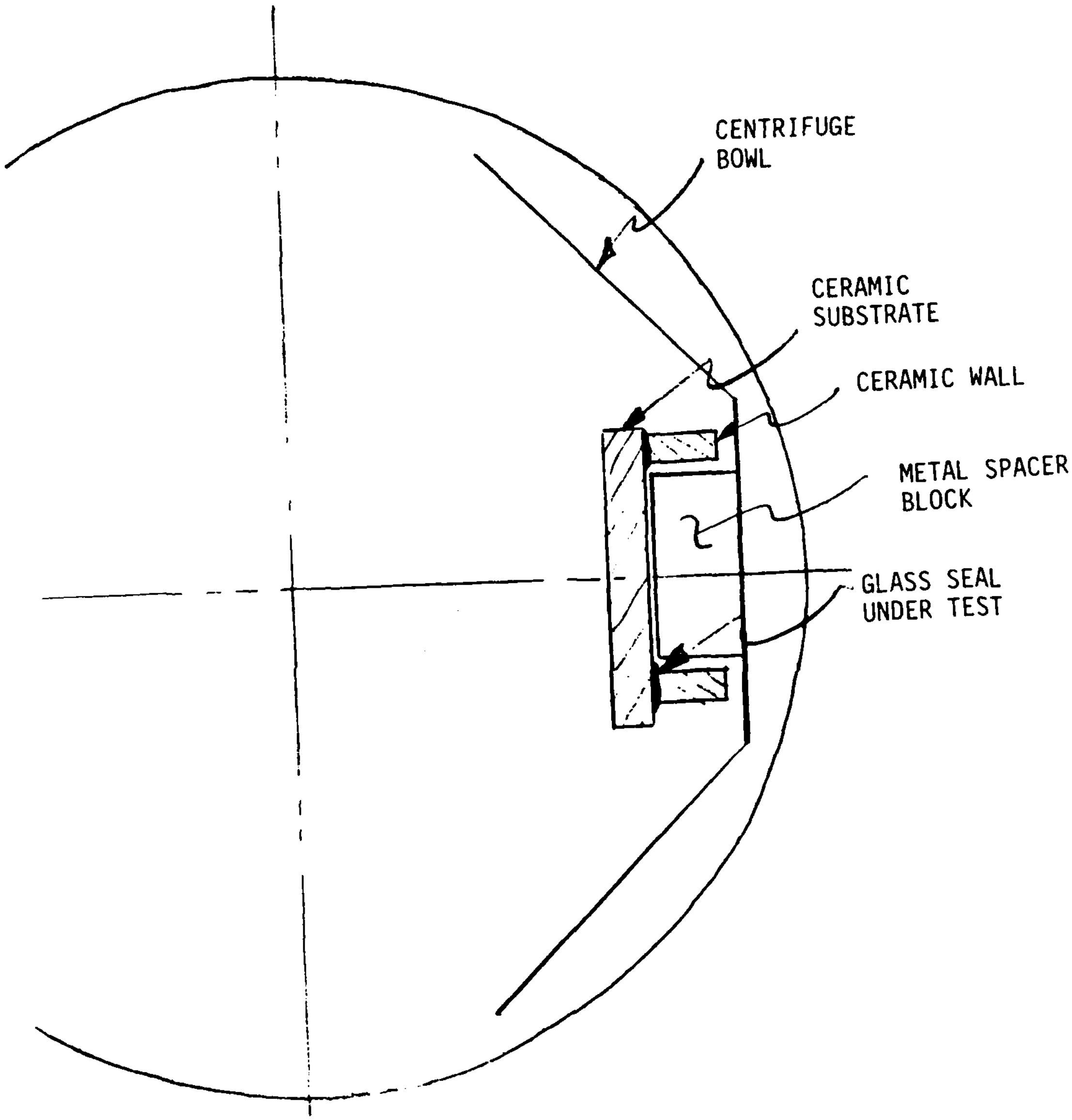


Figure 9. Glass Seal Centrifuge Test

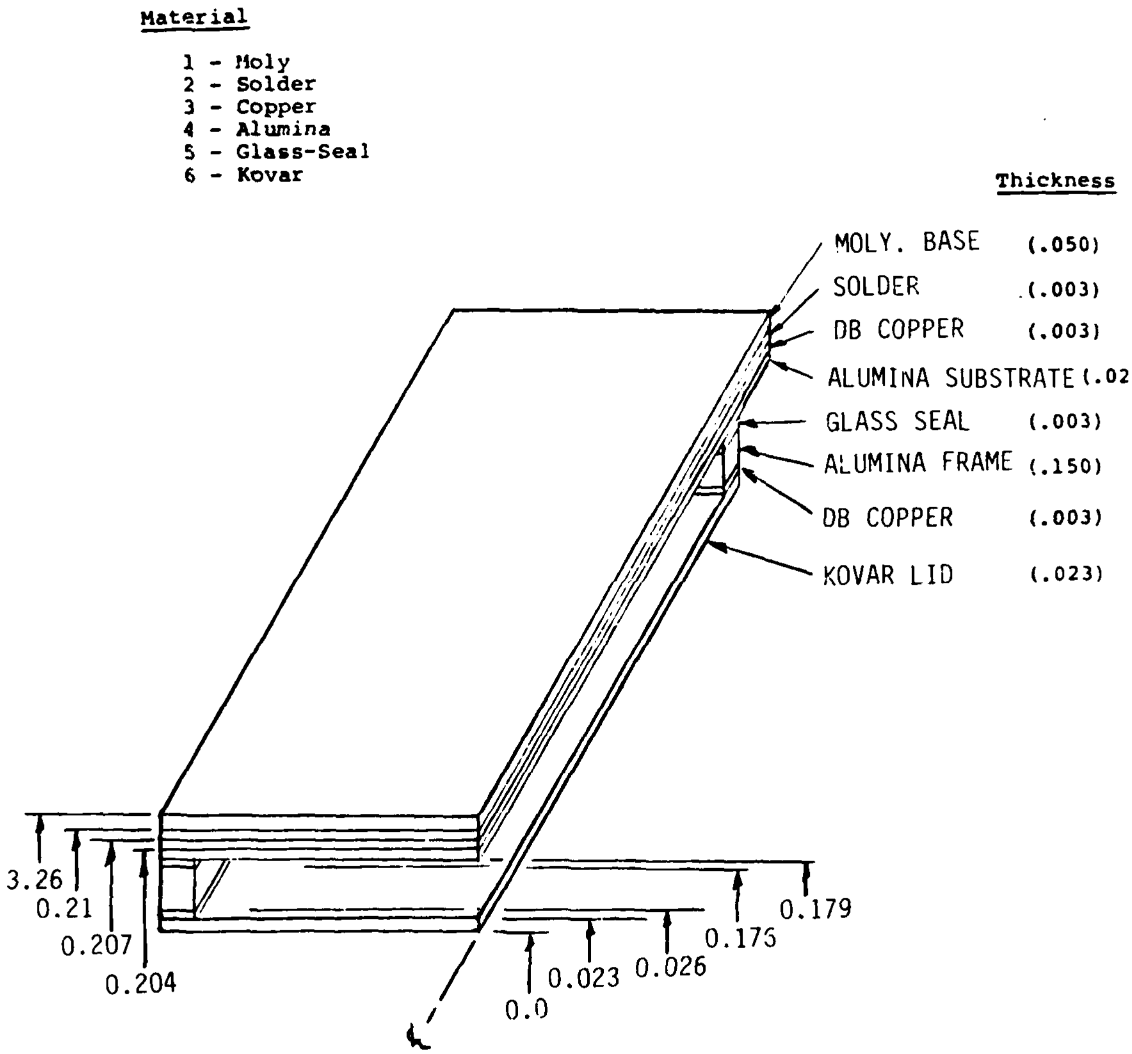


Figure 10. Section of 100W RF P.A. Module

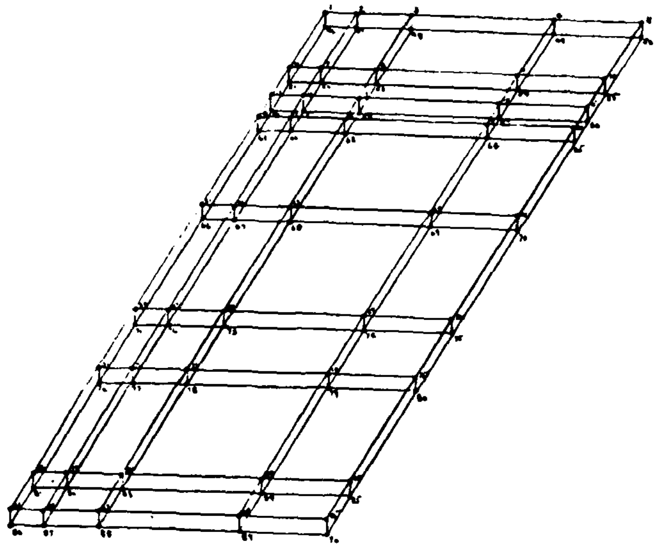


Figure 11. Finite Element Model (Moly Base)

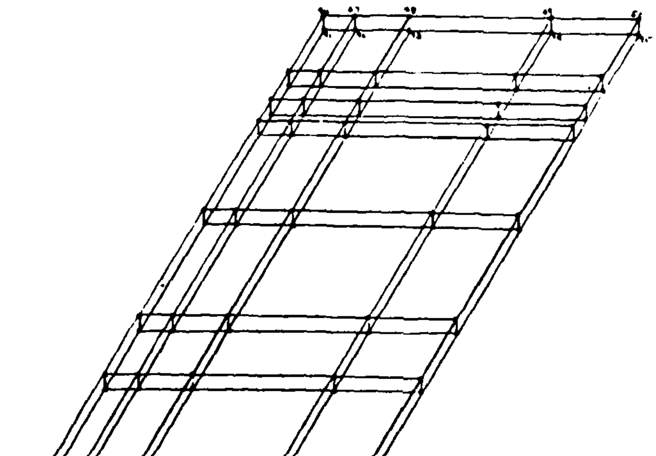


Figure 12. Finite Element Model (Solder)

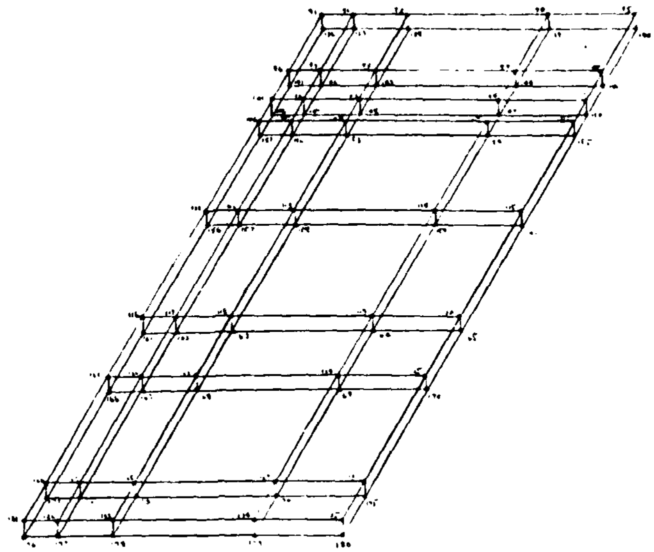


Figure 13. Finite Model (DB Copper)

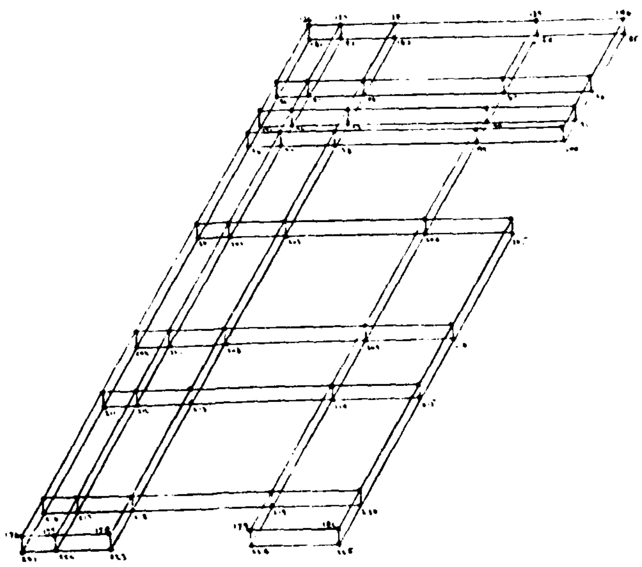


Figure 14. Finite Model (Substrate)

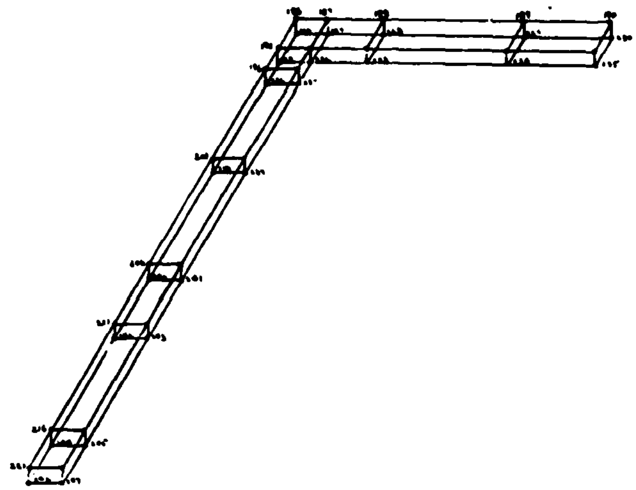


Figure 15. Glass Seal

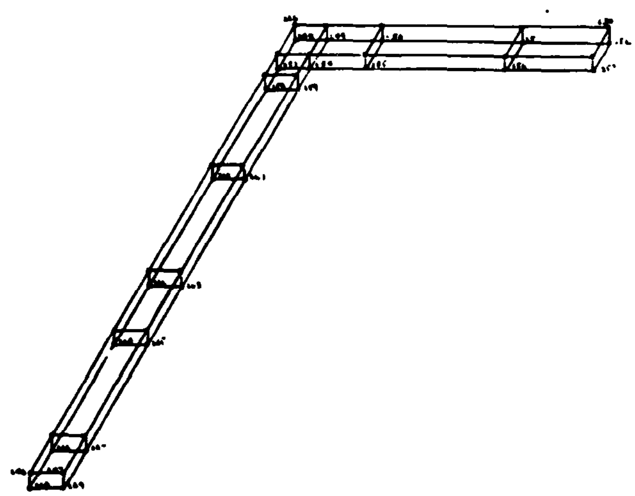


Figure 16. Alumina Wall

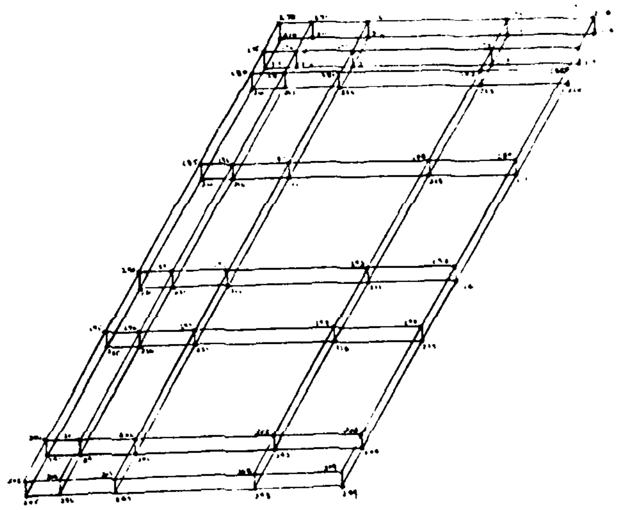


Figure 17. DB Copper

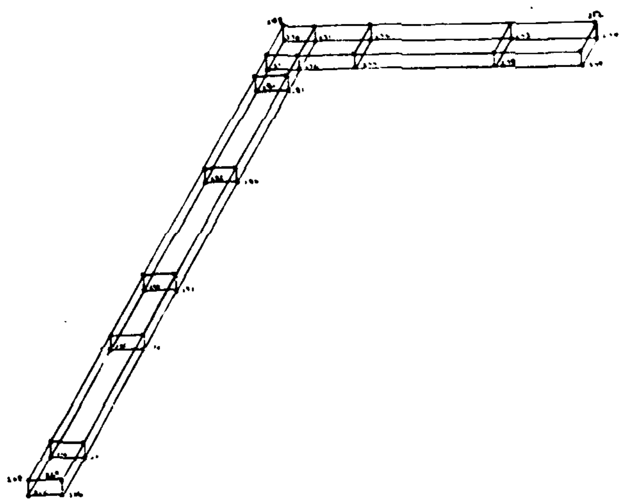


Figure 18. Kovar Lid

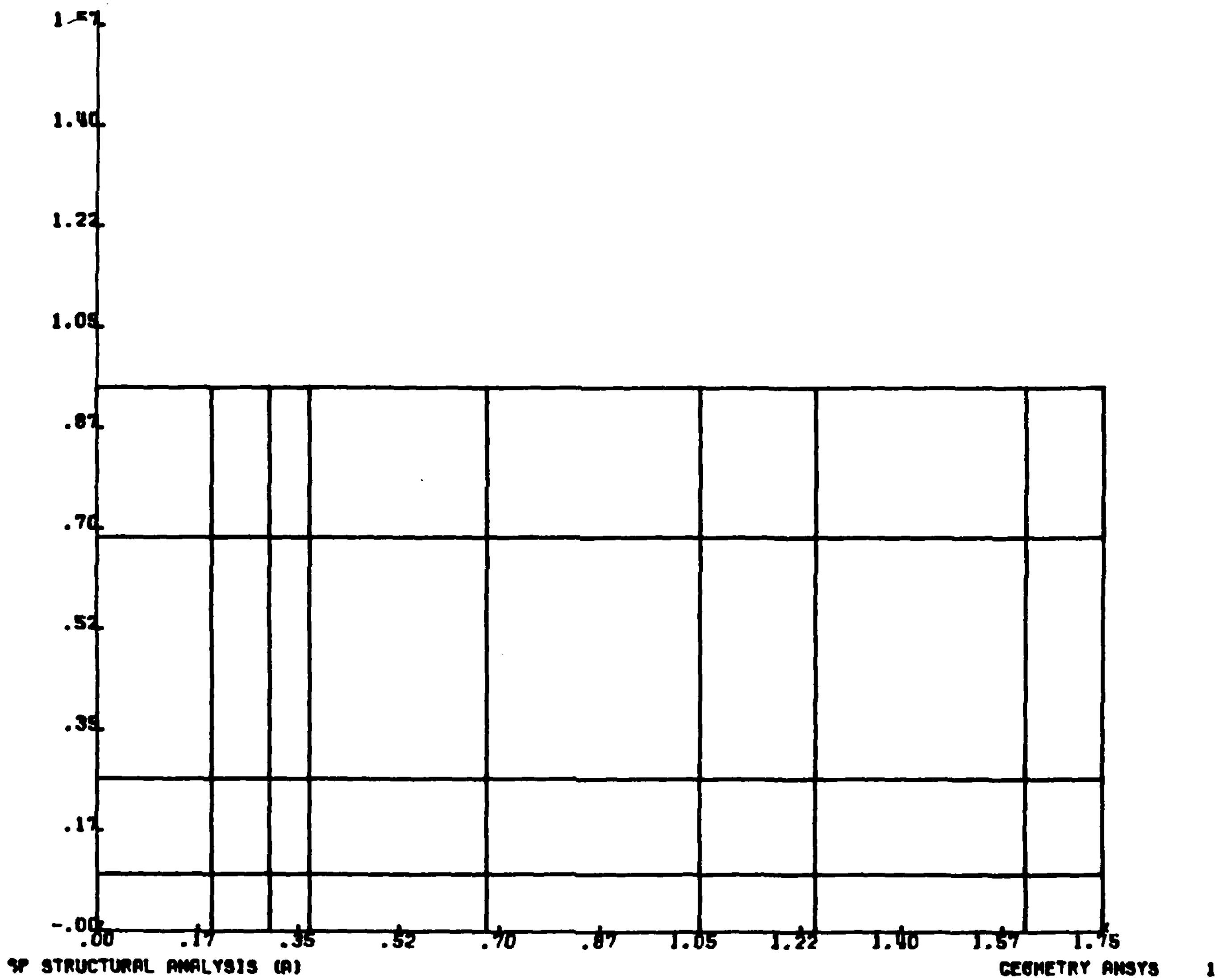


Figure 19. Plan View ¼ Module

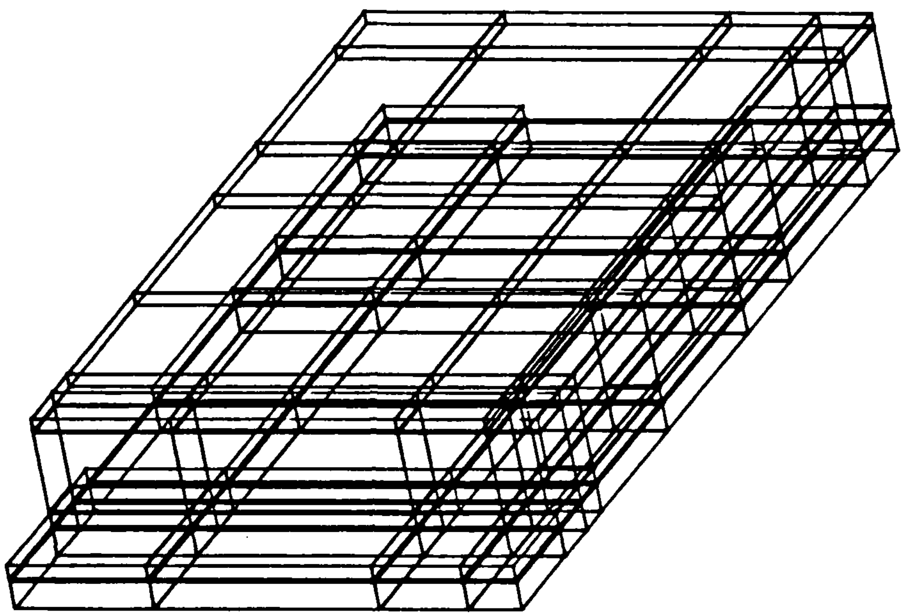


Figure 20. Node Geometry

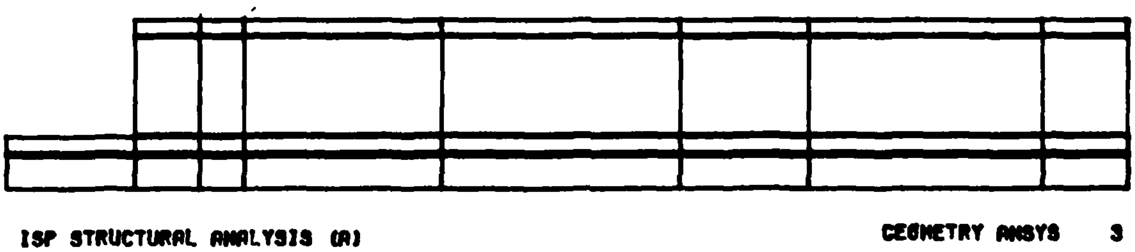


Figure 21. Side View ¼ Module

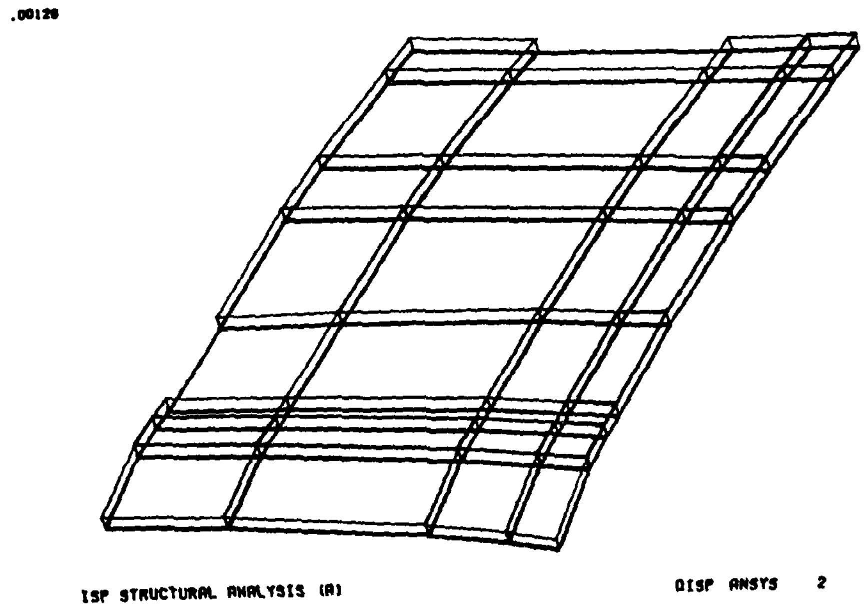


Figure 22. Substrate Displacement Resulting From Temp Extremes

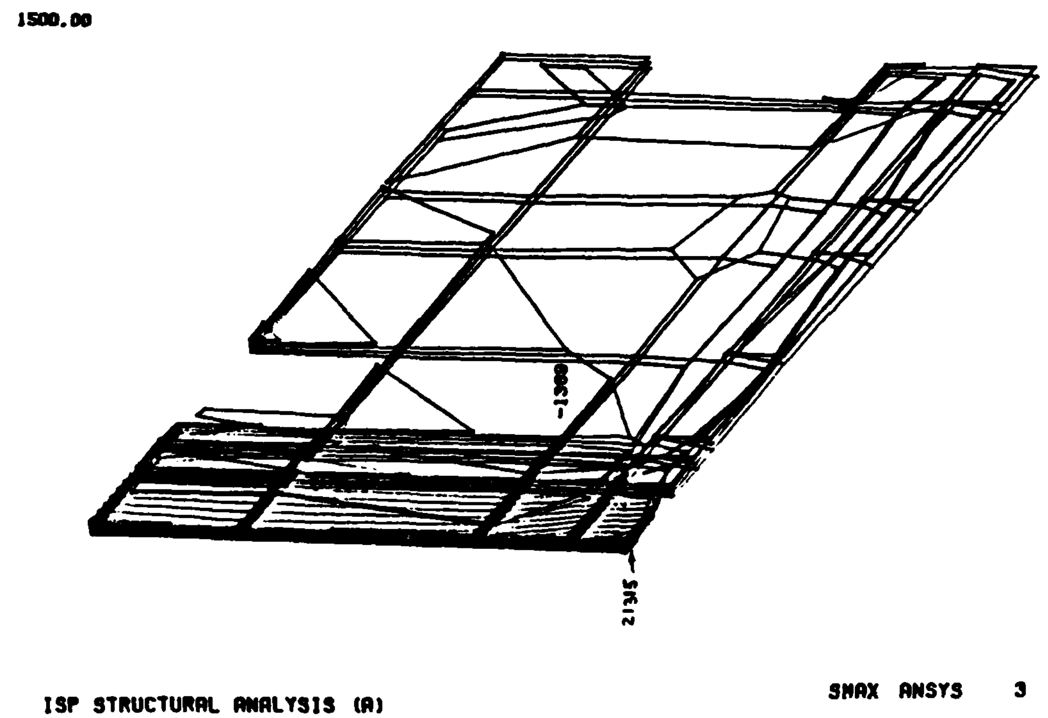


Figure 23. Max. Stresses on Sub Due to Temp Extremes

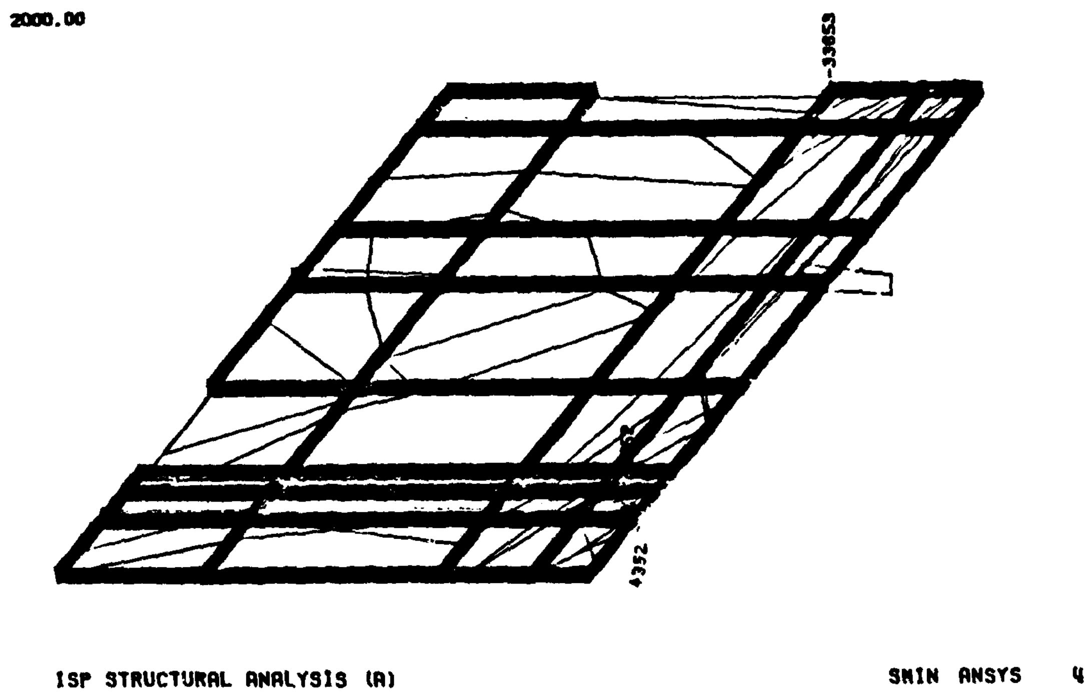


Figure 24. Min Stresses on Sub Due to Temp Extremes

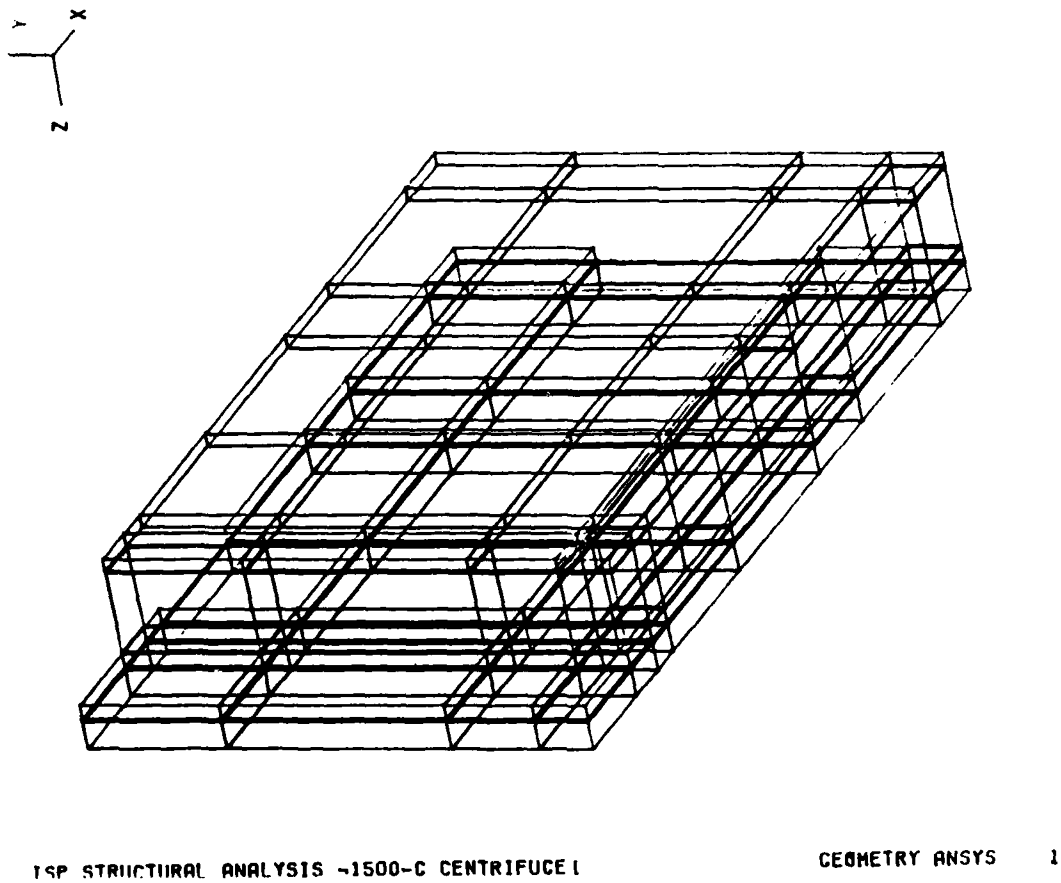


Figure 25. Input Geometry for Centrifuge Stress

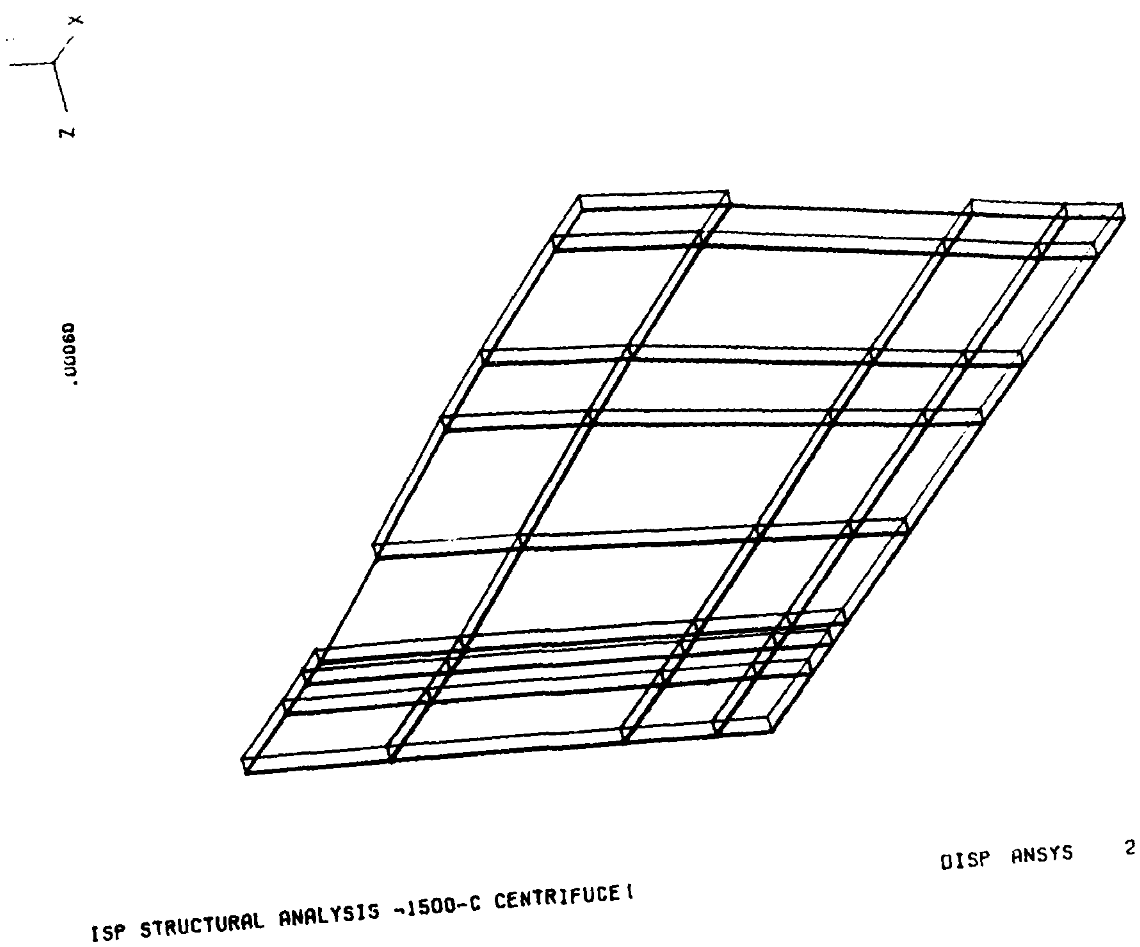


Figure 26. Displacement of Sub Due to Cent. Stress

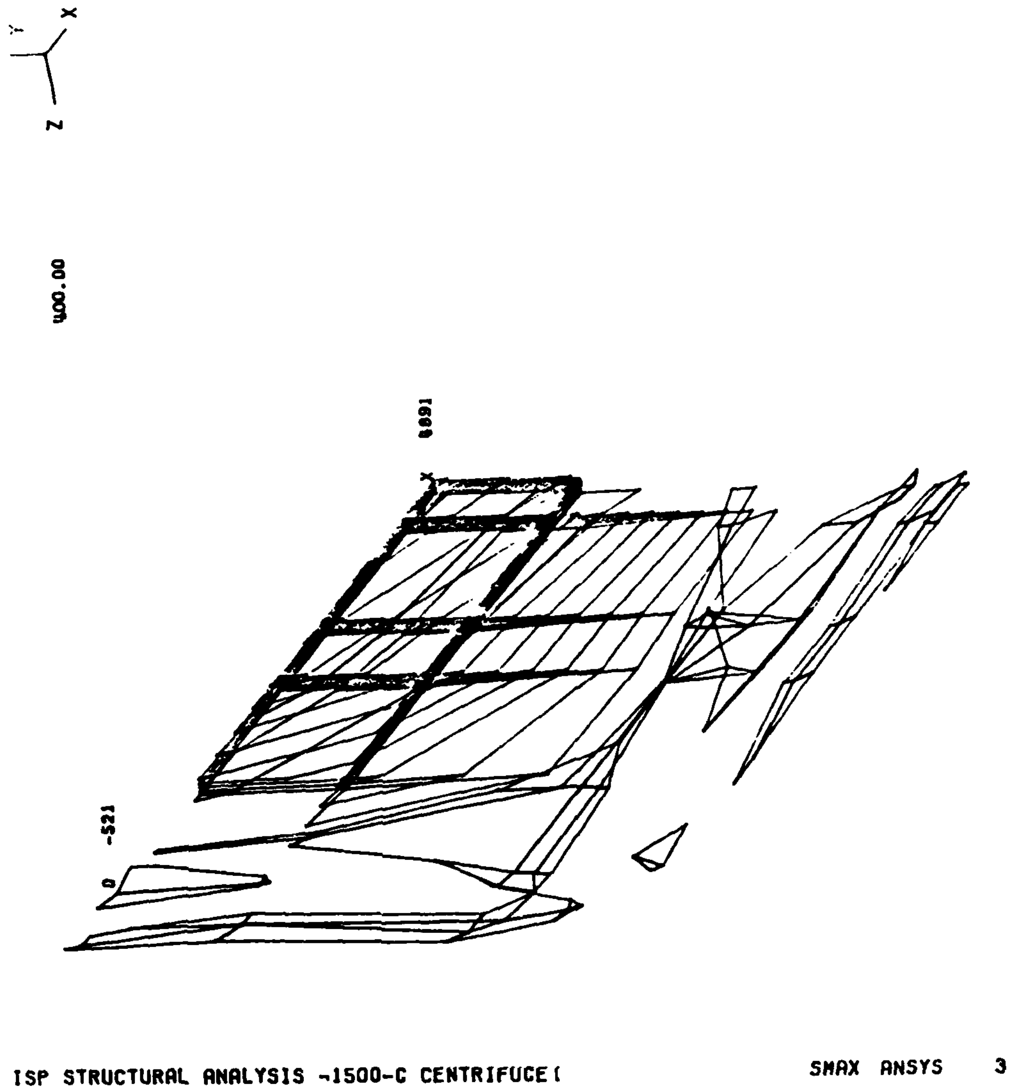


Figure 27. Sub Max. Stress Due to Centrifuge

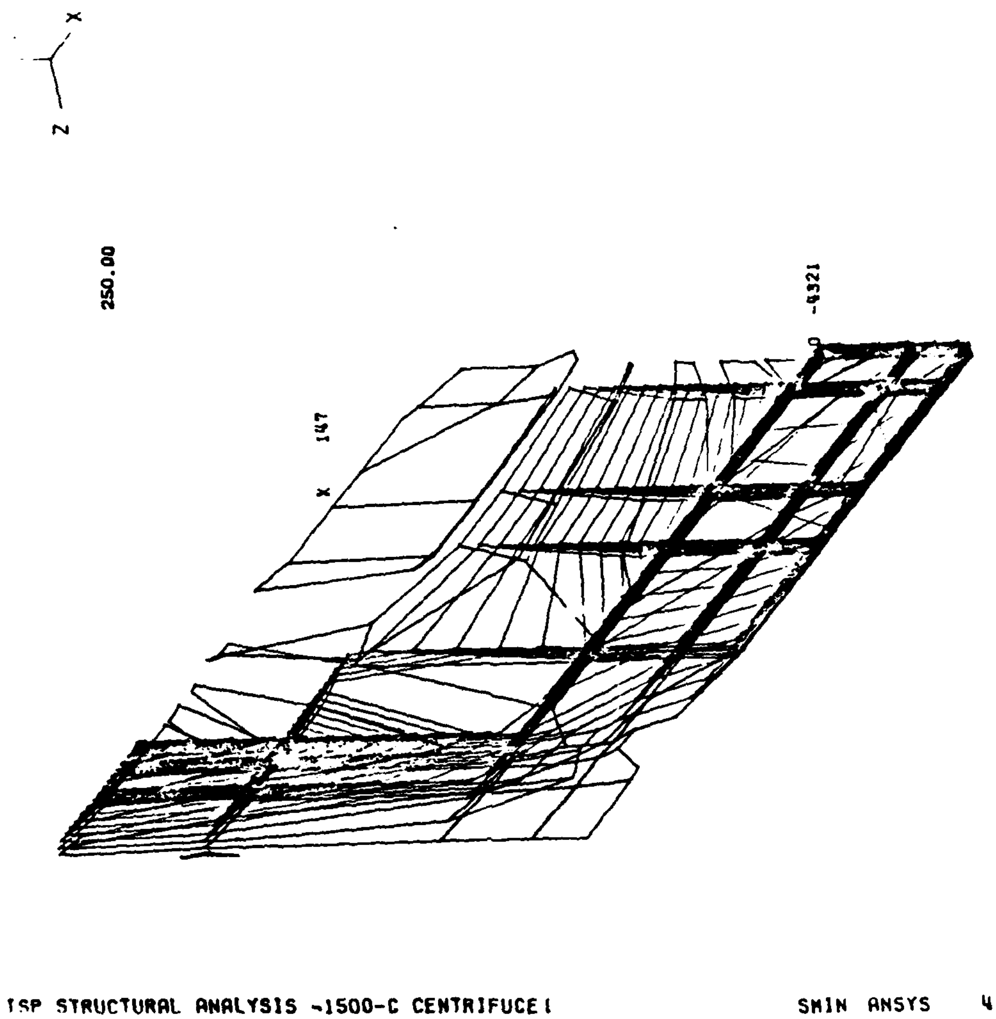


Figure 28. Sub Min Stress Due to Centrifuge

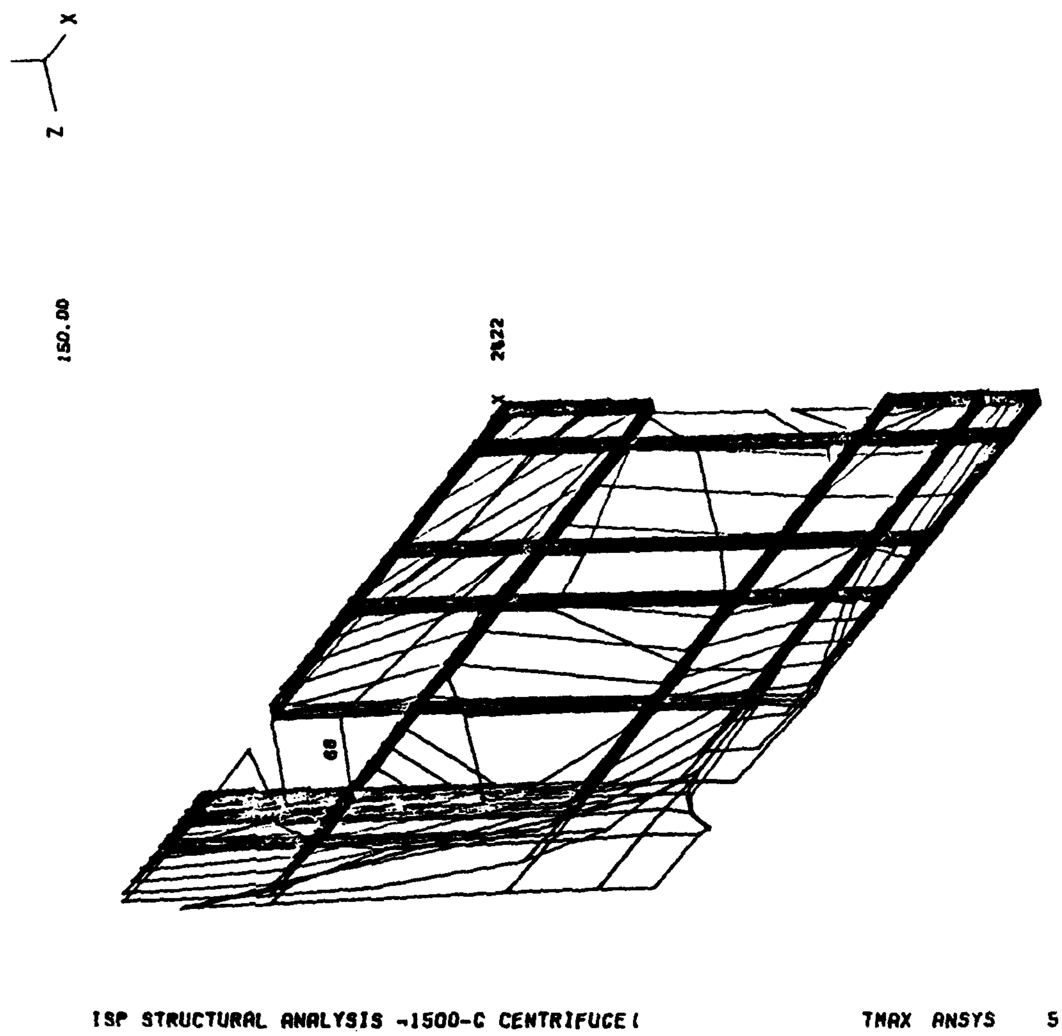


Figure 29. Sub Tot. Max. Stress Due to Centrifuge

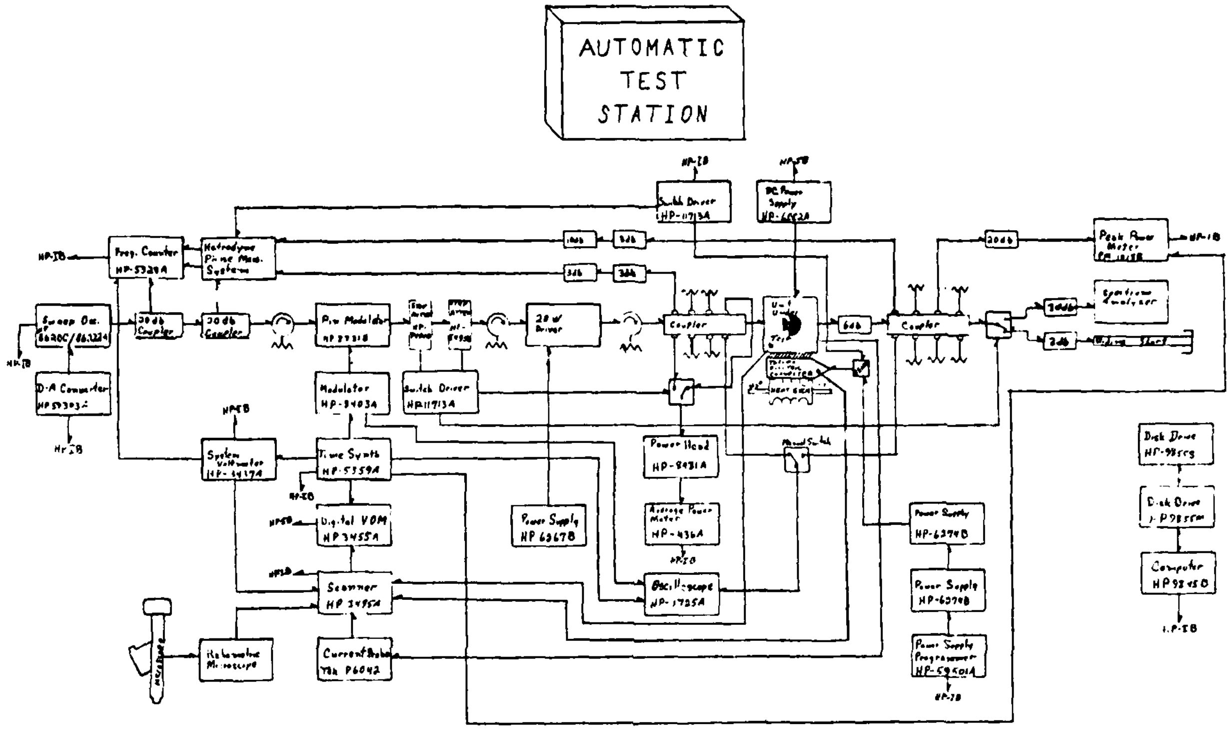


Figure 30. Semi-Automatic Test Station Block Diagram

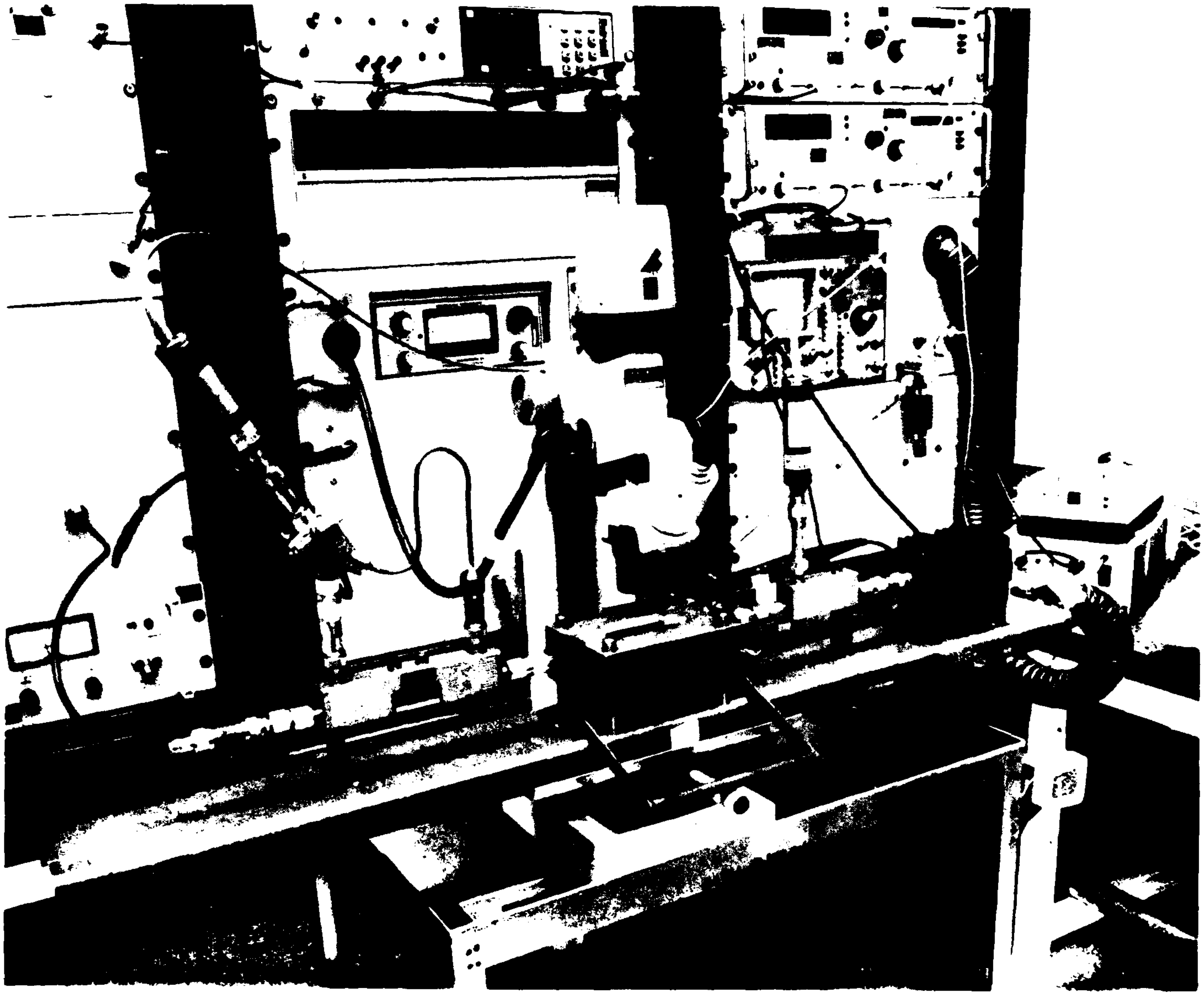
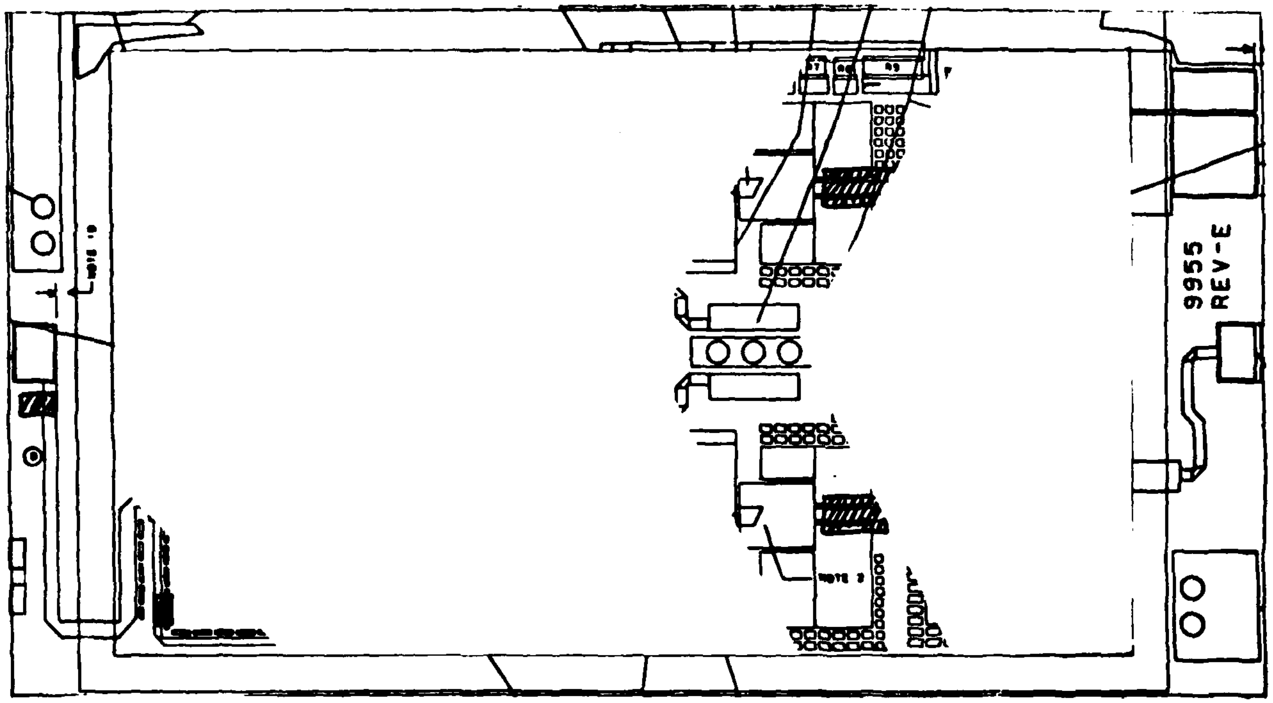


Figure 31. Semi-Automatic Test Station

SN 2438



Rev	Tuning Tab Information		
1	Add Tabs Noted B&B 2-19-81	MAS	2-20-81
2	Scribe 29 ℋ 2-23-81	ℋ	2-23-81

Figure 32. Typical Traveler Showing Location of Tuning Pads

(PMT2 Revised 010581)
(Phase Cal Module Serial No.-2 , Data Run Of 0718/021981)
Amplifier, RF (power) 77D608042
Serial No.[redacted] R No.1
Module Status 1
Time 1514 Hours, Date 021981
TJH At Station No.2
Vcc Is [redacted] 37.3dBm RF Power Input At [redacted] Duty
Pulse =[redacted]uS, RepRate =[redacted]ertz
Temperature Is 32DegC

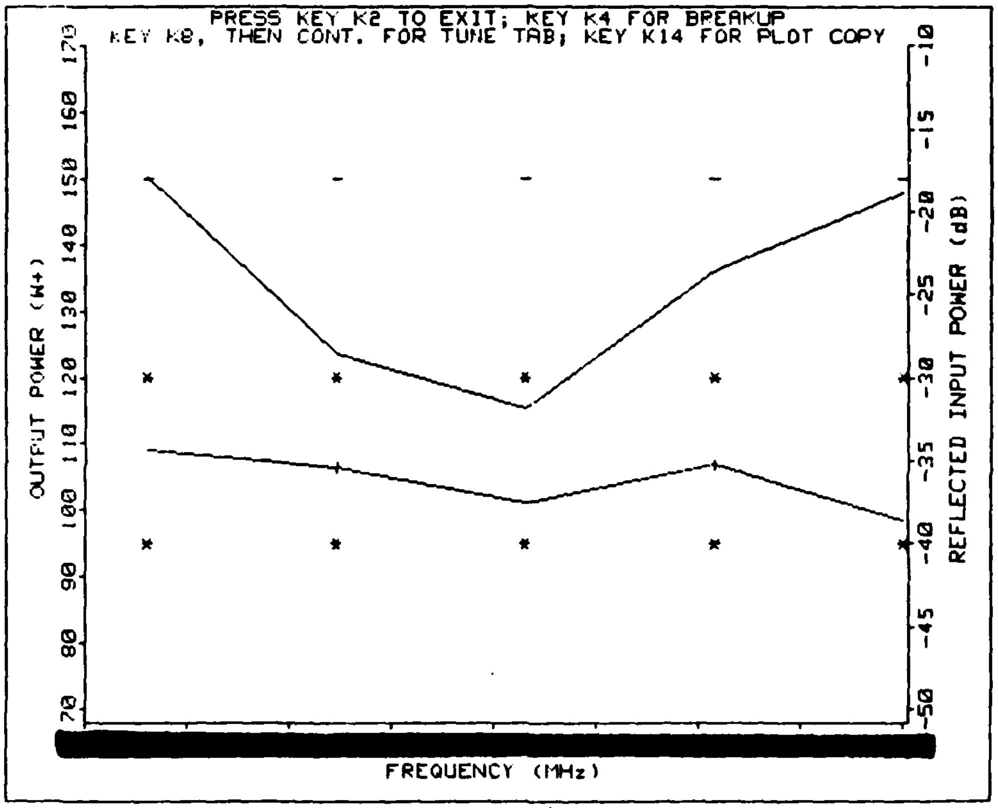


Figure 33. Typical Machine Plot of f/Output Power vs Refl Inp Power Vs Reflected Input Power

(PMT2 Revised 010581)
(Phase Cal Module Serial No.-2 , Data Run Of 0718/021981)
Amplifier, RF (power) 77D608042
Serial No [redacted] R No.1
Module Status 1
Time 1515 Hours, Date 021981
TJH At Station No.2
Vcc Is [redacted] 37.3dBm RF Power Input At [redacted] Duty
Pulse = [redacted] uS, RepRate = [redacted] Hertz
Temperature Is 32DegC

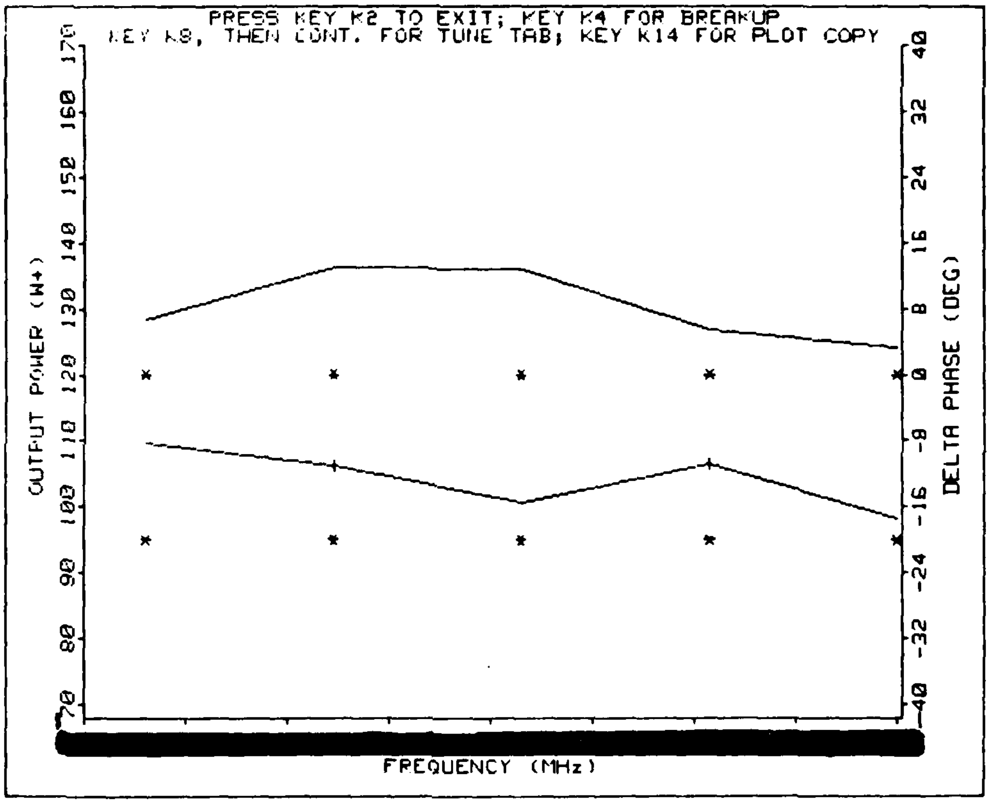


Figure 34. Typical Mach Plot of f/Output Power Vs Delta Phase

(TPMT1 Revised 010581)
(Phase Cal Module Serial No.-2 , Data Run Of 0716/020481)
Amplifier, RF (power) 77D608042
Serial No[redacted], R No.3
Module Status 1
Time 0937 Hours, Date 020481
BGB At Station No.1
Vcc Is[redacted]; 37.3dBm RF Power Input At[redacted] Duty
Temperature Is 32DegC
Module Phase Tab Designator Is 4

Freq MHz	Pout W	Ret Loss (dB)	Ic Amps	Eff % (40% Min)	Droop % (12% Max)	Phase Deg
F1	109.8	21.2	9.7	40.9	7.2	-38.4
F2	108.8	21.8	9.7	40.6	8.5	34.0
F3	108.6	19.2	9.7	40.3	9.6	104.1
F4	103.9	24.0	9.0	41.8	8.4	167.2
F5	100.4	22.3	8.6	41.8	7.5	-125.7

Freq MHz	Harm (35dB Min)	Other Spur (60dB Min)	Pulse Break-up
F1	N	N	X
F2	N	N	X
F3	N	N	X
F4	N	N	X
F5	N	N	X

	Transistor Hottest Cell ([redacted] Duty)		
	Q1	Q2	Q3
F,MHz	[redacted]	[redacted]	[redacted]
CNUM	3	12	1
CT,DegC	115.3	141.1	141.8
ST,DegC	32.9	32.9	32.9
DT,DegC	82.4	108.3	109.0
Ic,A	9.7	9.7	9.7

Where: CNUM=Cell Number
CT=Cell Temperature
ST=Sink Temperature
DT=Delta Temperature

Figure 35. Typical Computer Print-Out Data Sheet

N AVELEX M.T. - MILESTONES - CLIN 0001 - STUDY OF IMPROVED METHODS

TASK 3.3.1A

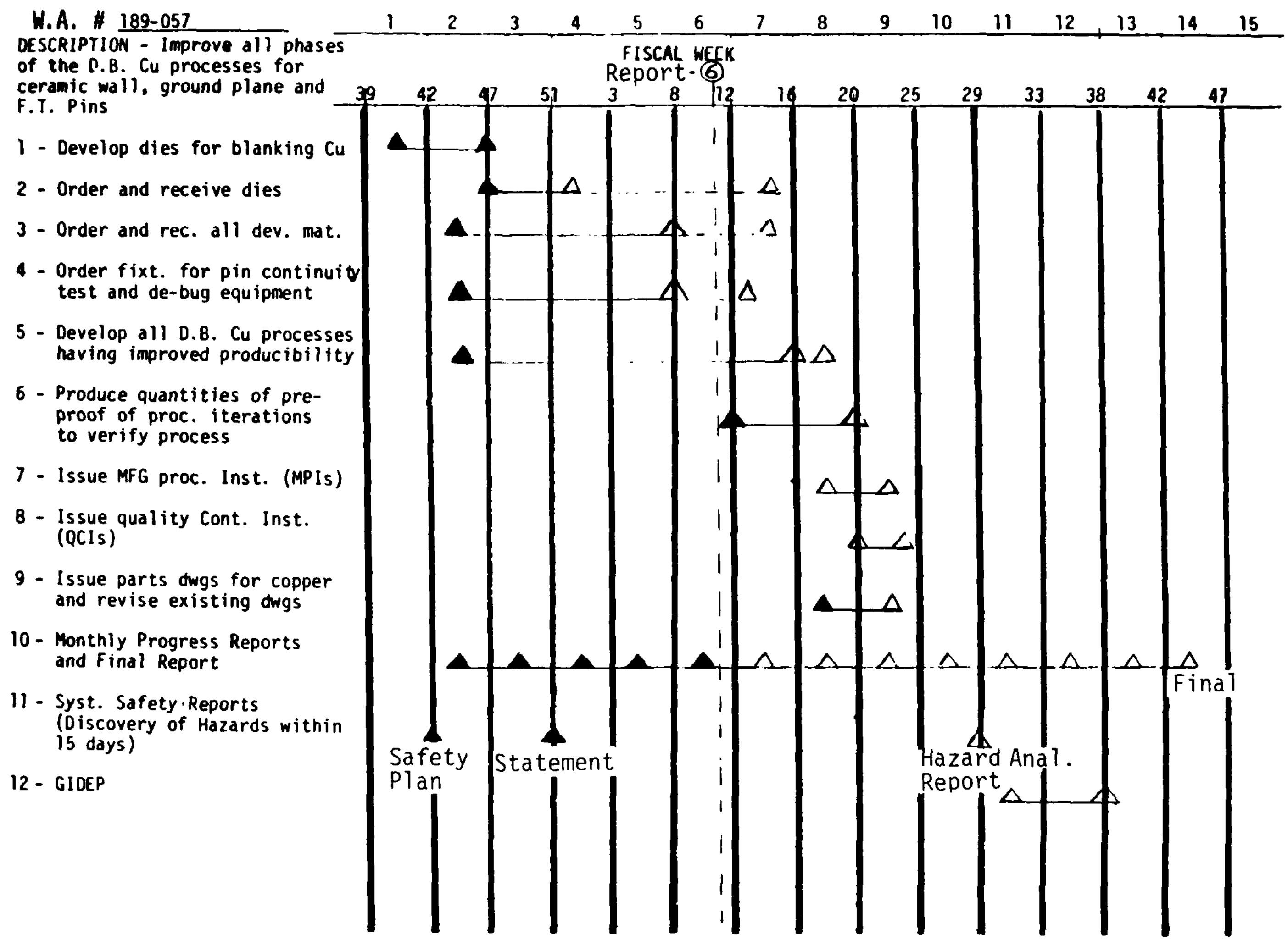


Exhibit "A" (Sheet 1 of 5)
Program Milestone Charts for Tasks and Subtasks

N AVELEX M.T. - MILESTONES - CLIN 0001 - STUDY OF IMPROVED METHODS

TASK 3.3.1B

W.A. # 189-058

DESCRIPTION - Develop N_2 Fireable seal glass

1 - Literature search

2 - Evaluate candidate glasses

3 - Reformulate glass for this specific application

4 - Order & receive production glass

5 - Develop glass seal processes having improved producibility

6 - Produce quantities of pre-proof of proc. iterations to verify process

7 - Issue MPIs

8 - Develop Q.C. procedure and issue QCIs

9 - Revise existing dwgs if required

10 - Monthly Progress Reports and Final Report

11 - System Safety Reports (Discovery of Hazards within 15 Days)

12 - GIDEP

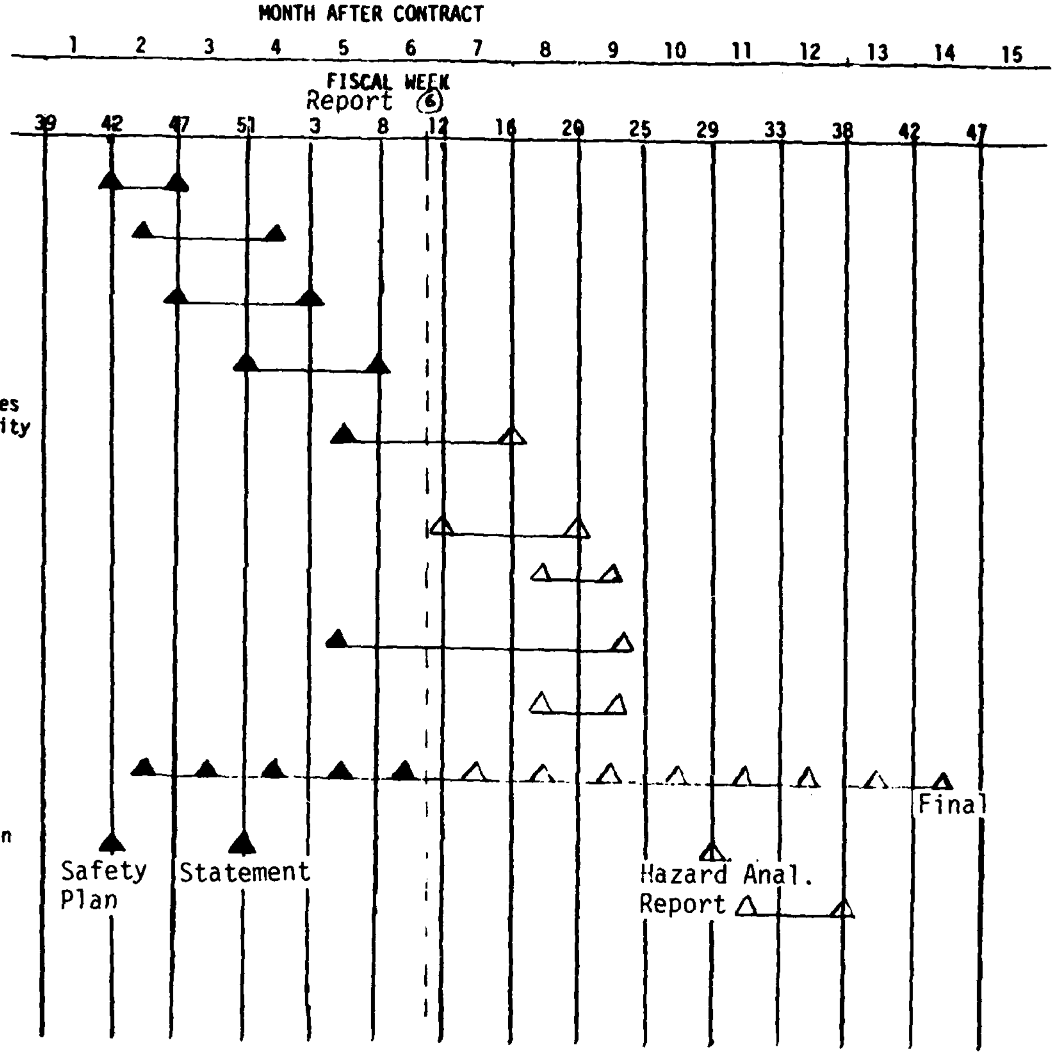


Exhibit "A" (Sheet 2 of 5)
Program Milestone Charts for Tasks and Subtasks

NAVELEX M.T. - MILESTONES - CLIN 0001 - STUDY OF IMPROVED METHODS

TASK 3.3.1C

W.A. # 189-056

DESCRIPTION - Develop lid seal process for sealing non-clad kovar lid

1 - Order and receive kovar lids with nickel plate

2 - Develop pre-tin process for lid

3 - Develop seam seal process having improved producibility

4 - Produce quant. of pre-proof of process iterations to verify process

5 - Issue MPIs

6 - Issue QCIs

7 - Issue and/or revise dwgs

8 - Monthly Progress Reports and Final Report

9 - System Safety Reports (Report discovery of Hazard within 15 days)

10 - GIDEP

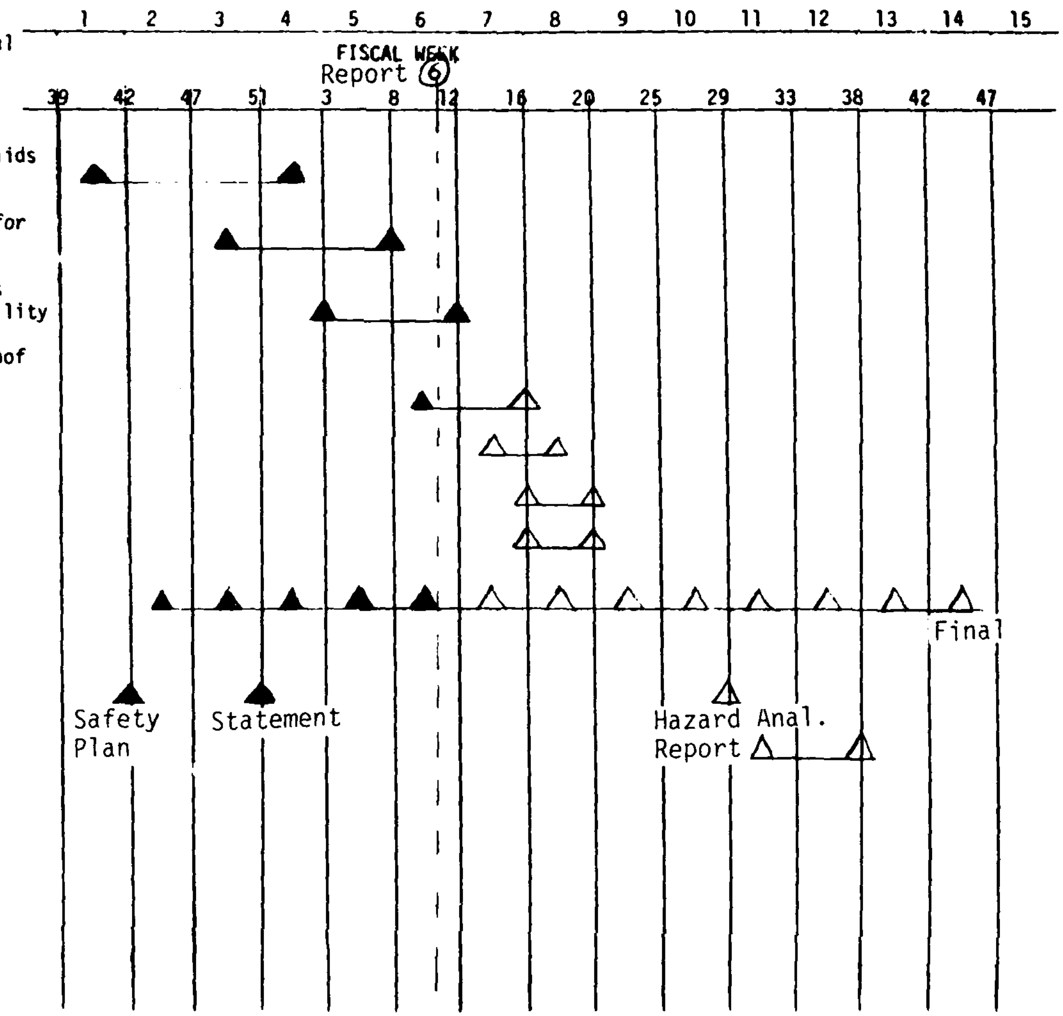


Exhibit "A" (Sheet 3 of 5)
Program Milestone Charts for Tasks and Subtasks

NAVELEX M.T. - MILESTONES - CLIN 0001 - Semi-Automated Tuning

TASK 3.3.2

W.A. # 189-059

DESCRIPTION - Debug equipment and software integration

1 - Complete individual software modules

2 - Interface each software mod. with instrument

3 - Perform partial systems test of software/hardware

4 - Test complete system using all instruments of software

5 - Perform complete testing of a quantity of power modules

6 - Revise and modify software and test procedures

7 - Complete documentation of Test Procedure

8 - Test proof of process modules

9 - Monthly Progress Reports and Final Report

10 - Syst. Safety Reports Discovery of Hazards report within 15 days

11 - GIDEP

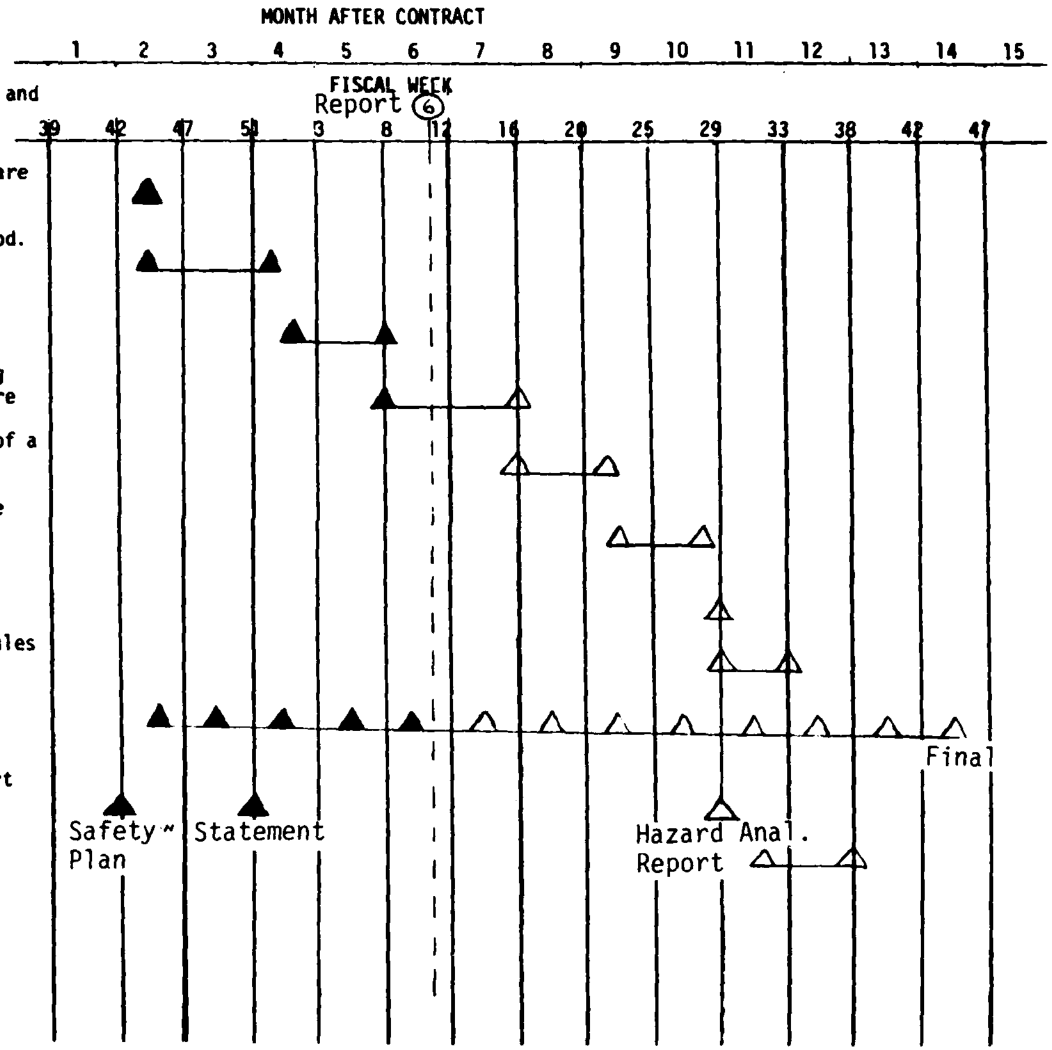


Exhibit "A" (Sheet 4 of 5)
Program Milestone Charts for Tasks and Subtasks

N AVELEX M.T. - MILESTONES - CLIN 0002 - Produce 25 Final Proof of Process Demonstration Power Mod.

TASK 3.3.2

W.A. # 189-109

DESCRIPTION - Build 25 power mod. with improved documented processes and tune/test with improved T.E.

1 - Order materials for build

2 - Build 25 power modules using documented improved processes

3 - *Tune & test assembled modules with documented instructions on improved test equipment*

4 - Develop Qualification Test Plan and Qual. Test

5 - Issue Qual. Test Report

6 - Revise assembly dwgs as required

7 - Monthly Progress Reports and Final Report

8 - *System Safety Reports* Report discovery of hazards within 15 days

9 - *GIDEP*

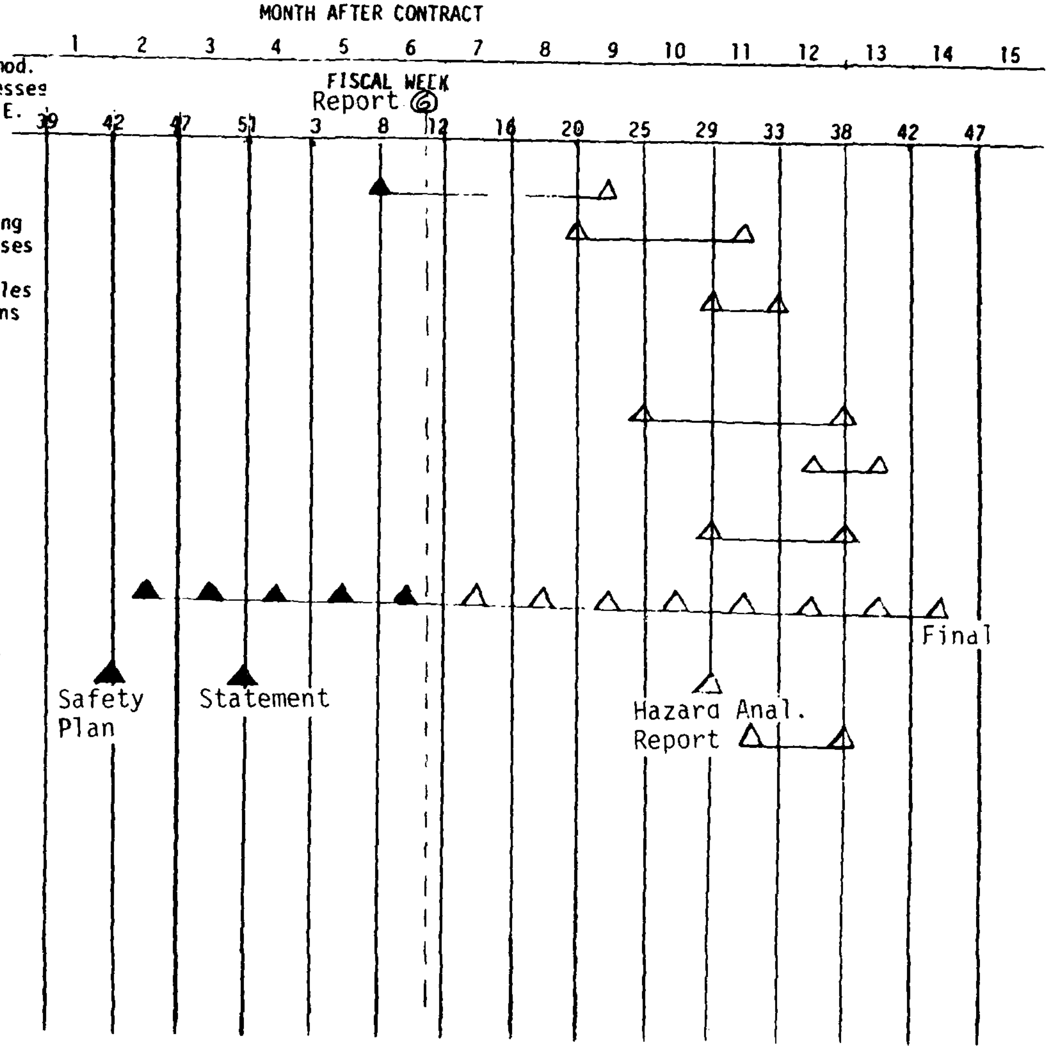


Exhibit "A" (Sheet 5 of 5)
Program Milestone Charts for Tasks and Subtasks

AD-A105 892 GENERAL ELECTRIC CO SYRACUSE NY MILITARY ELECTRONIC --ETC F/G 17/9
MANUFACTURING TECHNOLOGY STUDY ON RADIO FREQUENCY POWER MODULES--ETC(U)
1981 N00039-79-C-0378

UNCLASSIFIED NL

2 OF 3
AD A
105892

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APPENDIX A

RADIO FREQUENCY AMPLIFIER (POWER)
(Specification Control Drawings)
(2 Pages)

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	UPDATED REV STATUS BLOCK ECN A77L10333		
	B	(1) CHNG W1S STATEMENT DRAWING (2) CHNG NOTE 1.1 (3) ADDED TABLE ECN B6GL10104		

1. NOTES

1.1 SUGGESTED SOURCE(S) OF SUPPLY: SEE TABLE

1.1.1 SUGGESTED SOURCES ARE NOT INTENDED TO REPRESENT THE ONLY SOURCE FOR THE ITEM.

1.2 DESCRIPTION: THE ITEM DESCRIBED HEREIN IS AN RF POWER AMPLIFIER, IN HYBRID MICROCIRCUIT FORM.

1.3 FOR GE EBU-SY ONLY

1.3.1 PURCHASE ONLY FROM AN APPROVED VENDOR.

1.3.2 APPROVAL REQUIRED FROM ESD-SY COMPONENTS ENGINEERING PRIOR TO USE ON NEW DESIGNS.

2. REQUIREMENTS

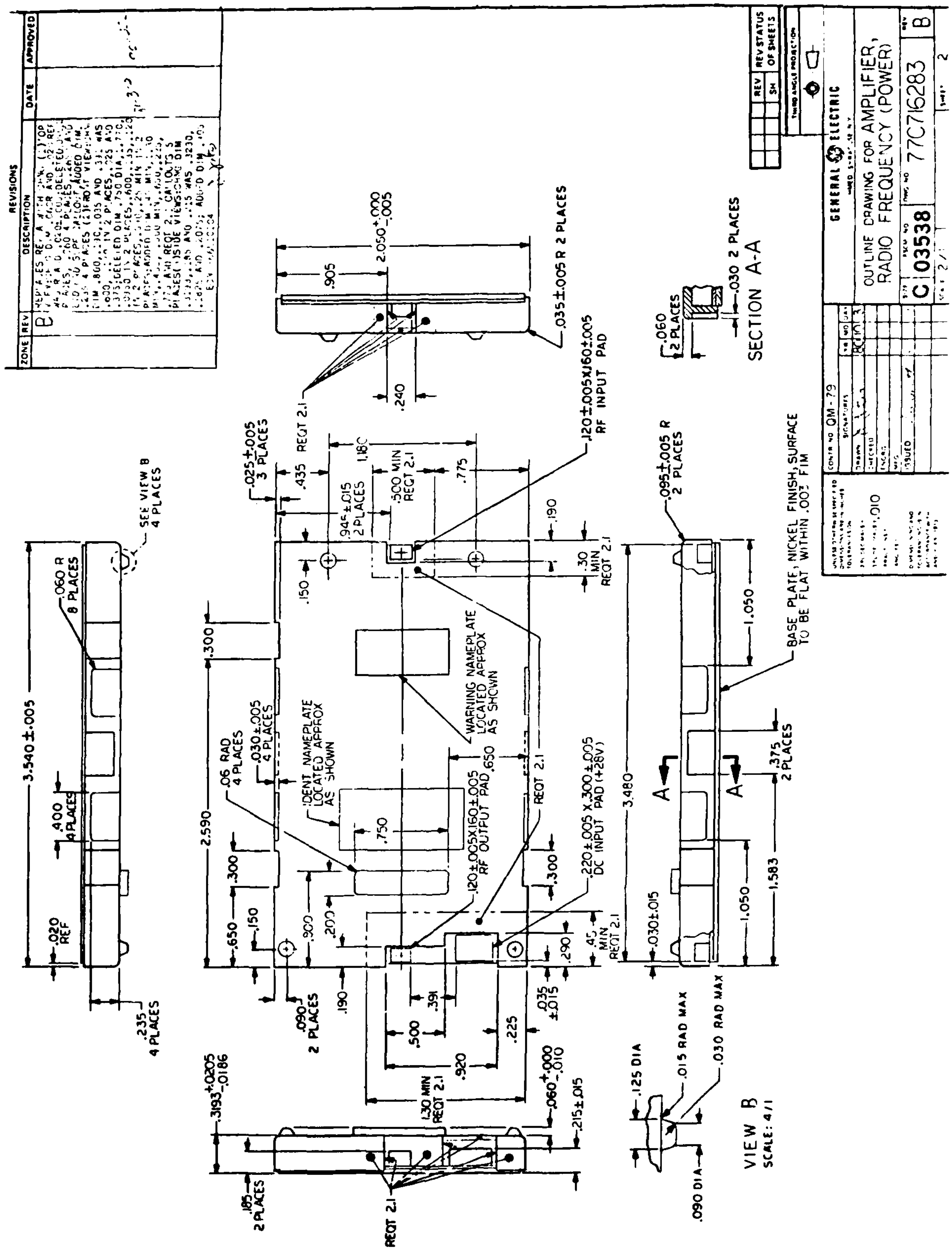
2.1 THESE SURFACES TO BE ELECTRICALLY NON-CONDUCTIVE. CONDUCTIVITY OF THOSE SURFACES NOT DEFINED IS OPTIONAL.

PART NO.	MANUFACTURER'S ITEM IDENT NO.	MANUFACTURER'S ITEM IDENT NO.	MANUFACTURER'S ITEM IDENT NO.	ELECTRICAL SPEC
	GENERAL ELECTRIC CO.ESD SURFACE-BASED ELECTRONICS DEPT SYRACUSE, NY FSCM NO. 03538			
1	1238-1			
2	9955			77A100244
3				

SPECIFICATION CONTROL DRAWING

		B	B	REVISION	DOCUMENT REVISION STATUS
		2	1	SHEET	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES– TOLERANCES ON 2 PLACE DECIMALS ± 3 PLACE DECIMALS ±.010 ANGLES ± FRACTIONS ± ALL SURF ✓ MATERIAL–	
CONT'R NO 6TN143	GENERAL ELECTRIC HMED SYRACUSE N.Y.
ORIG DATE OF DRAWING 14 APR 78	AMPLIFIER, RADIO FREQUENCY (POWER)
DRAWN	
ENGR	
CHECKED	
ISSUED 18 Apr 78	
SIZE C	CODE IDENT NO 03538 — 77C716283
SCALE	SHEET 1 OF 2



REVISIONS
GENERAL ELECTRIC
OUTLINE DRAWING FOR AMPLIFIER, RADIO FREQUENCY (POWER)
C 03538
77C716283
B
SECTION A-A
VIEW B
SCALE: 4/1
WARNING NAMEPLATE LOCATED APPROX AS SHOWN
IDENT NAMEPLATE LOCATED APPROX AS SHOWN
.120±.005X.160±.005 RF INPUT PAD
.120±.005X.160±.005 RF OUTPUT PAD
.220±.005 X .300±.005 DC INPUT PAD (+28V)
BASE PLATE, NICKEL FINISH, SURFACE TO BE FLAT WITHIN .002 FIM
3.540±.005
3.480
2.590
SEE VIEW B 4 PLACES

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APPENDIX B

RADIO FREQUENCY AMPLIFIER (POWER)
(Specifications) (25 Pages)

77A100244

THIRD ANGLE PROJECTION

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
2 PL DECIMALS ±
3 PL DECIMALS ±
FRACTIONS ±
ANGLES ±
DIMENSIONING AND TOLERANCING IS IN ACCORDANCE WITH ANSI Y14.5 1973

–	–	–	–	–	–	–	–	–	–
16	17	18	19	20	21	22	23	24	25

REV STATUS OF SHEETS																
	REV	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

CONTR NO QM-79

SIGNATURES		YR	MO	DAY
DRAWN	Em Junit	80	6	9
CHECKED	J Thurston	80	11	17
ENGRG	P C Holl	80	11	17
MFG				
ISSUED	C Sa...	80	11	17

GENERAL ELECTRIC
HMED SYRACUSE N Y

AMPLIFIER, RADIO FREQUENCY (POWER)

SIZE	FSCM NO	DWG NO	REV
A	03538	77A100244	
SCALE		SHEET 1 OF 25	

DWG NO 77A100244 REV 2

1. SCOPE

1.1 SCOPE: THIS SPECIFICATION COVERS THE DETAIL REQUIREMENTS FOR A 100-WATT HYBRID MICROCIRCUIT MICROWAVE POWER AMPLIFIER MODULE. THE SPECIFICATION PROVIDES FOR A LEVEL OF HYBRID MICROCIRCUIT QUALITY AND RELIABILITY ASSURANCE FOR PROCUREMENT OF MICROCIRCUITS BASED ON MIL-M-38510 AND MIL-STD-883.

1.2 PART NUMBER: THE COMPLETE PART NUMBER SHALL BE AS FOLLOWS:

03538-77C716283P2

1.3 ABSOLUTE MAXIMUM RATINGS:

SUPPLY VOLTAGE, VCC	32.0 VDC
HEAT SINK TEMPERATURE, OPERATING	80°C
PEAK RF INPUT DRIVE POWER LEVEL	38.5 DBM
PULSE WIDTH	2.0 MS
CONTINUOUS DUTY FACTOR	20 %
STORAGE TEMPERATURE RANGE	-65 TO +125°C
VSWR, LOAD	3:1

1.4 TYPICAL OPERATING CONDITIONS:

SUPPLY VOLTAGE	28.0 VDC
HEAT SINK TEMPERATURE RANGE	-40 TO +69°C
FREQUENCY RANGE	1215 TO 1400 MHZ
PULSE WIDTH, MAXIMUM	2.0 MS
DUTY FACTOR, MAXIMUM	18 %
PEAK RF INPUT DRIVE POWER LEVEL	37.3 DBM
VSWR, LOAD, MAXIMUM	1.3:1
PEAK POWER OUTPUT	50 DBM

2. APPLICABLE DOCUMENTS

GENERAL ELECTRIC HMED SYRACUSE N.Y.	SIZE A	FSCM NO 03538	DWG NO 77A100244	REV
DRAWN Em Stuart				
ISSUED 80-11-17	SCALE		SHEET 2	

2.1 THE FOLLOWING DOCUMENTS AND ISSUES AND REVISIONS THERETO IN EFFECT ON THE DATE OF THIS SPECIFICATION FORM A PART OF THIS SPECIFICATION TO THE EXTENT SPECIFIED HEREIN:

GOVERNMENT DOCUMENTS

MIL-M-38510	MICROCIRCUITS, GENERAL SPECIFICATION FOR
MIL-G-45204	GOLD PLATING, ELECTRODEPOSITED
MIL-STD-883	TEST METHODS AND PROCEDURES FOR MICROELECTRONICS
MIL-HDBK-217	RELIABILITY PREDICTION OF ELECTRONIC EQUIPMENT

NON-GOVERNMENT DOCUMENTS

03538-7327371	MODULE TEST FIXTURE
03538-7342817G1	MODULE PHASE REFERENCE
03538-77C716283P2	AMPLIFIER, RADIO FREQUENCY
IEEE STANDARD NO. 260	STANDARD LETTER SYMBOLS FOR UNITS OF MEASUREMENT
NP 261734	IDENTIFICATION PLATE

3. REQUIREMENTS

3.1 TERMS DEFINITIONS AND SYMBOLS: THE TERMS, DEFINITIONS, AND SYMBOLS OF IEEE STANDARD NO. 260 AND THOSE DEFINED HEREIN SHALL APPLY TO THIS SPECIIFICATION. IN CASE OF CONFLICT, THE LATTER SHALL GOVERN.

3.1.1 DEFINITIONS

3.1.1.1 MODULE: A MODULE IS AN AMPLIFIER, RADIO FREQUENCY (POWER) BUILT TO THE REQUIREMENTS OF THIS SPECIFICATION.

3.1.1.2 INSPECTION LOT: AN INSPECTION LOT SHALL CONSIST OF 50 OR LESS MODULES SUBMITTED AT ONE TIME FOR QUALITY CONFORMANCE INSPECTION IN ACCORDANCE WITH THE REQUIREMENTS OF THIS SPECIFICATION. EACH INSPECTION LOT SHALL CONSIST OF MODULES, ALL OF WHICH WERE MANUFACTURED ON THE SAME PRODUCTION LINE, TO THE SAME DESIGN, WITH THE SAME MATERIAL REQUIREMENTS, WITH THE SAME PROCESSES AND SEALED WITHIN THE SAME PERIOD NOT EXCEEDING 6 WEEKS.

3.1.1.3 HEATSINK: THE TERM HEATSINK AS USED HEREIN SHALL REFER TO THE HEATSINK WHICH IS AN INTEGRAL PART OF THE TEST FIXTURE SPECIFIED IN 3.3.1.1.

3.1.1.4 PEAK POWER OUTPUT: PEAK POWER OUTPUT IS THE AVERAGE POWER OUTPUT, DIVIDED BY THE DUTY FACTOR.

3.1.2 SYMBOLS AND ABBREVIATIONS:

T_{HS} = HEATSINK TEMPERATURE

G = GRAVITATIONAL UNIT OF ACCELERATION

T.I.R. = TOTAL INDICATED RUNOUT

3.2 DESIGN AND CONSTRUCTION: THE DESIGN, CONSTRUCTION AND PHYSICAL DIMENSIONS SHALL BE AS SPECIFIED HEREIN AND ON OUTLINE DRAWING 03538-77C716283P2.

3.2.1 MATERIALS, PROCESSES, AND PARTS

3.2.1.1 TRANSISTOR METALLIZATION: ONLY GOLD/REFRACTORY METALLIZATION SHALL BE USED.

3.2.1.2 BASE PLATE FINISH: THE MAJOR EXPOSED SURFACE OF THE MODULE BASEPLATE (REFER TO OUTLINE DRAWING) SHALL HAVE A NICKEL FINISH, WITH A THICKNESS OF 500 MICROINCHES, MINIMUM.

3.2.1.3 TERMINAL FINISH: THE TOP SURFACES OF THE RF INPUT, RF OUTPUT AND DC INPUT PADS (REFER TO OUTLINE DRAWING) SHALL BE GOLD PLATED PER MIL-G-45204, TYPE I, GRADE A, CLASS 3.

3.2.1.4 HERMETIC SEALS: HERMETIC SEALS SHALL BE CONSTRUCTED OF GLASS, METAL, CERAMIC OR A COMBINATION OF THESE MATERIALS.

3.2.1.5 MODULE TYPES. AMPLIFIER MODULE TYPES MAY BE EITHER OF THE FOLLOWING:

TYPE I HERMETICALLY-SEALED MODULE
TYPE II NONHERMETICALLY-SEALED MODULE

TYPE I MODULE SHALL BE HERMETICALLY SEALED; SEMICONDUCTOR DEVICES USED THEREIN ARE NOT REQUIRED TO BE INDIVIDUALLY HERMETICALLY SEALED. TYPE II MODULE SHALL BE ENCLOSED; SUCH ENCLOSURE SHALL BE CAPABLE OF WITHSTANDING ENVIRONMENTAL TESTING SPECIFIED HEREIN; ALL SEMICONDUCTOR DEVICES USED IN THE TYPE II MODULE SHALL BE INDIVIDUALLY OR COLLECTIVELY SEALED USING HERMETIC SEAL CONSTRUCTION.

3.2.1.6 TERMINAL ISOLATION: THE TERMINAL PADS (SEE OUTLINE DRAWING) ARE INTENDED TO BE MATED WITH SPRING CONTACTS. TO PREVENT ELECTRICAL SHORTS BETWEEN THESE SPRING CONTACTS AND OTHER PARTS OF THE MODULE, MODULE SURFACES IMMEDIATELY ADJACENT TO THE TERMINAL PADS SHALL BE NON-CONDUCTIVE.

3.2.2 SHIELDING, ELECTROMAGNETIC: THE MODULE SHALL BE SHIELDED BY THE USE OF INTERCONNECTED CONDUCTIVE SURFACES.

3.2.3 MARKING: MARKING SHALL BE LOCATED AS INDICATED ON THE OUTLINE DRAWING (SEE 3.2) AND SHALL INCLUDE: MANUFACTURER'S IDENTIFICATION AND ITEM NUMBER, COMPLETE PART NUMBER (SEE 1.2), UNIQUE SERIAL NUMBER (SEE 4.2.6 AND 6.2) AND A 4-DIGIT DATE CODE INDICATING THE WEEK AND YEAR OF MANUFACTURE. THE MARKING SHALL BE LEGIBLE AND SHALL MEET THE ENVIRONMENTAL REQUIREMENTS OF THIS SPECIFICATION.

3.2.3.1 BERYLLIUM OXIDE PACKAGE IDENTIFIER: IF THE MODULE CONTAINS BERYLLIUM OR BERYLLIUM OXIDE (SEE 6.3), IDENTIFICATION PLATE (DANGER LABEL) NP261734 SHALL BE AFFIXED TO THE MODULE IN THE LOCATION SHOWN ON THE OUTLINE DRAWING (SEE 3.2).

3.2.4 REWORK PROVISIONS: ALL REWORK SHALL BE IN ACCORDANCE WITH THE SUPPLIER'S APPROVED PRODUCT ASSURANCE PLAN (3.6.1.2). REWORK PROCEDURES SHALL BE AVAILABLE FOR REVIEW BY THE PROCURING ACTIVITY.

3.3 ELECTRICAL PERFORMANCE REQUIREMENTS

3.3.1 GENERAL REQUIREMENTS AND CONDITIONS

3.3.1.1 TEST FIXTURE: THE ELECTRICAL PERFORMANCE REQUIREMENTS HEREIN SHALL APPLY WHEN THE MODULE IS MOUNTED IN TEST FIXTURE 03538-7327371. THIS TEST FIXTURE HAS A HEATSINK WITH A SURFACE FLATNESS OF .001 INCH T.I.R., AGAINST WHICH THE MODULE IS HELD WITH A FORCE OF 10 POUNDS.

3.3.1.2 TEMPERATURE: THE MODULE SHALL MEET THE ELECTRICAL PERFORMANCE REQUIREMENTS HEREIN AS STATED BELOW FOR THE INDICATED TEMPERATURE RANGE:

HEATSINK TEMPERATURE	REQUIREMENT
-50° TO +69°C	FULL PERFORMANCE AFTER 30 MINUTES OF OPERATION, AT 10 PERCENT DUTY FACTOR.
-40° TO +69°C	FULL PERFORMANCE.
-65° TO +80°C	OPERATION WITHOUT DAMAGE.

3.3.1.3 BANDWIDTH: THE MODULE SHALL MEET ALL PERFORMANCE REQUIREMENTS ANY WHERE WITHIN THE BAND FROM 1215 TO 1400 MEGAHERTZ.

3.3.1.4 SUPPLY VOLTAGE: THE MODULE SHALL BE CAPABLE OF MEETING ALL PERFORMANCE REQUIREMENTS WHEN SUPPLIED WITH A DC VOLTAGE OF 28 ±0.05 VOLTS, WITH 0.6 VOLT DECREASE OVER A 2.0 MILLISECOND OUTPUT PULSE.

3.3.1.5 ABNORMAL SUPPLY VOLTAGE CONDITION: THE MODULE SHALL OPERATE WITHOUT DAMAGE DURING OCCASIONAL PERIODS OF UP TO ONE SECOND DURATION WHEN THE SUPPLY VOLTAGE IS AS HIGH AS 32 VOLTS DC.

3.3.1.6 RF INPUT POWER: THE MODULE SHALL OPERATE AS SPECIFIED WHEN THE INPUT PEAK PULSE POWER IS AS DEFINED FOR STANDARD TEST CONDITIONS FOR ELECTRICAL TESTING, TABLE III.

3.3.1.7 PULSE WIDTH: UNLESS OTHERWISE SPECIFIED HEREIN, THE MODULE SHALL MEET ALL PERFORMANCE REQUIREMENTS AT ANY PULSE WIDTH FROM 50 TO 2000 MICROSECONDS.

3.3.1.8 DUTY FACTOR: THE MODULE SHALL BE CAPABLE OF SUSTAINED OPERATION AT A DUTY FACTOR OF 18 PERCENT AND INTERMITTENT OPERATION, FOR 10 MILLISECOND PERIODS, AT A DUTY FACTOR OF 36 PERCENT.

3.3.2 POWER OUTPUT: THE MODULE SHALL PROVIDE A PEAK POWER OUTPUT OF AT LEAST 49.23 DBM AVERAGED OVER THE INPUT POWER RANGE, P_1 TO P_3 (DEFINED IN TABLE III). THE PEAK POWER OUTPUT AVERAGED OVER ANY INSPECTION LOT (3.1.1.2) AND AVERAGED OVER THE INPUT POWER RANGE SHALL BE AT LEAST 49.73 DBM. ABOVE A HEAT SINK TEMPERATURE OF 57 DEGREES C, THE POWER REQUIREMENT IS REDUCED BY 0.01 DB PER DEGREE C UP TO THE MAXIMUM RATED OPERATING HEAT SINK TEMPERATURE. THE MAXIMUM PEAK POWER OUTPUT SHALL NOT EXCEED 51.46 DBM.

3.3.3 PHASE AND AMPLITUDE STABILITY: FOR A SEQUENCE OF THREE 100-MICROSECOND PULSES, SPACED 800 MICROSECONDS APART, THE VARIATION IN PHASE AND AMPLITUDE FROM A LINEAR FIT SHALL NOT EXCEED 0.01 DEGREE AND 0.001 DB.

3.3.4 PUSHING FACTOR, WITH CHANGE IN SUPPLY VOLTAGE: THE PHASE AND AMPLITUDE CHANGE WITH CHANGE IN THE 28-VOLT SUPPLY SHALL NOT EXCEED 6 DEGREES PER VOLT AND 0.3 DB PER VOLT, AVERAGED OVER EACH INSPECTION LOT. PHASE SHALL BE MEASURED 50 MICROSECONDS INTO THE PULSE.

3.3.5 PUSHING FACTOR, WITH CHANGE IN RF INPUT POWER: THE PHASE AND AMPLITUDE CHANGE WITH CHANGE IN RF INPUT POWER SHALL NOT EXCEED 20 DEGREES PER DB AND 1.0 DB PER DB FOR EACH POWER MODULE. PHASE SHALL BE MEASURED 700 MICROSECONDS INTO THE PULSE.

3.3.6 PULSE DROOP: WHEN THE SUPPLY VOLTAGE FOR THE MODULE DECREASES 0.6 VOLT OVER A 2-MILLISECOND PULSE, THE PHASE AND AMPLITUDE CHANGE OVER THE PULSE SHALL NOT EXCEED 25 DEGREES AND 0.5 DB.

3.3.7 SPURIOUS OUTPUTS: AT FREQUENCIES MORE THAN 69 MHz, AND LESS THAN 250 MHz, REMOVED FROM THE CARRIER, THE SPECTRAL DENSITY FOR A 100 MICROSECOND SIMPLE PULSE SHALL NOT EXCEED -80 DB WITH RESPECT TO THE MAXIMUM SPECTRAL DENSITY. THE POWER MODULE SHALL HAVE NO OUTPUTS UNRELATED TO THE INPUT SIGNAL, GREATER THAN -10 DBM DURING THE RF PULSE. THE NOISE POWER OUT OF A POWER MODULE UNDER NO-PULSE CONDITIONS SHALL NOT EXCEED -170 DBM/HZ.

3.3.8 HARMONIC OUTPUT: ANY HARMONIC OR SUBHARMONIC OF THE OUTPUT SIGNAL SHALL NOT EXCEED 15 DBM PEAK.

GENERAL ELECTRIC HMED SYRACUSE N.Y.	SIZE A	FSCM NO 03538	DWG NO 77A100244	REV
DRAWN Emswart	SCALE		SHEET 6	
ISSUED 80-11-17				

DWG NO 77A100244 SH 6

3.3.9 SUPPLY CURRENT: THE AVERAGE SUPPLY CURRENT AT 18 PERCENT DUTY FACTOR, AT ANY FREQUENCY AND TEMPERATURE, AND AVERAGED OVER $P_{IN} = P_2$, P_3, AND P_4 (DEFINED IN TABLE III), SHALL NOT EXCEED 1.84 AMPERES DC. THE AVERAGE OF ANY INSPECTION LOT UNDER THE SAME CONDITIONS SHALL NOT EXCEED 1.67 AMPERES DC.

3.3.10 OUTPUT PULSE RISE TIME: THE RISE TIME OF THE OUTPUT PULSE MEASURED FROM THE 10 PERCENT TO THE 90 PERCENT VOLTAGE AMPLITUDE POINTS SHALL NOT EXCEED 0.15 MICROSECONDS.

3.3.11 OUTPUT PULSE FALL TIME: THE FALL TIME OF THE OUTPUT PULSE MEASURED FROM THE 90 PERCENT TO THE 10 PERCENT VOLTAGE AMPLITUDE POINTS SHALL NOT EXCEED 0.15 MICROSECONDS

3.3.12 PHASE ERROR: AT $P_{IN} = P_2$ (SEE TABLE III) AND AT ANY MEASUREMENT TEMPERATURE, THE DIFFERENCE BETWEEN THE MEASURED MODULE PHASE SHIFT AND THE TARGET PHASE SHIFT OF TABLE I SHALL NOT EXCEED ±22 DEGREES. ALL PHASE SHIFT MEASUREMENTS SHALL BE WITH RESPECT TO THE 32°C PHASE SHIFT OF THE PHASE REFERENCE MODULE (SEE 2.1). THE INSPECTION LOT AVERAGE PHASE ERROR SHALL NOT EXCEED 8.3 DEGREES RMS AT 50 MICROSECONDS INTO THE PULSE OR 8.0 DEGREES RMS AT 700 MICROSECONDS INTO THE PULSE.

TABLE I (REQT 3.3.12)

TARGET PHASE SHIFT, $\Phi(F, T_{HS}, t)$

t, μs	T_{HS}, °C	FREQUENCY IN MEGAHERTZ (F)				
		1215	1261.25	1307.5	1353.75	1400
50	-40					
50	+32					
50	+57					
700	-40					
700	+32					
700	+57					

TO BE DETERMINED

GENERAL ELECTRIC
HMED SYRACUSE, N.Y.

DRAWN Em Swart
ISSUED 80-11-17

SIZE	FSCM NO	DWG NO	REV
A	03538	77A100244	

SCALE | SHEET 7

3.3.13 INPUT VSWR: THE INPUT VSWR OF THE MODULE AS MEASURED IN TEST FIXTURE 03538-7327371 SHALL NOT EXCEED 1.3:1.

3.3.14 LOAD VSWR TOLERANCE: WITH A 1.3:1 VSWR AT ANY ANGLE, THE DETECTED OUTPUT PULSE ENVELOPE SHALL BE VIEWED ON AN OSCILLOSCOPE WITH A MINIMUM PULSE AMPLITUDE OF 5 CENTIMETERS AND A MAXIMUM OF 8 CENTIMETERS ON THE OSCILLOSCOPE FACE. THERE SHALL BE NO DISCONTINUITIES BETWEEN THE 90 PERCENT AMPLITUDE POINTS AT ANY FREQUENCY WITHIN THE SPECIFIED FREQUENCY BAND.

3.3.14.1 VSWR CAPABILITY: THE MODULE SHALL NOT BE DAMAGED BY A LOAD VSWR OF 3 : 1 AT ANY PHASE ANGLE, AT STANDARD ELECTRICAL TEST CONDITIONS DEFINED IN TABLE III AND HEAT SINK TEMPERATURES OF -40, 32, AND 57 DEGREES C.

3.3.15 JUNCTION TEMPERATURE: FOR AN 800-MICROSECOND PULSE WIDTH, A 16 ±1 PERCENT DUTY FACTOR, A HEATSINK TEMPERATURE OF 32 ±3°C AND $P_{IN} = P_2$ (DEFINED IN TABLE III), THE MAXIMUM PEAK TRANSISTOR JUNCTION TEMPERATURE SHALL NOT EXCEED 150 DEGREES C.

3.4 MECHANICAL AND ENVIRONMENTAL REQUIREMENTS

3.4.1 GENERAL: THE MODULE SHALL BE DESIGNED FOR OPERATION, TRANSPORT, AND STORAGE UNDER ANY PRACTICAL COMBINATION OF THE CONDITIONS GIVEN HEREIN.

3.4.2 SHOCK, MECHANICAL: UP TO 30 G PEAK IN ACCORDANCE WITH TEST CONDITIONS AND PROCEDURES IN MIL-STD-883, METHOD 2002.

3.4.3 VIBRATION: THE MODULE SHALL HAVE NO MECHANICAL RESONANT FREQUENCIES UNDER 25 HERTZ WHEN TESTED IN ACCORDANCE WITH MIL-STD-883, METHOD 2007, CONDITION A.

3.4.4 ACCELERATION: UP TO 5000 G CONSTANT ACCELERATION WHEN TESTED IN ACCORDANCE WITH MIL-STD-883, METHOD 2001, CONDITION A, IN THE Y-1 DIRECTION.

3.4.5 THERMAL SHOCK: THE MODULE SHALL MEET ALL SPECIFIED REQUIREMENTS AFTER BEING SUBJECTED TO THE THERMAL SHOCK TEST OF 4.4.4.1.

3.4.6 HUMIDITY AND MOISTURE: THE MODULE SHALL BE DESIGNED FOR OPERATION AND STORAGE AT RELATIVE HUMIDITY CONDITIONS FROM ZERO TO 100 PERCENT. THE MODULE SHALL BE CAPABLE OF MEETING MOISTURE RESISTANCE TESTING IN ACCORDANCE WITH MIL-STD-883, METHOD 1004.

3.4.7 SALT ATMOSPHERE: THE MODULE SHALL BE CAPABLE OF MEETING SALT ATMOSPHERE TESTING IN ACCORDANCE WITH MIL-STD-883, METHOD 1009, CONDITION A.

3.4.8 ALTITUDE: ZERO TO 15,000 FEET, OPERATING; ZERO TO 50,000 FEET, NON-OPERATING.

3.4.9 TEMPERATURE CYCLING: -55 TO +125 DEGREES C, IN ACCORDANCE WITH MIL-STD-883, METHOD 1010, CONDITION B.

3.5 RELIABILITY

3.5.1 FAILURE RATE: THE PREDICTED FAILURE RATE OF THE MODULE SHALL BE LESS THAN 2.0 FAILURES PER MILLION HOURS.

3.5.1.1 FAILURE RATE PREDICTION: THE PREDICTION SHALL BE IN ACCORDANCE WITH MIL-HDBK-217, FOR A GROUND FIXED ENVIRONMENT, A PACKAGE TEMPERATURE OF 67 DEGREES C AND A QUALITY LEVEL B (SEE 3.6.1.2).

3.6 PRODUCT ASSURANCE REQUIREMENTS

3.6.1 QUALIFICATION: A PRODUCT FURNISHED UNDER THIS SPECIFICATION SHALL NOT BE APPROVED FOR DELIVERY, NOR ACCEPTED, UNTIL SUCH PRODUCT HAS BEEN QUALIFIED. QUALIFICATION SHALL CONSIST OF ALL REQUIREMENTS IN 3.6.1.1 THROUGH 3.6.1.3. QUALIFICATION APPROVAL WILL BE GRANTED IN WRITING BY THE PROCURING ACTIVITY UPON SUCCESSFUL COMPLETION OF THE REQUIREMENTS SPECIFIED THEREIN.

3.6.1.1 PREDICTION REPORT: A REPORT OF THE FAILURE RATE PREDICTION OF 3.5.1.1, OR SUFFICIENT DESIGN AND CONSTRUCTION DATA NEEDED TO GENERATE SUCH A PREDICTION, SHALL BE SUBMITTED TO THE PROCURING ACTIVITY FOR APPROVAL PRIOR TO QUALIFICATION INSPECTION (SEE 3.6.1.3). APPROVAL SHALL BE FOR TECHNICAL CONTENT.

3.6.1.2 PRODUCT ASSURANCE PLAN: THE SUPPLIER SHALL ESTABLISH, IMPLEMENT AND MAINTAIN A PRODUCT ASSURANCE PROGRAM FOR THE MODULE IN GENERAL ACCORDANCE WITH THE APPLICABLE PROVISIONS OF MIL-M-38510 APPENDIX A. A PRODUCT ASSURANCE PROGRAM PLAN SHALL BE SUBMITTED TO THE PROCURING ACTIVITY FOR APPROVAL PRIOR TO QUALIFICATION INSPECTION. APPROVAL SHALL BE FOR CONSISTENCY WITH THE MODULE QUALITY LEVEL ASSUMED IN THE PREDICTION OF 3.5.1.1.

3.6.1.3 QUALIFICATION INSPECTION: MODULE SAMPLES SHALL BE SUBJECTED TO AND PASS THE QUALIFICATION INSPECTION OF 4.4. QUALIFICATION INSPECTION SHALL BE PERFORMED ON INITIAL PROCUREMENT, AND THEREAFTER AS SPECIFIED BY THE PROCURING ACTIVITY. EACH TIME QUALIFICATION INSPECTION IS PERFORMED, A QUALIFICATION TEST REPORT (SEE 4.5.4) SHALL BE SUBMITTED TO THE PROCURING ACTIVITY FOR APPROVAL. APPROVAL WILL BE FOR COMPLETENESS, AND CONFORMANCE OF THE TEST RESULT TO THE REQUIREMENTS OF THIS SPECIFICATION.

DWG NO 77A100244 REV 10

3.6.2 SCREENING: EACH MODULE FURNISHED UNDER THIS SPECIFICATION SHALL HAVE BEEN SUBJECTED TO AND PASSED THE SCREENING TESTS OF 4.2.

3.6.3 QUALITY CONFORMANCE: MODULES SHALL NOT BE APPROVED FOR DELIVERY; NOR ACCEPTED, UNTIL THE INSPECTION LOT COMPRISED OF THOSE MODULES HAS PASSED THE QUALITY CONFORMANCE INSPECTION OF 4.3. ALL MODULES OFFERED FOR ACCEPTANCE SHALL BE MANUFACTURED ON THE SAME PRODUCTION LINE, TO THE SAME DESIGN, WITH THE SAME MATERIAL REQUIREMENTS AND WITH THE SAME PROCESSES AS THE MODULES WHICH HAVE BEEN QUALIFIED (3.6.1). NO CHANGE IN DESIGN, PARTS, MATERIALS OR PROCESSES SHALL BE INCORPORATED INTO THE MODULES OFFERED FOR ACCEPTANCE WITHOUT PRIOR APPROVAL OF THE PROCURING ACTIVITY.

4. QUALITY ASSURANCE PROVISIONS

4.1 GENERAL

4.1.1 RESPONSIBILITY FOR INSPECTION: UNLESS OTHERWISE SPECIFIED, THE SUPPLIER IS RESPONSIBLE FOR THE PERFORMANCE OF ALL INSPECTIONS SPECIFIED HEREIN. THE PROCURING ACTIVITY RESERVES THE RIGHT TO PERFORM ANY OF THE INSPECTIONS SET FORTH IN THIS SPECIFICATION WHERE SUCH INSPECTIONS ARE DEEMED NECESSARY TO ASSURE THAT THE PRODUCT CONFORMS TO THE PRESCRIBED REQUIREMENTS.

4.1.2 CLASSIFICATION OF INSPECTIONS: THE EXAMINATIONS AND TESTS REQUIRED TO ASSURE CONFORMANCE TO THE REQUIREMENTS OF SECTION 3.0 ARE CLASSIFIED AS FOLLOWS:

REQUIREMENT	PARAGRAPH
SCREENING	4.2
QUALITY CONFORMANCE	4.3
QUALIFICATION	4.4
DATA	4.5

4.2 SCREENING

4.2.1 SCREENING PROCEDURES: SCREENING SHALL BE IN ACCORDANCE WITH TABLE II AND AS SPECIFIED HEREIN.

4.2.2 ELECTRICAL MEASUREMENTS: THE DETAIL REQUIREMENTS OF SCREENING STEPS 6 OR 8 MAY BE MODIFIED BASED ON THE RESULTS OF ELECTRICAL TESTING DURING QUALIFICATION. ALL SCREENING MODIFICATIONS SHALL BE APPROVED BY THE PROCURING ACTIVITY PRIOR TO IMPLEMENTATION.

GENERAL ELECTRIC HMED SYRACUSE, N.Y.	SIZE A	FSCM NO 03538	DWG NO 77A100244	REV
DRAWN Emlunit				
ISSUED 80-11-17	SCALE		SHEET 10	

4.2.3 INTERNAL VISUAL INSPECTION: FOR TYPE I MODULES (SEE 3.2.1.5) INTERNAL VISUAL INSPECTION SHALL BE PERFORMED IMMEDIATELY PRIOR TO SEALING THE MODULE. FOR TYPE II MODULES, INTERNAL VISUAL INSPECTION(S) SHALL BE PERFORMED AT THE LATEST POINT(S) IN THE FABRICATION PROCESS BEYOND WHICH SUCH INSPECTION IS NOT FEASIBLE.

4.2.4 SEAL TEST: FOR TYPE II MODULES (SEE 3.2.1.5) THE SEAL OF EACH HERMETIC COMPONENT OR SUBASSEMBLY SHALL BE TESTED PER TABLE II PRIOR TO BURN-IN. THE SEAL TEST(S) SHALL BE PERFORMED AT A SUITABLE POINT(S) IN THE FABRICATION AND SCREENING PROCESS.

4.2.5 JUNCTION TEMPERATURE TESTS: THE JUNCTION TEMPERATURE SHALL BE MEASURED BY MEANS OF AN INFRA-RED RADIOMETER (INFRA-RED MICROSCOPE) SENSITIVE IN THE RANGE OF 2 TO 10 MICRONS; MEASUREMENT BANDWIDTH SHALL BE AT LEAST 10 KILOHERTZ; HALF-POWER FOCAL DIAMETER SHALL BE 1.5 MILS. THE INFRA-RED MICROSCOPE SHALL BE USED TO SCAN THE AREA OF EACH CELL OF EACH TRANSISTOR IN THE MODULE, AT EACH OF THE SPECIFIED FREQUENCIES. THE MAXIMUM PEAK TEMPERATURE OF EACH TRANSISTOR SHALL BE RECORDED.

4.2.5.1 EMISSIVITY: THE RADIOMETER EMISSIVITY SETTING SHALL BE EITHER THE EMISSIVITY OF THE INDIVIDUAL TRANSISTOR CHIP BEING MEASURED OR THE AVERAGE EMISSIVITY FOR THE WAFER LOT APPLICABLE TO THAT TRANSISTOR CHIP.

4.2.6 SERIALIZATION: PRIOR TO THE START OF SCREENING PER TABLE II, EACH MODULE SHALL BE MARKED WITH A UNIQUE SERIAL NUMBER. REFER TO REQUIREMENT 3.2.3 AND NOTE 6.2.

4.2.7 BURN-IN DELTA LIMITS: AT ANY SPECIFIED TEST FREQUENCY, THE DIFFERENCE BETWEEN THE VALUES OF PEAK POWER OUTPUT (TEST 2) MEASURED IN STEPS 6 AND 8 OF TABLE II SHALL BE RECORDED AND SHALL NOT EXCEED 0.5 DB. FOR ALL OTHER TESTS SPECIFIED IN STEP 6, THE DELTA VALUES SHALL BE COMPUTED DURING STEP 8, AND RECORDED FOR INFORMATION ONLY.

4.3 QUALITY CONFORMANCE INSPECTION

4.3.1 GENERAL: ALL MODULES IN THE INSPECTION LOT SUBMITTED TO QUALITY CONFORMANCE INSPECTION SHALL HAVE BEEN SCREENED IN ACCORDANCE WITH 4.2.

4.3.2 INSPECTION PROCEDURE: QUALITY CONFORMANCE INSPECTION SHALL CONSIST OF THE EXAMINATIONS AND TESTS OF 4.3.3 THROUGH 4.3.5.

DWG NO 77A100244 REV 12

4.3.3 ELECTRICAL TESTS: THREE MODULES, RANDOMLY SELECTED FROM EACH INSPECTION LOT SHALL BE SUBJECTED TO ALL TESTS OF TABLE III EXCEPT AS FOLLOWS:

A. TESTS MAY BE PERFORMED IN ANY ORDER EXCEPT THAT TEST NO. 1 SHALL BE PERFORMED FIRST.

B. TESTS 14, 15 AND 16 SHALL BE PERFORMED AT A HEATSINK TEMPERATURE OF 32°C ONLY.

C. TESTS 17 AND 18 SHALL BE PERFORMED AT A HEATSINK TEMPERATURE OF 32°C AND -40°C ONLY.

D. FOR THOSE TESTS (NO's 4, 5, 8, 9 AND 20) REQUIRING LOT AVERAGE CALCULATIONS, SUCH CALCULATIONS SHALL BE PERFORMED OVER THE ENTIRE INSPECTION LOT FOR DATA AT A HEATSINK TEMPERATURE OF 32°C (USE FINAL ELECTRICAL TEST DATA FROM TABLE II). FOR TEMPERATURES OTHER THAN 32°C, THE CALCULATIONS SHALL BE PERFORMED OVER THE QUALITY CONFORMANCE INSPECTION SAMPLE ONLY.

4.3.3.1 ACCEPTANCE CRITERIA: IF ONE OR MORE MODULES FAILS ANY TEST OF 4.3.3, AN ADDITIONAL SAMPLE OF FIFTEEN (15) MODULES (OR 100% OF THE LOT WHICHEVER IS LESS) SHALL BE SELECTED FROM THE INSPECTION LOT AND TESTED TO 4.3.3. IF ONE OR MORE OF THESE MODULES FAILS ANY TEST, THE ENTIRE LOT SHALL BE TESTED AND ACCEPTANCE SHALL BE ON A MODULE BASIS. FAILED MODULES SHALL BE REMOVED FOR THE LOT.

4.3.4 PHYSICAL DIMENSIONS: TWO MODULES RANDOMLY SELECTED FROM THE INSPECTION LOT SHALL BE SUBJECTED TO THE INSPECTION OF MIL-STD-883, METHOD 2016.

4.3.4.1 ACCEPTANCE CRITERIA: IF ONE OR MORE MODULES FAILS THE INSPECTION OF 4.3.4, IT SHALL BE REMOVED FROM THE LOT AND 100% OF THE MODULES IN THE INSPECTION LOT SHALL BE INSPECTED. REJECTS SHALL BE REMOVED FROM THE LOT.

4.3.5 BOND STRENGTH (IF APPLICABLE): THE INSPECTION LOT SHALL BE SUBJECTED TO THE BOND STRENGTH TEST OF MIL-STD-883, METHOD 5005, GROUP B, CLASS B. BONDS SHALL BE SELECTED FROM A MINIMUM OF 3 MODULES. THIS INSPECTION APPLIES ONLY TO BONDS WHICH HAVE NOT PREVIOUSLY BEEN SUBJECTED TO BOND STRENGTH TESTING.

GENERAL ELECTRIC HMED SYRACUSE N Y	SIZE A	FSCM NO 03538	DWG NO 77A100244	REV
DRAWN EmSwait				
ISSUED 80-11-17	SCALE		SHEET 12	

4.4 QUALIFICATION INSPECTION

4.4.1 GENERAL: MODULES SUBMITTED TO QUALIFICATION INSPECTION SHALL HAVE PASSED ALL SCREENING TESTS OF 4.2. QUALIFICATION INSPECTION SHALL CONSIST OF THE TESTS AND INSPECTIONS OF 4.4.2 THROUGH 4.4.4. NO FAILURES ARE ALLOWED.

4.4.2 ELECTRICAL TESTS: ALL TESTS OF TABLE IV SHALL BE PERFORMED ON THE SPECIFIED NUMBER OF QUALIFICATION SAMPLES.

4.4.2.1 SPECIAL ELECTRICAL TEST: THE PROCURING ACTIVITY WILL SUBJECT THE GROUP OF QUALIFICATION ELECTRICAL TEST SAMPLES TO COMBINED TESTING IN THE INTENDED APPLICATION. THIS TEST, TO BE DEFINED DURING PRE-AWARD CONFERENCE, WILL PRIMARILY CONSIDER THOSE MODULE PARAMETERS FOR WHICH LOT AVERAGE REQUIREMENTS ARE SPECIFIED.

4.4.3 LIFE TEST: A MINIMUM OF 10 QUALIFICATION SAMPLES SHALL BE SUBJECTED TO AN OPERATING LIFE TEST UNDER THE BURN-IN CONDITIONS OF TABLE II, STEP 7, EXCEPT THAT TEST DURATION SHALL BE 1000 HOURS. AT COMPLETION OF THE LIFE TEST EACH LIFE TEST SAMPLE SHALL BE SUBJECTED TO AND PASS ALL TESTS OF TABLE III, EXCEPT THAT TESTS 4, 5, 6, 7, 8, 9 AND 20 NEED NOT BE PERFORMED.

4.4.4 ENVIRONMENTAL TESTS: A MINIMUM OF 5 QUALIFICATION SAMPLES SHALL BE SUBJECTED TO EACH SUBGROUP OF TABLE V.

4.4.4.1 THERMAL SHOCK: EACH MODULE SHALL BE SUBJECTED TO 15 CYCLES, MINIMUM, OF THERMAL SHOCK. EACH CYCLE (SHOCK) SHALL CONSIST OF THE FOLLOWING STEPS IN THE ORDER GIVEN:

A. NON-OPERATING STORAGE AT -56°C UNTIL THERMALLY STABLE.

B. ELECTRICAL OPERATION UNDER THE FOLLOWING CONDITIONS UNTIL THERMALLY STABLE:

V_{CC} = 28.0 ±0.5 VDC

F_T = 1260 MHZ

P.W. = 2.0 MILLISECONDS

D.F. = 18%

P_{IN} = P_4 (SEE TABLE III)

4.5 DATA REQUIREMENTS

4.5.1 DATA STRUCTURE: ALL ELECTRICAL TEST DATA REQUIRED HEREIN SHALL BE SUPPLIED IN A MACHINE READABLE FORM APPROVED BY THE PROCURING ACTIVITY.

GENERAL ELECTRIC HMED SYRACUSE, N.Y.	SIZE A	FSCM NO 03538	DWG NO 77A100244	REV
DRAWN Eminweit				
ISSUED 80-11-17	SCALE		SHEET 13	

DWG NO 77A100244 REV SH 14

4.5.2 SERIALIZED TEST DATA: THE FOLLOWING SERIALIZED TEST DATA SHALL BE SUPPLIED WITH EACH MODULE SHIPPED:

A. FINAL ELECTRICAL TEST DATA OF TABLE II, STEP 8.

B. DELTA DATA OF 4.2.7.

C. JUNCTION TEMPERATURE DATA OF 4.2.5.

4.5.3 LOT SUMMARY DATA: EACH MODULE SHIPMENT SHALL INCLUDE, FOR EACH INSPECTION LOT INVOLVED:

A. THE SERIAL NUMBERS OF MODULES SHIPPED FROM THAT INSPECTION LOT.

B. THE SERIAL NUMBERS OF MODULES, FROM THAT INSPECTION LOT, WHICH WERE SUBJECTED TO THE QUALITY CONFORMANCE INSPECTIONS OF 4.3.4 AND 4.3.5, AND A SUMMARY REPORT OF THE INSPECTION RESULTS.

C. THE SERIALIZED QUALITY CONFORMANCE TEST DATA OF 4.3.3, INCLUDING THE LOT AVERAGE DATA (AT 32°C) TAKEN OVER THE ENTIRE LOT (SEE 4.3.3D).

4.5.4 QUALIFICATION TEST REPORT: WHEN QUALIFICATION TESTING IS REQUIRED (SEE 3.6.1.3). THE SUPPLIER SHALL SUBMIT A REPORT OF THE RESULTS OF EACH TEST PERFORMED. ALL DATA SHALL BE SERIALIZED. NON-ELECTRICAL TEST DATA, AND SUMMARY RESULTS OF ALL TESTS, SHALL BE IN WRITTEN FORM. ELECTRICAL TEST DATA SHALL BE PER 4.5.1.

5. PREPARATION FOR DELIVERY: THE PREPARATION FOR DELIVERY REQUIREMENTS OF MIL-M-38510 SHALL APPLY.

6. NOTES

6.1 SOURCE OF SUPPLY: FOR SUGGESTED SOURCES OF SUPPLY, REFER TO OUTLINE DRAWING 03538-77C716283P2.

6.2 SERIALIZATION (REQT 3.2.3): SERIAL NUMBER ASSIGNMENTS SHALL BE COORDINATED WITH AND APPROVED BY THE PROCURING ACTIVITY.

6.3 HAZARDOUS MATERIALS (3.2.3.1): MODULES CONTAINING BERYLLIUM OR BERYLLIUM OXIDE SHALL NOT BE GROUND, SAND-BLASTED, MACHINED OR HAVE OTHER OPERATIONS PERFORMED ON THEM WHICH WILL PRODUCE BERYLLIUM OR BERYLLIUM OXIDE DUST. FURTHERMORE, MODULES CONTAINING BERYLLIUM OR BERYLLIUM OXIDE SHALL NOT BE PLACED IN ACIDS THAT WILL PRODUCE FUMES CONTAINING BERYLLIUM.

GENERAL ELECTRIC HMED SYRACUSE N Y	SIZE A	FSCM NO 03538	DWG NO 77A100244	REV
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ISSUED 80-11-17	SCALE		SHEET 14	

TABLE II
SCREENING STEPS (REQT 4.2) SEE NOTE 1/

STEP NO.	INSPECTION OR TEST	TEST METHODS AND REQUIREMENTS
1	JUNCTION TEMPERATURE	PER 4.2.5 AND 3.3.15
2	INTERNAL VISUAL INSPECTION	MIL-STD-883, METHOD 2017, CONDITION B AND 4.2.3
3	STABILIZATION BAKE	MIL-STD-883, METHOD 1008, CONDITION B; 125°C; DURATION = 24 HOURS, MINIMUM
4	TEMPERATURE CYCLING	MIL-STD-883, METHOD 1010, CONDITION B; 10 CYCLES; -55 TO +125°C
5	SEAL TEST	MIL-STD-883, METHOD 1014, CONDITIONS A2 AND C AND 4.2.4
6	PRE-BURN-IN ELECTRICAL MEASUREMENTS	TABLE III TESTS 2, 3 AND 19 AT T_{HS} = 32°C ONLY (SEE 4.2.2).
7	BURN-IN	160 HOURS MINIMUM, T_{HS} = 65 ±5°C, F_T = 1260 MHZ, PW = 2000 μs, D.F. = 18%, P_{IN} = P_2 MINIMUM (SEE TABLE III)
8	FINAL ELECTRICAL AND DELTA MEASUREMENTS	TABLE III TESTS 1, 2, 3, 6, 7, 10, 11, 12, 13, 19, 21, 22 AND 23 AT T_{HS} = 32°C ONLY (SEE 4.2.2). ALSO SEE NOTE 2/
9	EXTERNAL VISUAL INSPECTION	MIL-STD-883, METHOD 2009

NOTES: 1/ UNLESS OTHERWISE SPECIFIED, STEPS SHALL BE PERFORMED IN THE ORDER SHOWN.

2/ PERFORM DELTA MEASUREMENTS PER 4.2.7.

TABLE III

ELECTRICAL TESTS

EXCEPT AS OTHERWISE NOTED, ALL TESTS SHALL BE PERFORMED IN THE TEST FIXTURE OF 3.3.1.1, UNDER THE FOLLOWING STANDARD TEST CONDITIONS.

MODE OF OPERATION: PULSED

V_{CC} = 28 ±0.05 VDC

T_{HS} = 32° ±3°C

TEST FREQUENCY (F_T) = 1215.00, 1261.25, 1307.50
1353.75 AND 1400.00 MHz

PULSE WIDTH (P.W.) = 2000 μs
DUTY FACTOR (D.F.) = 18%
PEAK INPUT POWER (P_{IN}) = P_2

WHERE: P_1 = 36.8, ±0.1, DBM
P_2 = 37.3, ±0.1, DBM
P_3 = 37.8, ±0.1, DBM
P_4 = 38.3, ±0.1, DBM

TEST NO.	PARAMETER	SYMBOL	CONDITIONS	T_{HS}±3°C	LIMITS MIN	LIMITS MAX	UNIT
1	MAXIMUM SUPPLY VOLTAGE CAPABILITY (REQT 3.3.1.5)	V_{CC}	APPLY STANDARD TEST CONDITIONS FOR ONE SECOND, MINIMUM; EXCEPT V_{CC} = 32.0, +0.0 VDC -0.1,		MODULE SHALL NOT BE DAMAGED		
2	PEAK POWER OUTPUT (REQT 3.3.2)	P_O(PK)	DATA AT EACH FREQ. SHALL BE AVERAGED FOR P_{IN} = P_1, P_2, P_3	32°C	49.48	51.46	DBM
				57°C	49.23	51.46	DBM
				-40°C	49.23	51.46	DBM

FOOTNOTES ARE AT END OF TABLE

GENERAL ELECTRIC
HMED SYRACUSE, N.Y.
DRAWN Em Swart
ISSUED 80-11-17

SIZE	FSCM NO	DWG NO	REV
A	03538	77A100244	
SCALE		SHEET 16	

TABLE III - CONTINUED

TEST NO.	PARAMETER	SYMBOL	CONDITIONS	T_{HS} ±3°C	LIMITS MIN	LIMITS MAX	UNIT
3	SUPPLY CURRENT (REQT 3.3.9)	I_{CC}	DATA AT EACH FREQ. SHALL BE AVERAGED FOR $P_{IN} = P_2, P_3, P_4$	32°C		1.84	A
				57°C		1.84	A
				-40°C		1.84	A
4	LOT AVERAGE PEAK POWER OUTPUT (REQT 3.3.2)	$\overline{P_O(PK)}$	USE TEST DATA FROM TEST NO. 2; SEE NOTE 1/	32°C	49.98	51.46	DBM
				57°C	49.73	51.46	DBM
				-40°C	49.73	51.46	DBM
5	LOT AVERAGE SUPPLY CURRENT (REQT 3.3.9)	$\overline{I_{CC}}$	USE TEST DATA FROM TEST NO. 3; SEE NOTE 1/	32°C		1.67	A
				57°C		1.67	A
				-40°C		1.67	A
6	PUSHING FACTOR PHASE VS VCC (FOR USE IN TEST 8)	$\Delta\phi$	VCC1 = 27 ±0.05 VDC VCC2 = 28 ±0.05 VDC SEE NOTE 2/	32°C	RECORD DATA		°/V
				57°C			
				-40°C			
7	PUSHING FACTOR POWER OUT VS VCC (FOR USE IN TEST 9)	ΔP_O	VCC1 = 27 ±0.05 VDC VCC2 = 28 ±0.05 VDC SEE NOTE 2/	32°C	RECORD DATA		DB/V
				57°C			
				-40°C			
8	LOT AVERAGE OF $\Delta\phi$ (REQT 3.3.4)	$\overline{\Delta\phi}$	SAME AS TEST 6; SEE NOTE 3/	32°C		6	°/V
				57°C		6	°/V
				-40°C		6	°/V

FOOTNOTES ARE AT END OF TABLE

GENERAL ELECTRIC
HMED SYRACUSE, N.Y.
DRAWN Em Swart
ISSUED 80-11-17

SIZE A | FSCM NO 03538 | DWG NO 77A100244 | REV
SCALE | SHEET 17

TABLE III - CONTINUED

TEST NO.	PARAMETER	SYMBOL	CONDITIONS	T_{HS}±3°C	LIMITS MIN	LIMITS MAX	UNIT
9	LOT AVERAGE OF ΔP_0 (REQT 3.3.4)	$\overline{\Delta P_0}$	SAME AS TEST 7; SEE NOTE 3/	32°C		0.3	DB/V
				57°C		0.3	DB/V
				-40°C		0.3	DB/V
10	PUSHING FACTOR, PHASE VS P_{IN} (REQT 3.3.5)	$\delta\phi$	$P_{IN} = P_1$ AND P_3 SEE NOTE 4/	32°C		20	°/DB
				57°C		20	°/DB
				-40°C		20	°/DB
11	PUSHING FACTOR, POWER VS P_{IN} (REQT 3.3.5)	δP_0	SAME AS TEST 10 SEE NOTE 4/	32°C		0.7	DB/DB
				57°C		1.0	DB/DB
				-40°C		1.0	DB/DB
12	PULSE DROOP (REQT 3.3.6), PHASE CHANGE	$\Delta\Phi$	VCC DECREASING BY 0.6 VOLT OVER THE 2 MS PULSE DURATION; SEE NOTE 5/	32°C		25	DEG
				57°C		25	DEG
				-40°C		25	DEG
13	PULSE DROOP (REQT 3.3.6), AMPLITUDE CHANGE	ΔA	SAME AS TEST 12 SEE NOTE 5/	32°C		0.5	DB
				57°C		0.5	DB
				-40°C		0.5	DB
14	SPURIOUS OUTPUTS: SPECTRAL DENSITY (REQT 3.3.7)	ΔS	P.W. = 100 μs SEE NOTE 6/	32°C		-80	DB
				57°C		-80	DB
				-40°C		-80	DB

FOOTNOTES ARE AT END OF TABLE

GENERAL ELECTRIC
HMED SYRACUSE, N.Y.
DRAWN Emsweet
ISSUED 80-11-17
SIZE A | FSCM NO 03538 | DWG NO 77A100244 | REV
SCALE | SHEET 18

TABLE III - CONTINUED

TEST	PARAMETER	SYMBOL	CONDITIONS	T_{HS}±3°C	LIMITS MIN	LIMITS MAX	UNIT
15	SPURIOUS OUTPUTS: NOT RELATED TO INPUT (REQT 3.3.7)	ΔU	P.W. = 100 μs SEE NOTE 6/	32°C		-60	DB
				57°C		-60	DB
				-40°C		-60	DB
16	HARMONIC OUTPUT (REQT 3.3.8)	ΔH	SEE NOTE 6/	32°C		-35	DB
				57°C		-35	DB
				-40°C		-35	DB
17	OUTPUT PULSE RISE TIME. (REQT 3.3.10)	t_R		32°C		0.15	μs
				-40°C			
18	OUTPUT PULSE FALL TIME. (REQT 3.3.11)	t_F		32°C		0.15	μs
				-40°C			
19	PHASE ERROR (REQT 3.3.12)	E(F, T_{HS}, t) SEE NOTE 7/	t = 50 μs	32°C		20	DEG
			t = 700 μs	32°C		20	DEG
			t = 50 μs	57°C		22	DEG
				-40°C			
			t = 700 μs	57°C		22	DEG
				-40°C			

FOOTNOTES ARE AT END OF TABLE

GENERAL ELECTRIC
HMED SYRACUSE, N.Y.
DRAWN Emswait
ISSUED 80-11-17

SIZE	FSCM NO	DWG NO	REV
A	03538	77A100244	

SCALE
SHEET 19

DWG NO 77A100244 | 20 | REV

TABLE III - CONTINUED

TEST NO.	PARAMETER	SYMBOL	CONDITIONS	T_{HS}±3°C	LIMITS MIN	LIMITS MAX	UNIT
20	LOT AVERAGE PHASE ERROR (REQT 3.3.12)	E_{RMS}(F, T_{HS}, t) SEE NOTE 8/	t = 50 μs	32°C		7.5	DEG
			t = 700 μs	32°C		7.2	DEG
			t = 50 μs	57°C -40°C		8.3	DEG
			t = 700 μs	57°C -40°C		8.0	DEG
21	INPUT VSWR (REQT 3.3.13)	VSWR		32°C 57°C -40°C		1.3:1	----
22	LOAD VSWR TOLERANCE (REQT 3.3.14) STABILITY		VSWR = 1.3:1 P_{IN} = P_1, P_4 SEE NOTE 9/	32°C 57°C -40°C	PER 3.3.14		
23	LOAD VSWR CAPABILITY, (REQT 3.3.14.1)		VSWR = 3:1 P_{IN} = P_3 SEE NOTE 9/	32°C 57°C -40°C	MODULE SHALL NOT BE DAMAGED.		

FOOTNOTES ARE AT END OF TABLE

GENERAL ELECTRIC HMED SYRACUSE, N.Y.	SIZE A	FSCM NO 03538	DWG NO 77A100244	REV
DRAWN Em Swet	SCALE		SHEET 20	
ISSUED 80-11-17				

DWG NO 77A100244 SH 21 REV

TABLE III NOTES

1/ THE TEST DATA OF TEST 2 (OR 3) SHALL BE AVERAGED OVER THE INSPECTION LOT FOR EACH TEMPERATURE. IN EACH CASE THE AVERAGE VALUE, $\overline{P_0(PK)}$ (OR $\overline{I_{CC}}$), SHALL BE WITHIN THE LIMITS SHOWN.

2/ DEFINITIONS:

$$\Delta\phi = \frac{1}{VCC2-VCC1}\left|\phi_{VCC2} - \phi_{VCC1}\right| \quad \text{AT } t = 50\ \mu s$$

$$\Delta P_0 = \frac{1}{VCC2-VCC1}\left|P_{O_{VCC2}} - P_{O_{VCC1}}\right| \quad \text{AT } t = 50\ \mu s$$

DATA FOR $\Delta\phi$ AND ΔP_0 SHALL BE RECORDED FOR USE IN TESTS 8 AND 9.

3/ THE QUANTITY $\Delta\phi$ (OR ΔP_0) MEASURED IN TEST 6 (OR 7) SHALL BE AVERAGED OVER THE INSPECTION LOT FOR EACH TEMPERATURE. IN EACH CASE THE AVERAGE VALUE SHALL BE WITHIN THE LIMITS SHOWN.

4/ DEFINITIONS:

$$\delta\phi = \frac{1}{P_3 - P_1}\left|\phi_{P_3} - \phi_{P_1}\right| \quad \text{AT } t = 700\ \mu s$$

$$\delta P_0 = \frac{1}{P_3 - P_1}\left|P_{O_{P_3}} - P_{O_{P_1}}\right| \quad \text{AT } t = 700\ \mu s$$

5/ PHASE MEASUREMENTS SHALL BE MADE AT 50 μs AND 700 μs INTO THE PULSE. POWER OUTPUT MEASUREMENTS SHALL BE MADE AT 50 μs AND 1800 μs INTO THE PULSE.

DEFINITIONS:

$$\Delta\Phi = \left|\Phi_{50} - \Phi_{700}\right|$$

$$\Delta A = \left|P_{O_{50}} - P_{O_{1800}}\right|$$

GENERAL ELECTRIC HMED SYRACUSE, N.Y.	SIZE	FSCM NO	DWG NO	REV
DRAWN Emswart	A	03538	77A100244	
ISSUED 80-11-17	SCALE		SHEET 21	

TABLE III NOTES - CONTINUED

6/ MEASUREMENTS TO BE MADE WITH SPECTRUM ANALYZER:

P_T = POWER DENSITY AT TEST FREQ (F_T)

P_S = POWER DENSITY AT SPURIOUS FREQ (F_S)

P_U = POWER DENSITY AT UNRELATED FREQ.

P_H = POWER DENSITY AT HARMONIC FREQ.

$\Delta S = P_S(DBM) - P_T(DBM)$; $69\ MHZ < |F_S - F_T| < 250\ MHZ$

$\Delta U = P_U(DBM) - P_T(DBM)$

$\Delta H = P_H(DBM) - P_T(DBM)$

7/ DEFINITION:

$$E(F, T_{HS}, t) = \left| \hat{\Phi}(F, T_{HS}, t) - \Phi(F, T_{HS}, t) \right|$$

WHERE: $\Phi(F, T_{HS}, t)$ = TARGET PHASE SHIFT FROM TABLE I.

$\hat{\Phi}(F, T_{HS}, t)$ = MEASURED PHASE SHIFT WITH RESPECT TO THE 32°C PHASE SHIFT OF THE PHASE REFERENCE MODULE.

t = TIME INTO PULSE, IN MICROSECONDS.

8/ DEFINITION:

$$E_{RMS}(F, T_{HS}, t) = \sqrt{\frac{1}{N} \sum_{i=1}^{N} E_i^2 (F, T_{HS}, t)}$$

WHERE: N = NUMBER OF MODULES IN THE LCT

$E_i(F, T_{HS}, t)$ IS DEFINED IN NOTE 7/

9/ THIS TEST SHALL BE PERFORMED BY SWEEPING THE ANGLE OF THE LOAD IMPEDANCE TO COVER ALL ANGLES OF REFLECTION COEFFICIENT THROUGH 360 DEGREES, USING A SWEEP PERIOD DURATION OF NOT LESS THAN 30 SECONDS.

GENERAL ELECTRIC HMED SYRACUSE, N.Y.	SIZE	FSCM NO	DWG NO	REV
DRAWN EmSwart	A	03538	77A100244	
ISSUED 80-11-17	SCALE			SHEET 22

DWG NO 77A100244 REV 22

TABLE IV (REQT 4.4.2)

QUALIFICATION TESTS - ELECTRICAL

TEST GROUP NO.	SAMPLE SIZE	TEST	CONDITIONS	LIMITS
1	20	TESTS FROM TABLE III: NO. 2 P_0(PK); NO. 3 I_{CC}; NO. 19 E(F, T_{HS}, 50); NO. 19 E(F, T_{HS}, 700); NO. 21 VSWR	ALL COMBINATIONS OF THE FOLLOWING: F_T = 1215.00, 1261.25, 1307.50, 1353.75 AND 1400.00 MHZ VCC = 27, 28, 29 VDC ±0.05 VDC P_{IN} = P_1, P_2, P_3, P_4 T_{HS} = -40, -20, +32 AND +57°C, ±3°C P.W. AND D.F. = 100 μs AT 7%, 800 μs AT 15% AND 2000 μs AT 18%	PER TABLE III AS APPLIC-ABLE; OTHERWISE DATA IS FOR INFO ONLY
		ALL TESTS OF TABLE III EXCEPT TESTS 2,3,19 AND 21	PER TABLE III	PER TABLE III
2	5	STABILITY (PULSE BREAK-UP)	ALL COMBINATIONS OF THE FOLLOWING: F_T = SAME AS TEST GROUP NO. 1 VCC = 28 ±0.05 VDC P_{IN} = P_1 AND P_4 T_{HS} = -40, +32 AND +57°C, ±3°C P.W. = 2000 μs, D.F. = 18% TEST LOAD PER NOTE 1/	PER 3.3.14
3	5	JUNCTION TEMPERATURE SEE NOTE 2/	SAME AS TEST GROUP NO. 2 EXCEPT: T_{HS} = 57°C ±3°C ONLY, P_{IN}=P_3, P_4	DATA IS FOR INFO ONLY

NOTES: SEE NEXT SHEET

GENERAL ELECTRIC
HMED SYRACUSE, N.Y.

DRAWN

ISSUED 80-11-17

SIZE A | FSCM NO 03538 | DWG NO 77A100244 | REV

SCALE | SHEET 23

TABLE IV - CONTINUED

NOTES:

1/ MEASUREMENTS SHALL BE MADE WITH A LOAD WHOSE VOLTAGE REFLECTION COEFFICIENT IS ADJUSTED TO THE FOLLOWING:

ρ = 0.13 (VSWR = 1.3:1) AT ANGLES OF 0°, 90°, 180°, AND 270°, AND ρ = 0, AT THE PLANE OF THE MODULE TEST FIXTURE OUTPUT CONNECTOR.

2/ TO BE PERFORMED DURING SCREEN TESTING (SEE 4.4.1) OF TEST SAMPLES

TABLE V (REQT 4.4.4)
ENVIRONMENTAL QUALIFICATION TESTS SEE NOTE 1/

SUB-GROUP	NO.	INSPECTION OR TEST	METHOD	REQT REF.
I	1	PHYSICAL DIMENSIONS	MIL-STD-883, METHOD 2016	3.2
	2	THERMAL SHOCK	PER 4.4.4.1	3.4.5
	3	TEMPERATURE CYCLING	MIL-STD-883, METHOD 1010, CONDITION A, -55 TO +85°C; 100 CYCLES, MINIMUM	3.4.9
	4	MOISTURE RESISTANCE	MIL-STD-883, METHOD 1004,	3.4.6
	5	SEAL TEST	MIL-STD-883, METHOD 1014, CONDITION A2 AND C	
	6	VISUAL INSPECTION	MIL-STD-883, METHOD 2009,	
	7	ELECTRICAL TESTS	SEE NOTE 3/	
II	8	MECHANICAL SHOCK	MIL-STD-883, METHOD 2002, 30G PEAK	3.4.2
	9	VIBRATION VARIABLE FREQUENCY	MIL-STD-883, METHOD 2007, CONDITION A (20G)	3.4.3
	10	ACCELERATION	MIL-STD-883, METHOD 2001, CONDITION A, 5000G, Y1 DIRECTION ONLY.	3.4.4
	11	SEAL TEST	SAME AS STEP 5	
	12	VISUAL INSPECTION	MIL-STD-883, METHOD 2009	
	13	ELECTRICAL TESTS	SEE NOTE 3/	
III	14	SALT ATMOSPHERE SEE NOTE 2/	MIL-STD-883, METHOD 1009, CONDITION A, 24 HOURS	3.4.7

1/ WITHIN ANY SUBGROUP, PERFORM TESTS IN ORDER SHOWN.

2/ FOR TEST NO. 14 (SALT ATMOSPHERE), ELECTRICALLY INOPERATIVE MODULES TAKEN FROM THE SAME PRODUCTION RUN MAY BE USED AS TEST SAMPLES.

3/ ELECTRICAL END-POINTS MEASUREMENTS. PERFORM TESTS FROM TABLE III AS FOLLOWS: NO'S 2, 3, 12, 13, 19 AND 21 AT A HEATSINK TEMPERATURE OF 32 DEGREES C ONLY.

GENERAL ELECTRIC HMED SYRACUSE, N.Y.	SIZE A	FSCM NO 03538	DWG NO 77A100244	REV
DRAWN				
ISSUED 80-11-17	SCALE		SHEET 25	

DWG NO 77A100244 SH 25 REV

APPENDIX C

THE DIRECT BONDING OF METALS TO CERAMICS
AND APPLICATIONS IN ELECTRONICS

Technical Information Series
Report No. 75CRD105 (16 Pages)

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GENERAL ELECTRIC COMPANY
CORPORATE RESEARCH AND DEVELOPMENT
Schenectady, N.Y.

THE DIRECT BONDING OF METALS TO CERAMICS AND APPLICATIONS IN ELECTRONICS

by

J.F. Burgess, C.A. Neugebauer,
G. Flanagan,* and R.E. Moore†
Information Materials Branch
Electronics Science and Engineering

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TECHNICAL INFORMATION SERIES

*GE Heavy Military Electronic Systems Products Department, Syracuse, N.Y.

†GE Ordnance Systems Products Department, Pittsfield, MA

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SUMMARY

The direct bonding of metals to ceramics is possible utilizing a gas metal eutectic. The mechanism of direct bonding of copper foil to ceramics in a slightly oxidizing atmosphere is presented. It involves the formation of eutectic melt between copper and oxygen at a temperature slightly below the melting point of copper, which serves to bring the foil into intimate contact with the substrate. Metals to which this technique is applicable include Cu, Fe, Ni, Co, Ag, Cr, Mo and Al. A brief review of other metal-ceramic bonding techniques is given for comparison.

The process for fabricating direct bonded copper structures is given, and properties of the bond are discussed. The use of the direct bonding process in a number of electronic applications such as hybrid packages and power device heat sinks is indicated.

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*GE Heavy Military Electronic Systems Products Department, Syracuse, NY

†GE Ordnance Systems Products Department, Pittsfield, MA

KEY WORDS electronic materials, hybrid electronics, ceramic bonding, heat sinking

SUBJECT electronic materials

THE DIRECT BONDING OF METALS TO CERAMICS AND APPLICATIONS IN ELECTRONICS

J.F. Burgess, C.A. Neugebauer,
G. Flanagan, and R.E. Moore

Abstract

The direct bonding of metals to ceramics is possible utilizing a gas metal eutectic. The mechanism of direct bonding of copper foil to ceramics in a slightly oxidizing atmosphere is presented. It involves the formation of eutectic melt between copper and oxygen at a temperature slightly below the melting point of copper, which serves to bring the foil into intimate contact with the substrate. Metals to which this technique is applicable include Cu, Fe, Ni, Co, Ag, Cr, Mo and Al. A brief review of other metal-ceramic bonding techniques is given for comparison.

The process for fabricating direct bonded copper structures is given, and properties of the bond are discussed. The use of the direct bonding process in a number of electronic applications such as hybrid packages and power device heat sinks is indicated.

Introduction

Strong bonding of metals to ceramics generally does not take place unless an intermediary layer is present, or forms due to diffusion or reaction. The adhesion of the metal to this intermediary is better than to the ceramic directly. However, an intermediary layer is undesirable in many applications. This is true, for instance, where high heat conductivity is required.

The presence of an intermediary layer generally reduces heat conductivity, especially if the layer is non-metallic. Further, in high frequency applications, where the current flows in a thin skin at the metal-ceramic boundary, intermediary layers are undesirable because they are generally more resistive than the metal to be bonded. Finally, intermediary layers are often less corrosion resistant and lead to premature failure.

Unfortunately, strong direct metal to ceramic bonds are not common, either because the bond is inherently weak, or because of the difficulty of bringing the metal into intimate contact with the ceramic. In this paper, a new method of direct bonding of metals to ceramics will be given. For a better perspective, a short summary of the mechanisms of presently used metal-ceramic bonding techniques is given below.

Bonding Mechanisms Involving Intermediary Layers

Some of the more pertinent literature in this area has been reviewed by C. I. Helgesson,(1) and a short review was recently given by Loasby et. al.(2) Commonly used intermediary layers are glass layers, where the glass in intentionally added or is originally present in the ceramic itself, or polycrystalline semiconducting compounds formed by the reaction between the metal or metal oxide and the ceramic itself.

1. Glassy Intermediary Layers

Glassy phases are usually present in the grain boundaries of impure (<99.8%) ceramics. Thus, Al_2O_3 or BeO ceramics usually contain glassy mixtures of MgO, SiO_2 and CaO concentrated in the grain boundaries. When a metallizing mixture is applied to such a ceramic, and the temperature is raised to sintering temperatures, the glass from the ceramic penetrates into the (porous) metal layer and locks it to the ceramic after cooling by mechanical forces.

More commonly, glass is intentionally added to the metallizing mixture to form the intermediate layer. This is particularly true if the ceramic is pure. For example, to take advantage of the high thermal conductivity of BeO ceramic, glass must be kept out of the grain boundaries. Therefore, the common metallizing mixtures, such as Mo-Mn, when used on beryllia, contain up to 20% SiO_2. Thus the composition of a typical mixture is 71.5% Mo, 10.7% Mn, and 17.8% SiO_2, fired on BeO at 1300°C. The manganese diffuses into the glass.

Another commonly practiced method of bonding through an intermediary glass phase involves glass frit additions to the finely divided metal in the metallizing mixture. Thus, the majority of the so-called "thick film" conductor pastes contain a glass frit, generally chosen for low melting point and thermal expansion match, in addition to dispersed metal (normally noble metals) in an organic carrier. The glass frit melts and reacts with the ceramic (usually Al_2O_3), and it also forms a network within the metal conductor. Thus, the bond between the metal and the ceramic is due to mechanical locking by the reacted glass. It should be noted that the bond strength of glass frit compositions is best on alumina; for beryllia, cracking of the glass and spalling is generally observed.

2. Polycrystalline Intermediary Layers

Such layers are usually compounds formed between the metallizing mixture and the ceramic. In one method, the metal oxide is applied to the ceramic, and sintered with the ceramic to form a mixed oxide compound. For instance, such a compound is formed between copper oxide and alumina, possible $CuAlO_2$, when they are sintered together at 1150°C in air. Subsequent reduction gives an adherent metal layer bonded on the mixed oxide phase. This method is also applicable to cobalt, nickel, iron and silver.

The widely used moly-manganese process also falls into this category. In this process, a mixture of molybdenum and manganese oxide is fired on alumina (not beryllia) at 1400°C in an atmosphere of wet hydrogen. The hydrogen reduces the molybdenum oxide to the metal, but not the manganese oxide, which reacts with the alumina to form the intermediate layer compound $MnO \cdot Al_2O_3$. The molybdenum, which is unable to diffuse deeply into pure Al_2O_3, will diffuse readily into the manganese aluminate spinel. This leads to good adhesion of the Mo layer, When MoO_3 alone is used, some penetration of alumina by MoO_3 occurs, especially in hydrogen atmospheres at high humidities. A compound between Mo and Al_2O_3, perhaps $Al_2(MoO_4)_3$,[3,4] is formed to provide the intermediary bonding layer.

Direct Bonding

Direct bonding here implies the absence of a readily identifiable intermediate phase between the metal and the ceramic. It does not exclude, however, the presence of a transition layer one or two monolayers thick, such as perhaps oxygen bridges between the metal and ceramic.

A method of direct bonding which does not depend on any kind of intimate bond between metal and ceramic is that involving mechanical locking or keying.

In this process the metal is screened on the ceramic in the form of an organometallic paste. The paste decomposes on heating in air, with the result that metal particles are now locked in pores in the ceramic surface to give a mechanical bond. Films of noble metals, such as platinum, are typically applied in this way. However, poor adhesion is obtained in the mechanical locking process. Clearly, in order to get good adhesion by direct bonding it is required that

- the metal must be brought into intimate contact with the ceramic over the entire area on an atom to atom basis.
- the metal must form a strong bond with the ceramic, be it by Van der Wall's or chemical bonding, without extensive reaction or diffusion of the two phases into each other.

To get intimate contact between metal and a ceramic surface, the metal could be brought into the liquid state by melting. The liquid will replicate the ceramic surface where it wets it, and if a strong bond is formed, good adhesion is obtained after cool-down. For instance, when copper is melted in hydrogen on an alumina substrate, a molten droplet is formed with a melting angle of approx. 120°, which after cool-down to room temperature adheres strongly to the ceramic. The problem with simply melting the metal, of course, is that one or more droplets are formed, and the metal member to be bonded entirely loses its shape. This can be avoided by the gas metal eutectic method.

Direct Bonding by the Gas-Metal Eutectic Method

The basic idea here is to form a liquid skin around the metallic member to be bonded. The liquid must wet both the metallic member and the ceramic, and form a strong bond after cool-down. The melting point of this liquid should be near the melting point of the metal member itself, say within 50°C, so that the metal member becomes soft and pliant and conforms easily to the shape of the substrate surface. Further, the predominant constituent of this liquid should be the same element as makes up the metallic member, and any additional constituent should be present in only small amounts or be easily removable after bonding. The thickness of the molten skin must be kept small in comparison to the thickness of the member to be bonded.

Ideal for use as the skin material are eutectics formed by the flow gas in a bonding system with the metal member itself. Such a eutectic exists, for instance, between copper and oxygen, at 0.39% weight % oxygen.[5] The melting point of this eutectic is 1065°C, as compared to 1083°C for pure copper. Thus, if the oxidizing conditions in the flow gas are chosen properly, one may have the molten copper-oxygen eutectic mixture and solid copper (containing a small amount of dissolved oxygen) coexist together, in the temperature interval $1065° < T < 1083°C$. It is this copper-oxygen eutectic skin which is in effect used as a glue to bond the solid copper member to the ceramic, without the Cu member losing its shape. Thus, in order to bond copper foil to ceramic, the process is as follows:

The Cu foil is laid on top of the ceramic in a furnace containing a flow gas atmosphere consisting primarily of an inert gas, such as argon or nitrogen, with a small addition of oxygen, typically of the order of a few hundredths of a percent. Copper initially reacts during the heat-up period with the oxygen in the flow gas. A small amount of oxygen dissolves in the copper, but most of it reacts to form Cu_2O around the foil. When 1065°C or above is reached, a liquid phase of or near the eutectic composition forms a skin around the copper. The thickness of this molten skin depends on the O_2 partial pressure and the oxidation time. If the partial O_2 pressure in the flow gas is less than $1.5 \cdot 10^{-6}$ atm (the equilibrium partial pressure over Cu_2O at 1065°C), Cu_2O will not form and the eutectic phase also will not form. The formation of a molten layer between the Cu foil and the substrate serves to bring the copper in intimate contact with the ceramic, by wetting it over the entire interface. Once in intimate contact with the ceramic, copper forms a strong bond with it. The temperature must remain below 1083°, the melting point of copper, since otherwise the foil loses its structural integrity and liquid drops are formed. Similarly, if the partial pressure of oxygen is too high, all copper present is converted into eutectic melt. Thus, an intermediate O partial pressure is required where both phases are present simultaneously. On cool-down below 1065°, the eutectic segregates into Cu and

Cu_2O. Evidence of this is shown in Fig. 1, which is a micrograph through a section of bonded copper foil, and indicates the presence of a second phase. This oxide phase may now be reduced in hydrogen at low temperature, without loss of adhesion. The bonding process is schematically illustrated in Fig. 2.

Copper has been bonded successfully by the gas-metal eutectic methods on alumina, beryllia, silica, various other spinels, other metals and to itself. It does not bond, however, to boron nitride or carbon. The bond strength to oxygen-containing ceramics can be in excess of 20,000 psi. Removal of the copper by etching in nitric acid or ferric chloride solution leave no copper residue. Since the copper itself does not melt during bonding, pre-cut or stamped foils of copper of the desired shapes can be bonded. In addition, holes previously cut into ceramic substrates can be covered hermetically, and the copper can overhang the ceramic. Bonds between copper and other metals, and between two copper members, can also be made by this method. A photograph of various direct bonded copper structures prepared in this laboratory are shown in Fig. 3.

Properties of Direct Bonded Copper Structures

Some properties of direct bonded copper on ceramic structures are listed in Table I.

Table I

- o Electrical conductivity is at least within 5% of pure copper, in the as-bonded condition.
- o The hardness of the copper in the as-bonded condition is much higher than after hydrogen reduction, because of dispersion hardening due to precipitated Cu_2O from the eutectic.
- o The Cu-ceramic bond strength routinely exceeds 20,000 psi.
- o In spite of the expansion coefficient difference, repeated thermal cycling from 77°K to 600°K does not cause mechanical failure.
- o Brazing, soft and hard soldering, resistance and electron beam welding are possible to the bonded copper without causing bond failure.
- o Holes in the ceramic can be sealed hermetically by direct bonded copper.

Application of Direct Bonded Copper in Hybrid Packaging

The use of directly bonded Cu foil to ceramics for the construction of hybrid packages offers advantages because:

1. Foils from 1 to 250 mils thick or more thickness can be bonded on Al_2O_3, BeO or metals without the use of an intermediary layer and without losing the structural integrity of the foil.

2. Several layers of Cu foil and ceramic can be bonded in one single firing step. This allows fabrication of conductor crossovers and interconnections among various conductor layers; the inclusion of a Cu backplate for heat sinking; and, external package leads in one single step.

3. Since the Cu-ceramic bond does not require an intermediate interfacial layer, better heat sinking is possible.

4. Thick film conductor screening and firing steps can be entirely eliminated.

5. The Cu-ceramic bond is exceptionally strong.

6. Fabrication costs are considerably below conventional methods because of process simplicity and lower materials cost.

Figure 4 illustrates the use and versatility of the copper foil bonding process in fabricating electronic packages, including heat sinking, conductor crossovers and interconnections, and top to bottom straps. Copper foil and ceramic pieces are previously cut to the desired dimensions and are appropriately located on the ceramic substrate before the furnace pass for one step bonding. Alternatively, the pattern can be etched after bonding. This latter technique is particularly suitable for fine and complex geometries.

Figure 5 gives a sequence of steps to fabricate a hermetic ceramic package. Pieces of copper and ceramic are cut to the appropriate size and are bonded directly to give a lead frame, conductor pattern, pellet bonding pad, conductor crossover, and heat sink. The window frame for lid attachment is fired on by means of a glass ceramic frit at $500<T<700°C$. Pellet bonding and lid attachment complete the package.

When the direct bonded copper foil covers a hole previously cut into the ceramic, a hermetic seal is formed. This allows for the mounting of pins or tabs from the backside by soldering, welding, or plating on copper. Figure 6 illustrates a sequence of steps to fabricate a package in this manner. After direct bonding of a copper foil to a pre-drilled ceramic substrate, the conductor pattern and window frame are photoetched. After nickel plating, the pins are mounted and the pellet is attached. Lid attachment completes the hermetic package. Figure 7 is a photograph of a hybrid circuit fabricated by this process.

Application to Other Metal-Ceramic Systems

For the direct bonding of metal by the gas-metal eutectic method, the following prerequisites must be fulfilled:

a) a eutectic must exist between the metal and the flow gas,

b) the percentage of the gas component in the eutectic must be low and/or easily removable after bonding,

c) the eutectic temperature must be at least 10 degrees or so below the melting point of the metal to give a realistic temperature range for bonding,

d) the metal must be pliant at the bonding temperature so that it conforms to the substrate shape.

Inspection of phase diagrams of metals with the more common gases reveals a number of possibilities. In particular, oxygen, sulfur, and phosphorous form eutectics with several metals. These are listed in Table II, in addition to the eutectic temperature, the melting point of the metal, and the percentage of the gas component in the eutectic.

Table II: Metal-Gas Eutectics for Direct Bonding

Eutectic	Eutectic Temp. °C	Weight % non-metal	Melting Point of metal
Copper-oxygen	1065	0.39	1083
Iron-oxygen	1523	0.16	1535
Nickel-oxygen	1438	0.24	1452
Cobalt-oxygen	1451	0.23	1480
Copper-sulfur	1067	0.77	1083
Silver-sulfur	906	1.8	960
Chromium-sulfur	1550	2.2	1615
Silver-phosphorous	878	1.0	960
Nickel-phosphorous	714	11.0	1452
Copper-phosphorous	714	8.4	1083
Molybdenum-silicon	2070	5.5	2625
Aluminum-silicon	577	11.7	660

The flow gas would contain small amounts of oxygen, hydrogen disulfide, phosphine, or silane, as appropriate, However, in some cases a constituent of the flow gas such as silicon may not be easily removable, and the bond in such a case could not, strictly speaking, be called "direct".

References

1. C. I. Helgesson, Ceramic to Metal Bonding, Bost Tech. Publ., Cambridge, Mass. (1969).
2. R. G. Loasby, N. Davey, and H. Barlow, Sol. State Tech., May 1972, pg. 46.
3. A. G. Pincus, Ceramic Age 63, 16 (1954).
4. A. G. Pincus, Ceramic Age 63, 30 (1954).
5. A. Butts, Copper, The Science and Technology of the Metal, Its Alloys and Compounds, Reinhold Publ. Corp., N. Y. (1954), pg. 475.

Fig. 1 Micrograph of section through direct copper bond to alumina, showing the precipitated Cu_2O from the eutectic.

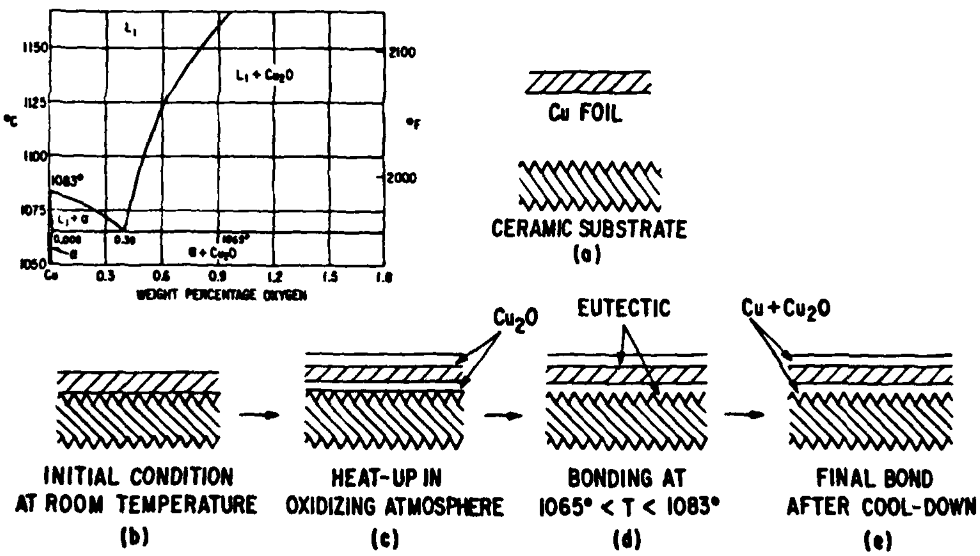

Fig. 2 Eutectic phase diagram and schematic of bonding process.

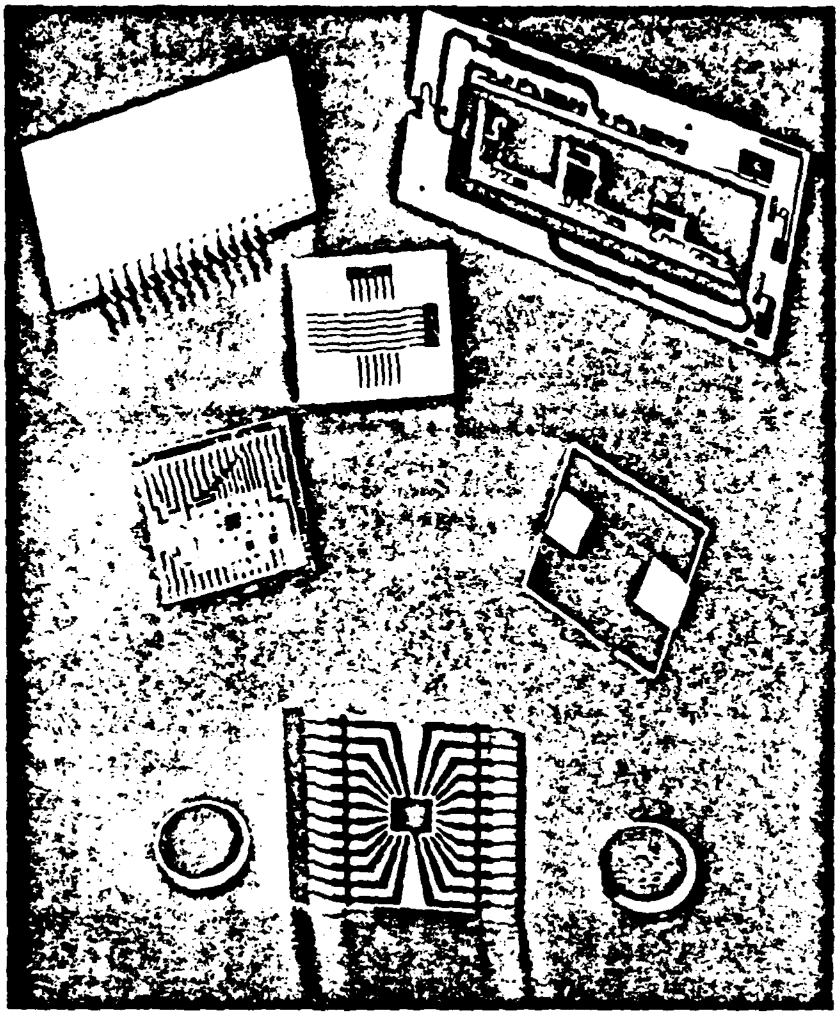

Fig. 3 Direct bonded copper structures.

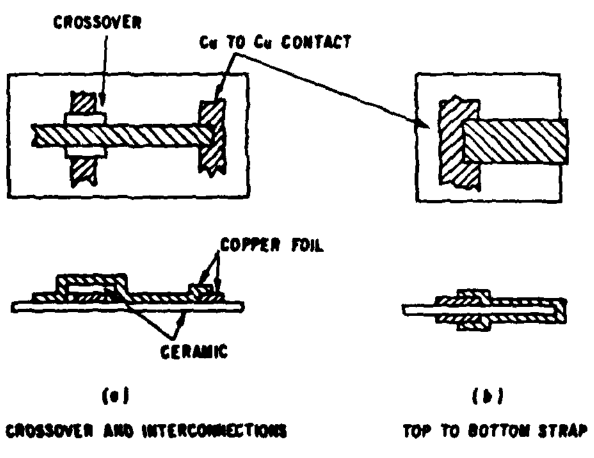

Fig. 4 Using direct bonded copper in constructing electronic packages.

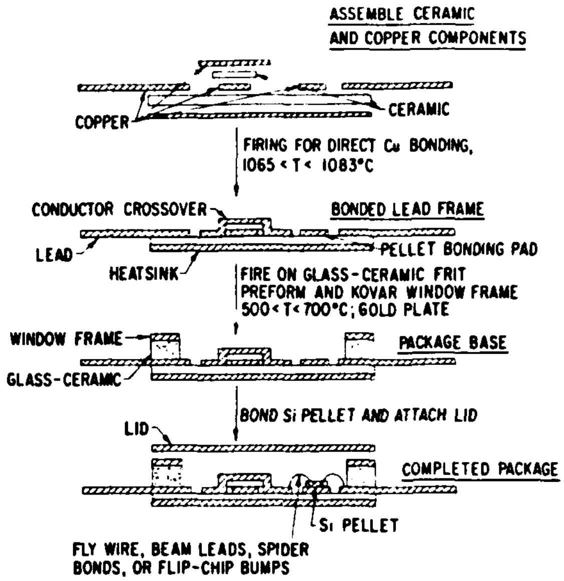

Fig. 5 Process steps to fabricate electronic package by direct bonding process.

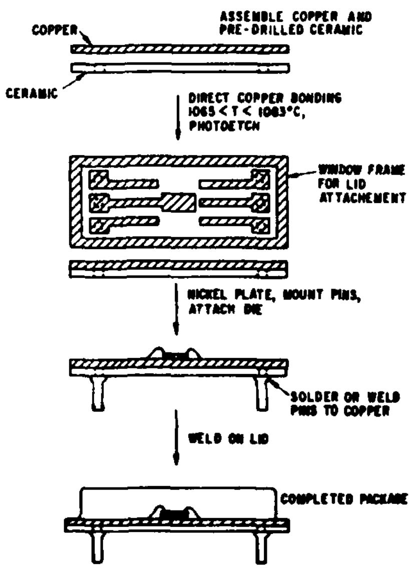

Fig. 6 Process steps to fabricate electronic package by direct copper bonding process.

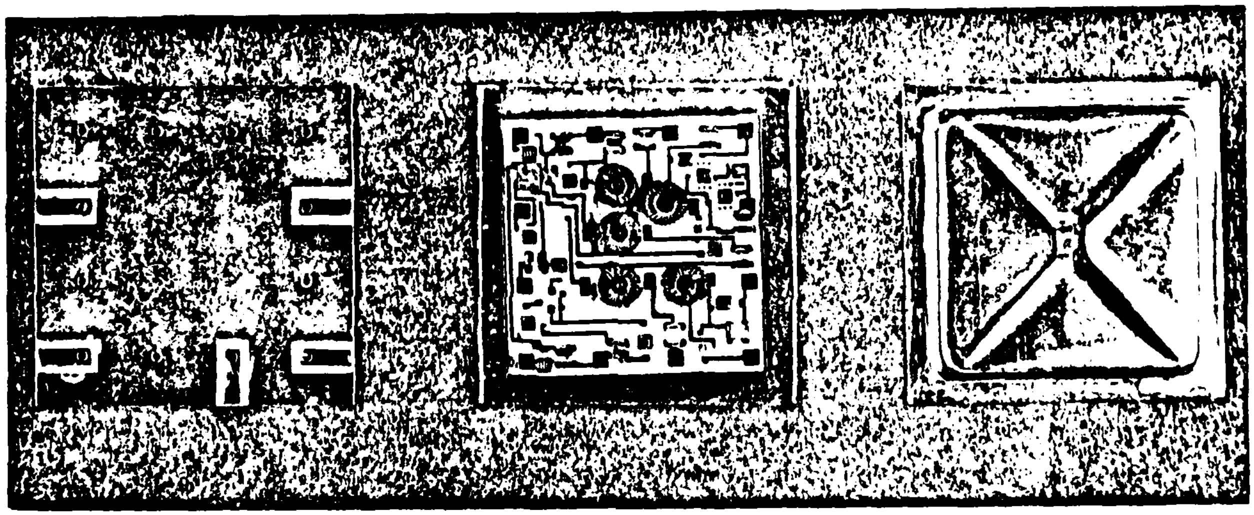

Fig. 7 Example of hybrid circuit fabricated by process illustrated in Fig. 6.

APPENDIX D

RADIO FREQUENCY POWER AMPLIFIER
(Qualification Procedure)
(15 Pages)

GENERAL ELECTRIC

QUALITY CONTROL TEST PROCEDURE

VOL.	CONTR. REF.		SEQ.	
85	47	10	1	0

SHEET NO 1 OF 15

COVER SHEET

TITLE QUALIFICATION PROCEDURE
R.F. POWER AMPLIFIER 77D609955

INITIATED BY R.J. Kelly DATE 3/13/81 REVIEW BY J. Chervenic DATE 3/16/81
APPROVED BY [signature] DATE [illegible]
PROGRAM Solid State Radar

REVISION LETTER	REVISED SHEETS	REVISION AUTHORITY	DATE	REVISED BY
(-)	BASIC			
A	Changed Sh. 2, 3, 4 and 6.	J. Chervenic	5-28-81	R. Kelly

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QUALIFICATION PROCEDURE - RF POWER AMP 77D609955

1. PURPOSE

Provide procedures for qualification tests and inspections for RF Power Amplifier hybrid microcircuit 77D609955.

2. REFERENCES

A.	77A100244	Specification, RF Power Amplifier
B.	77C716283	Specification Control
C.	MIL-STD-883	Test Methods for Microelectronics
D.	HIC-81-008	Shock/Vibration Test Fixture

3. QUALITY INFORMATION EQUIPMENT

Specified in body of procedure or referenced Mil Spec.

4. GOVERNMENT INSPECTION

If government witness of tests is required, notify local DCAS QA representative 24 hours before test is performed.

5. TEST INFORMATION

Conduct environmental tests/inspections in accordance with Table I. Perform life test per paragraph 6.M.

TABLE 1

ENVIRONMENTAL QUALIFICATION REQUIREMENTS 1/

SUB GROUP	TEST NO.	TEST/INSPECTION	QTY	METHOD/REQUIREMENT
N/A	N/A	Preconditioning	All	All modules submitted for qualification testing shall have passed screen tests per 77A100244 para. 4.2 (ref. 77A100244 para. 4.4.1).
1	1	Physical Dimensions	5	MIL-STD-883, Method 2016.
	2	Thermal Shock	↓	Cycle: soak @ -56°C non-operating, operate until thermally stable. Repeat for 15 cycles total. Ref. 77A100244 para. 4.4.4.1.
	3	Temperature Cycling	↓	MIL-STD-883, Method 1010, -55 to 85°C, 100 cycles.
	4	Moisture Resistance	↓	MIL-STD-883, Method 1004, 10 days.
	5	Seal Test	↓	MIL-STD-883, Method 1014, Condition A2 & C.
	6	Visual Inspection	↓	MIL-STD-883, Method 2009.
	7	Electrical Tests	↓	77A100244 Table III as follows: tests 2, 3 12, 13, 19, 21 at heatsink temperature = 32°C only.
2	8	Mechanical Shock	5	MIL-STD-883, Method 2002, 30G peak.
	9	Vibration, variable frequency	↓	MIL-STD-883, Method 2007, 20G.
	10	Constant Acceleration	↓	MIL-STD-883, Method 2001, 5KG, Y1 direction only.
	11	Seal Test	↓	Same as No. 5.
	12	Visual Inspection	↓	Same as No. 6.
	13	Electrical Tests	↓	Same as No. 7.
3	14	Salt Atmosphere 2/	5	MIL-STD-883, Method 1009, 24 hours.

1/ Within any subgroup, perform tests in order shown.

2/ Test 14 (salt atmosphere) may use electrically non-operating modules from same production run.

6. TEST PROCEDURE

A. PHYSICAL DIMENSIONS

1. Equipment

a. Calipers or equivalent - calibrated.
b. Shadowgraph or equivalent - calibrated.

2. Procedure

a. Measure/record dimension per MIL-STD-883, Method 2016 using Statement Drawing.
b. Record results on Qualification Product Traveller.

B. THERMAL SHOCK

1. Equipment

a. Automatic Module Test Station with thermo-electric heating/cooling (Peltier) fixture - calibrated - HIC module test area.

2. Procedure

a. Install test module in Module Test Station.
b. With test unit non-operating, adjust cooling system to cool module to -56 ± 3°C until thermally stable.

c. Operate test module under following test conditions until thermally stable.

V_{CC} = 28.0 ± 0.5 VDC

F_T = 1261.3 MHZ

P.W. = 2.0 milliseconds

D.F. = 18%

P_{IN} = 38.3 ± 0.1 dbm

d. Record stabilized temperature (change in $\Delta t < 0.2°C$) and time to stabilize on test data sheets by module serial number.
e. Repeat steps 6.B.2.b, 6.B.2.c, and 6.B.2.d 14 times for a total of 15 cycles.
f. Remove module from station fixture.
g. Repeat steps 6.B.2.a thru 6.B.2.f for remainder of modules in test subgroup.

6. TEST PROCEDURE (Cont'd)

C. TEMPERATURE CYCLING

1. Equipment

a. Automatic Temperature Cycling Chamber - calibrated - HIC Engineering Lab.

2. Procedure

a. Set test modules on a sheet of insulating material in a low walled cookie tray.
b. Set cookie tray in transfer chamber of temperature cycling machine.
c. Operate machine at -55 and 85°C for 100 cycles.
d. Complete Qualification Product Traveller at end of test.

D. MOISTURE RESISTANCE

1. Equipment

a. Automatic Humidity Chamber - Standards Engineering Lab, CSP4.

2. Procedure

a. Perform test in accordance with MIL-STD-883, Method 1004.
b. Complete Qualification Product Traveller at end of test.

E. SEAL TEST

1. Procedure

a. Fine Leak

1. Perform per QCIP 88.53.84.01 at P = 30 psig, Vol. = 11.2CC. Maximum leak rate $\leq 1.8 \times 10^{-7}$ units.
2. Record measured leak rate on Qualification Product Traveller for each module.
3. Complete Qualification Product Traveller after all modules are tested.

b. Gross Leak

1. Perform per 88.54.23.01.
2. Complete Qualification Product Traveller after all modules are tested.

6. TEST PROCEDURE (Cont'd)

F. VISUAL INSPECTION

1. Procedure

a. Inspect for general damage and applicable paragraphs from QCTP's 82.47.10.42 and 82.47.10.59.
b. Record inspection results on Qualification Product Traveller, or 7055 Inspection Record form. Attach 7055 form to Product Traveller.
c. Complete Qualification Product Traveller after all modules are inspected.

G. ELECTRICAL TESTS

1. Equipment

a. Same as 6.B.1.a.
b. Procedure

1. Perform tests from 77A100244 Table III as follows: tests 2,3,12,13,19 and 21 to be performed at heatsink temperature of 32°C only.

c. Record test results on Qualification Product Traveller.

H. MECHANICAL SHOCK

1. Equipment

a. Drop Shock Equipment - Standards Engineering Lab.
b. Test fixture, HIC-81-008.
c. Universal test block - Standards Engineering Lab.

2. Procedure

a. Select the proper arresting pad to meet "G" level requirement of test and mount pad on drop shock machine.
b. Mount test unit in test fixture.
c. Mount test fixture in universal test block.
d. Mount test block on drop shock test table in first test direction.
e. From equipment manual determine test table height above arresting pad to meet "G" level.
f. Raise test table to required height and set release mechanism to hold.
g. Position hand near arresting pad to catch table after it has rebonded up from arresting pad (if necessary).

6. TEST PROCEDURE (Cont'd)

H. MECHANICAL SHOCK (Cont'd)

2. Procedure (Cont'd)

h. Release table latch and allow table to free fall onto arresting pad.
i. Catch table during rebound to prevent secondary impact with pad (if needed).
j. Repeat steps 6.H.2.f thru 6.H.2.i for the required number of shocks for subject test direction.
k. Reorient universal test block mounting for next required orientation and repeat 6.H.2.f thru 6.H.2.k until all required directions have been tested.
l. Remove test unit from fixture. Repeat steps 6.H.2.b, 6.H.2.c, 6.H.2.d, 6.H.2.f thru 6.H.2.k for all remaining test units in test subgroup.
m. Complete Qualification Product Traveller.

J. VIBRATION, VARIABLE FREQUENCY

1. Equipment

a. Vibration Machine - Standards Engineering Lab.
b. Test fixture, HIC-81-008.
c. Universal test block - Standards Engineering Lab.

2. Procedure

a. Mount test unit in test fixture.
b. Mount test fixture in universal test block.
c. Mount test block on vibration table in first test plane.*
d. Perform test per referenced Mil Spec.
e. Change test block to second test plane.
f. Perform test per referenced Mil Spec.
g. Change test block to third test plane.
h. Perform test per referenced Mil Spec.
i. Repeat all steps in this procedure as necessary for each module in test subgroup.
j. Complete Qualification Product Traveller.

* NOTE: It may be necessary to isolate universal test block from direct contact with vibration tableto prevent mounting resonances. One method is use of tape between table and block.

6. TEST PROCEDURE (Cont'd)

K. CONSTANT ACCELERATION

1. Equipment

a. Per QCIP 85.99.90.27.
b. Balance scale - uncalibrated.

2. Procedure

a. Record special typed information from label for each test unit in sublot.
b. Order replacement labels with same information from Bud Hoffman.
c. Pencil serial number on bottom of heatsink.
d. Remove plastic covers from test units per MPI 1000.1.753.
e. Inspect top of metal covers on test units for solder projections and foreign material. See Process Engineer for removal.
f. Weigh each module and record weight to nearest 0.1 gram. Record by serial number.
g. Match modules by weight. Modules which match within 1 gram are acceptable for centrifuge testing as a set.
h. Modules which cannot be matched within 1 gram should be matched to another module by weighing small metal pieces to equal the delta weight. Record set S/N's and identify metal mass. Make enough combinations that all test modules can be centrifuged (2 modules per test).
i. Set up centrifuge test per QCTP 85.99.90.27.
j. Cover two opposing flats of insert with thin double sided tape butleave the paper covering on the outside tape surface. Tape will serve as bearing surface for test module.
k. Center one test module from matched set against one of taped flats such that cover is against tape (Y1 direction) and length of module is horizontal. Tape test module to flat to prevent it from falling toward center of rotor bowl. Repeat this step for second test module in matched set for opposite flat.
NOTE: Modules must be centered on flat so that substrate overhang beyond cover or electrical contacts do not touch adjacent flats. Tape weighed metal to proper flat as required.
l. Perform centrifuge test per QCTP 85.99.90.27.
m. Repeat steps 6.K.2.k and 6.K.2.l for each remaining set of test modules. Remove any metal mass from prior test as required. Add new metal mass as required.
n. Replace plastic covers per MPI 1000.1.104B (cleaning) and MPI 1000.1.402. Maintain identity by serial number.
p. Attach replacement labels (see 6.K.2.b). Add BeO warning label as necessary.
q. Complete Qualification Product Traveller.

6. TEST PROCEDURE (Cont'd)

L. SALT ATMOSPHERE

1. Equipment

a. Salt Test Chamber - Standards Engineering Lab.

2. Procedure

a. Perform per Mil Spec requirements using electrically non-operating modules from same production run.
b. Complete Qualification Product Traveller.

M. LIFE TEST

1. Equipment

a. SSR Burn-In test rack - HIC

2. Procedure

a. Perform 1000 hour life test on 10 modules minimum using burn-in conditions specified in 77A100244 Table II, Step 7.

b. Following Life Test each test unit shall pass tests in 77A100244 Table III except tests 4, 5, 6, 7, 8, 9 and 20 not required.

GENERAL ELECTRIC

QUALITY CONTROL TEST PROCEDURE

VOL.	CONTR. REF		SEQ
85	47	10 1	0
CONT ON 11		SHEET NO 10	
REV. (-)			

QUALIFICATION PRODUCT TRAVELLER

CIRCUIT________________DRAWING________________

SYSTEM____________

OP. #	SUB GROUP	TASK	IN	OUT	DATE	SIGN	COMMENTS
10	1	Physical Dimensions					
20	1	Thermal Shock					Record test data on attached date sheet.
30	1	Inspection (optional)					Mechanical damage.
40	1	Temperature Cycling					
50	1	Inspection (optional)					Mechanical damage.
60	1	Moisture Resistance					
70	1	Inspection (optional)					Mechanical damage.
80	1	Seal Test (Fine Leak)					Record leak rate. Max = 1.8×10^{-7} atm - cc/sec.
		Module #1 S/N					
		Module #2 S/N					
		Module #3 S/N					
		Module #4 S/N					
		Module #5 S/N					

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GENERAL ELECTRIC

QUALITY CONTROL TEST PROCEDURE

VOL.	CONTR. REF		SEQ.	
85	47	10	1	0
CONT. ON 12		SHEET NO 11		
REV. (-)				

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QUALIFICATION PRODUCT TRAVELLER

CIRCUIT________________DRAWING__________________

SYSTEM____________

OP. #	SUB GROUP	TASK	IN	OUT	DATE	SIGN	COMMENTS
90	1	Seal Test (Gross Leak)					
100	1	Inspection					
		Module #1					
		Module #2					
		Module #3					
		Module #4					
		Module #5					
110	1	Electrical Test					Attach test data.
		Module #1					
		Module #2					
		Module #3					
		Module #4					
		Module #5					
120	2	Mechanical Shock					
		Module #6 S/N					
		Module #7 S/N					
		Module #8 S/N					
		Module #9 S/N					
		Module #10 S/N					
130	2	Inspection (optional)					Mechanical damage.

GENERAL ELECTRIC

QUALITY CONTROL TEST PROCEDURE

VOL.	CONTR. REF		SEQ.
85	47	10 1	0
CONT ON	13	SHEET NO	12
REV.	(-)		

QUALIFICATION PRODUCT TRAVELLER

CIRCUIT__________ DRAWING__________

SYSTEM__________

OP. #	SUB GROUP	TASK	IN	OUT	DATE	SIGN	COMMENTS
140	2	Vibration, variable freq.					
		Module #6					
		Module #7					
		Module #8					
		Module #9					
		Module #10					
150	2	Inspection (optional)					Mechanical damage.
160	2	Constant Acceleration					
		Module #6					
		Module #7					
		Module #8					
		Module #9					
		Module #10					
170	2	Inspection (optional)					Mechanical damage.
180	2	Seal test (Fine Leak)					Record leak rate. Max = 1.8×10^{-7} atm - cc/sec.
		Module #6					
		Module #7					
		Module #8					
		Module #9					
		Module #10					

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GENERAL ELECTRIC

QUALITY CONTROL TEST PROCEDURE

VOL.	CONTR. REF		SEQ.	
85	47	10	1	0

CONT ON 14 SHEET NO 13

REV. (-)

QUALIFICATION PRODUCT TRAVELLER

CIRCUIT__________ DRAWING__________

SYSTEM__________

OP. #	SUB GROUP	TASK	IN	OUT	DATE	SIGN	COMMENTS
190	2	Seal Test (Gross Leak)					
200	2	Inspection					
		Module #6					
		Module #7					
		Module #8					
		Module #9					
		Module #10					
210	2	Electrical Test					Attach data sheets.
		Module #6					
		Module #7					
		Module #8					
		Module #9					
		Module #10					
220	3	Salt Atmosphere					
		Module #11					
		Module #12					
		Module #13					
		Module #14					
		Module #15					

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THERMAL SHOCK TEST DATA SHEET

CYCLE #	FUNCTION	SN TIME	SN TEMP	SN TIME	SN TEMP	SN TIME	SN TEMP	SN TIME	SN TEMP	SN TIME	SN TEMP
1	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
2	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
3	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
4	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
5	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
6	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
7	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
8	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										

VOL	CONTR REF			SEQ
85	47	10	1	0
CONT ON -	SHEET NO 15			
REV. (-)				

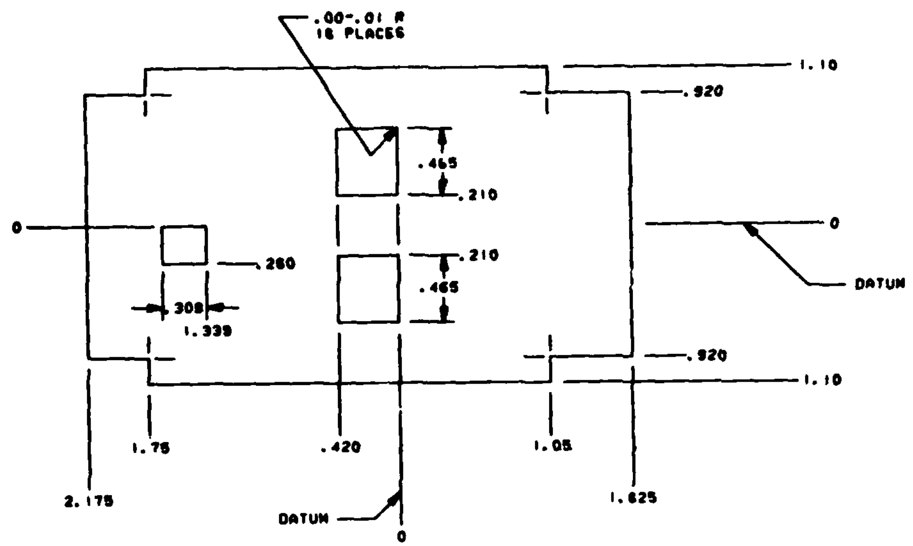
THERMAL SHOCK TEST DATA SHEET

CYCLE #	FUNCTION	SN TIME	TEMP	SN TIME	TEMP	SN TIME	TEMP	SN TIME	TEMP	SN TIME	TEMP
9	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
10	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
11	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
12	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
13	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
14	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										
15	Start										
	-56 ± 3°C										
	Δ Time/Temp										
	Stability (Power)										
	Δ Time/Temp										

APPENDIX E

GROUND PLANE BLANK #7248571

NOTES
1. MATERIAL: COPPER FOIL 7049789P2 (.003 THK REF).
2. REMOVE ALL SHARP EDGES .001R MAX OR .001 X 45° CHAMFER.
3. IDENTIFY PER MIL-STD-130. DO NOT MARK PART.



GENERAL ELECTRIC
SYRACUSE, N.Y.

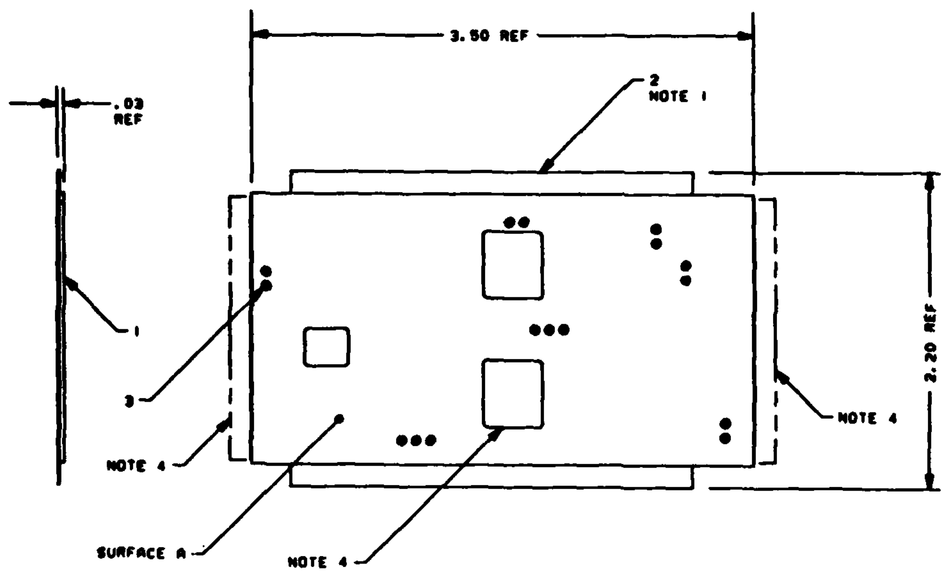
FOIL, GROUND

SIZE	FSCM NO	DWG NO	REV
C	03538	7248571	

APPENDIX F

GROUND PLANE AND FEEDTHROUGH SUB-ASSEMBLY
#77C720004

NOTES:
1. DIRECT BOND FIND NO. 2 TO FIND NO. 1.
2. DIRECT BOND FIND NO. 3 TO FIND NO. 1.
3. MACHINE FIND NO. 3 FLUSH TO ±.005 OF SURFACE A OF FIND NO. 1.
4. TRIM FIND NO. 2 FLUSH TO ±.005 TO EDGE OF HOLES IN FIND NO. 1 (3 PLACES) AND SIDES OF FIND NO. 1 (2 PLACES).
5. RESISTANCE OF FIND NO. 3 TO GROUND PLANE SHALL BE LESS THAN .1 OHM (16 PLACES).
6. IDENTIFY PER MIL-STD-130. DO NOT MARK PART.



G1

SEE SEPARATE PARTS LIST

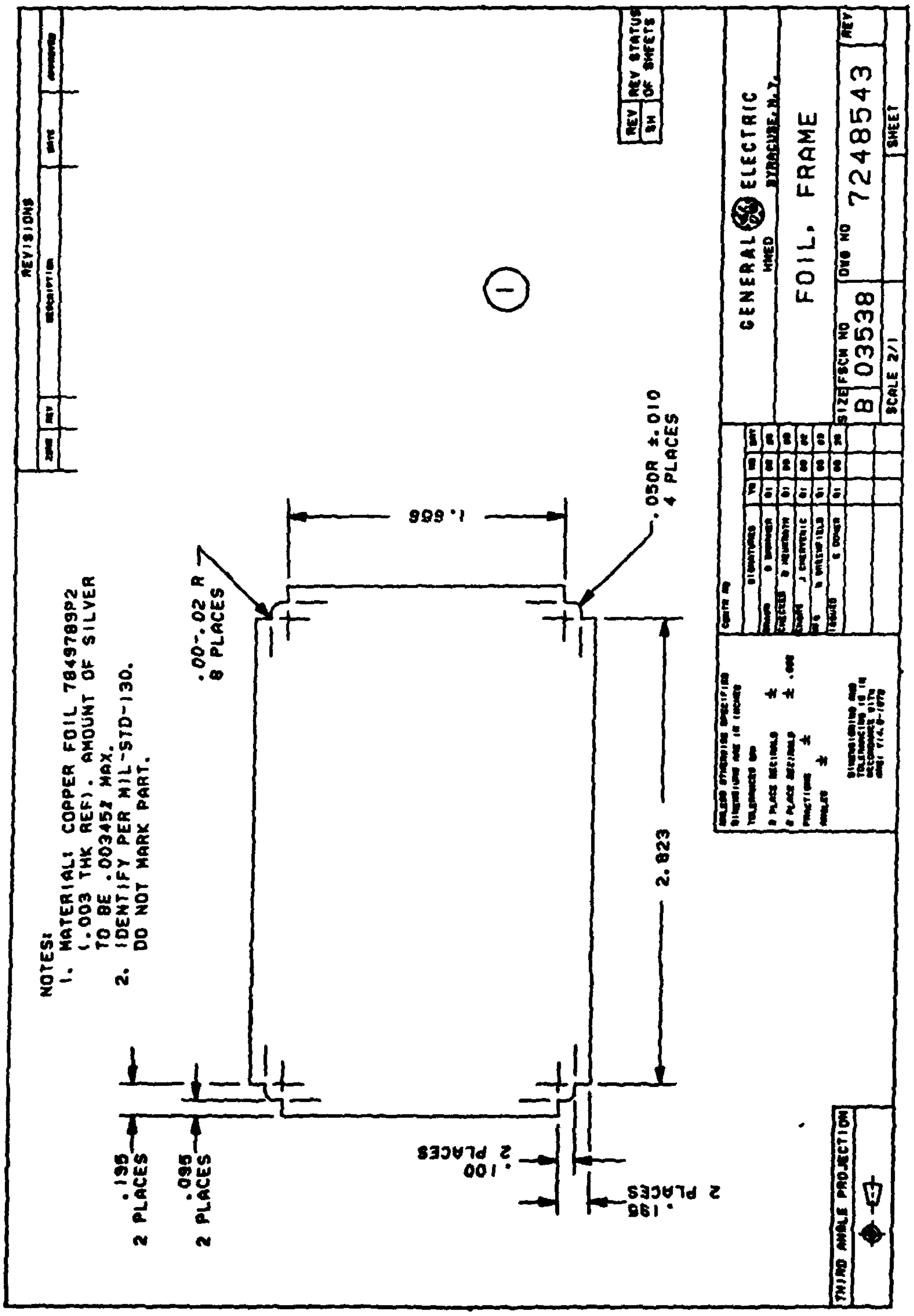
GENERAL ELECTRIC

AMPLIFIER SUBASSEMBLY

SIZE	FSCM NO	DWG NO
C	03538	77C720004

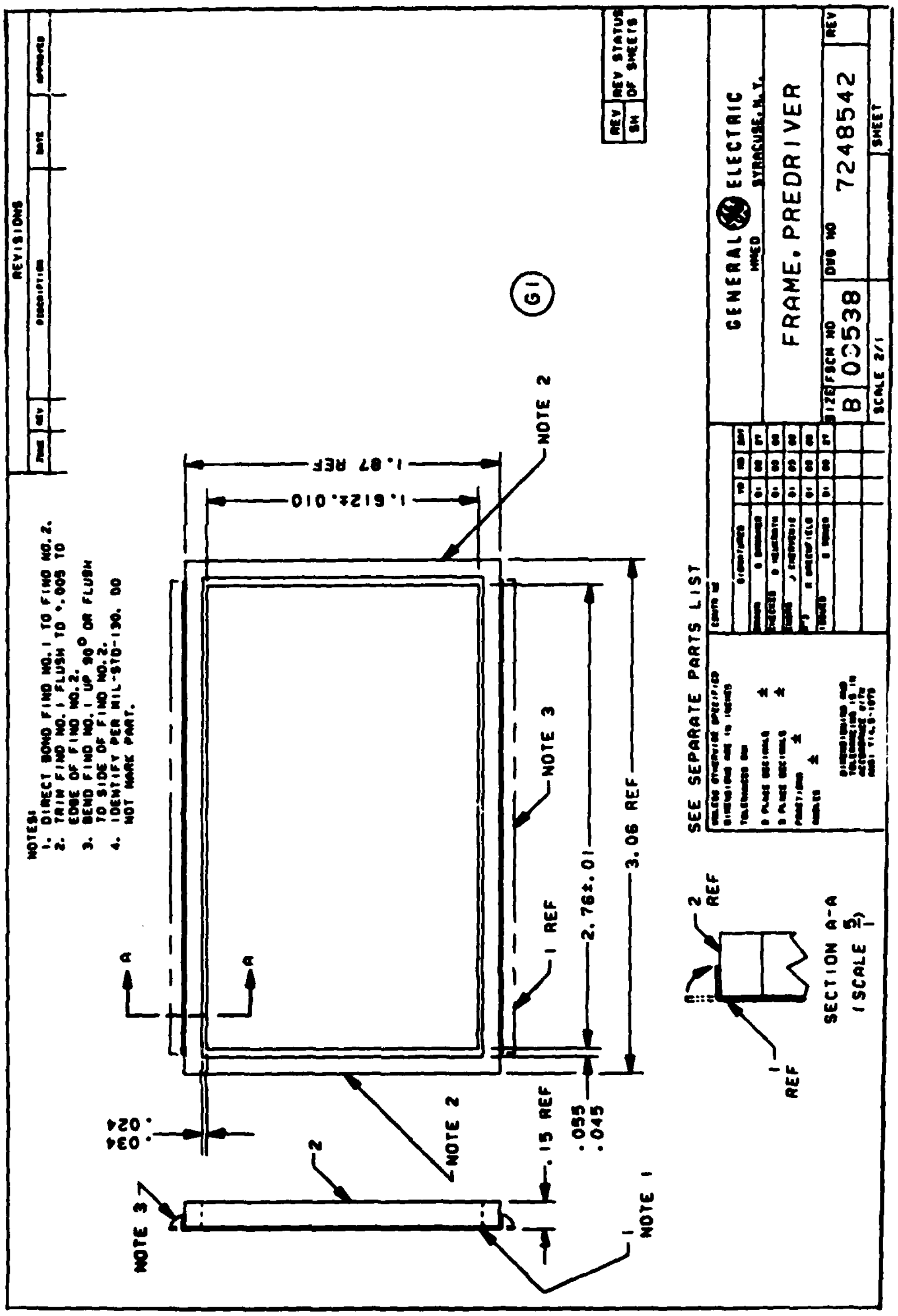
APPENDIX G

CERAMIC WALL FRAME BLANK
#7248543


NOTES:
1. MATERIAL: COPPER FOIL 7849789P2 (.003 THK REF). AMOUNT OF SILVER TO BE .00345% MAX.
2. IDENTIFY PER MIL-STD-130. DO NOT MARK PART.
REVISIONS
.195 2 PLACES
.095 2 PLACES
.00-.02 R 8 PLACES
1.656
.100 2 PLACES
.195 2 PLACES
2.823
.050R ±.010 4 PLACES
REV STATUS OF SHEETS
THIRD ANGLE PROJECTION
GENERAL ELECTRIC
FOIL, FRAME
SIZE B
FSCM NO 03538
DWG NO 7248543
SCALE 2/1
SHEET

APPENDIX H

WALL FRAME DB Cu SUB-ASSEMBLY
#7248542


REVISIONS
NOTES:
1. DIRECT BOND FIND NO.1 TO FIND NO.2.
2. TRIM FIND NO.1 FLUSH TO +.005 TO EDGE OF FIND NO.2.
3. BEND FIND NO.1 UP 90° OR FLUSH TO SIDE OF FIND NO.2.
4. IDENTIFY PER MIL-STD-130. DO NOT MARK PART.
1.87 REF
1.612±.010
NOTE 2
NOTE 3
1 REF
2.76±.01
3.06 REF
.15 REF
.055
.045
.034
.024
NOTE 1
SECTION A-A
(SCALE 5/1)
2 REF
SEE SEPARATE PARTS LIST
G1
REV STATUS OF SHEETS
GENERAL ELECTRIC
SYRACUSE, N.Y.
FRAME, PREDRIVER
SIZE B
FSCM NO 03538
DWG NO 7248542
SCALE 2/1
SHEET
REV

APPENDIX I

COPPER SPHERE FEEDTHROUGH
#7244612

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED
A	CORRECT 2.1 AND DIM .063 WAS .065 ECN A511362		

1. NOTES

1.1 SUGGESTED SOURCE(S) OF SUPPLY
LUCAS MILHA PT INC
CUDAHY, WI
MANUFACTURER'S FSCM NO.
MANUFACTURER'S ITEM IDENT .065 SPHERE

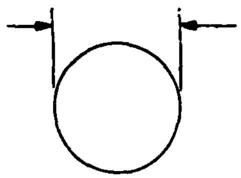
1.1.1 IDENTIFICATION OF THE "SUGGESTED SOURCE(S) OF SUPPLY" HEREON IS NOT TO BE CONSTRUED AS A GUARANTEE OF PRESENT OR CONTINUED AVAILABILITY AS A SOURCE OF SUPPLY FOR THE ITEM(S).

1.2 FOR GE ESD-SY ONLY

1.2.1 PURCHASE ONLY FROM AN APPROVED VENDOR

2. REQUIREMENTS

2.1 MATERIAL: ELECTROLYTICALLY TOUGH PITCH COPPER, QQ-C-576, MIL-C-121-66 (ORD) 99.9 PERCENT COPPER. MAXIMUM AMOUNT OF SILVER ALLOWABLE IS .034 PERCENT.



REV	REV STATUS
SH	OF SHEETS

SPECIFICATION CONTROL DRAWING

CNTR NO	QM-79		
SIGNATURES	YR	MO	DAY
DRAWN	80	12	16
CHECKED		12	
ENGR			
MFG			
ISSUED		12	22

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON: 2 PL DECIMALS ± 3 PL DECIMALS ± FRACTIONS ± ANGLES ± DIMENSIONING AND TOLERANCING IN ACCORDANCE WITH ANSI Y14.5 1973

GENERAL ELECTRIC
HMED SYRACUSE, N.Y.

FEEDTHRU, METALLIC

SIZE	FSCM NO	DWG NO	REV
B	03538	7244612	A
SCALE 20/1		SHEET	

THIRD ANGLE PROJECTION

APPENDIX J

ULTRASONIC FLAW DETECTION EXPERIMENTS

(12 Pages)

ULTRASONIC FLAW DETECTION EXPERIMENTS

Prepared by

S. Tehon
Electronics Laboratory
General Electric Company
Syracuse, New York

Prepared for

R. Mann
Hybrid Integrated Circuits
Military Electronic Systems Operations
Syracuse, New York

Introduction and Summary

This describes a brief set of experiments to investigate the feasibility of locating flaws in hybrid integrated circuit assemblies, particularly regions with voids such as due to poor bonding in regions between component layers of the assemblies. The unit tested, sketched in Figure 1, consists of a thin substrate, on which are formed circuit elements appearing as pad regions with approximately .013" thick solder surfaces, and supporting a ceramic rail .163" high. The joint between the substrate and the rail is of special importance.

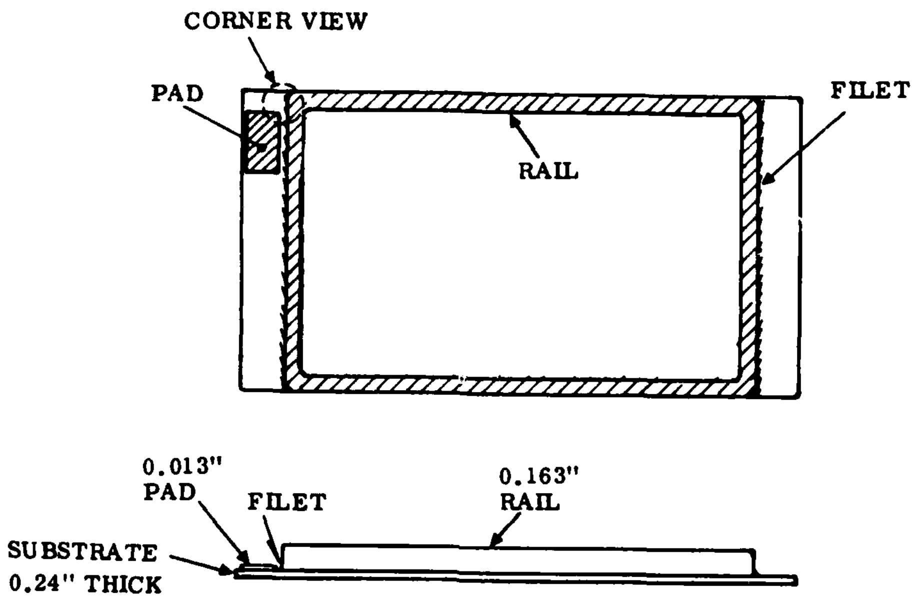


Figure 1. Circuit Assembly Dimensions

The experiments were carried out with a commercial focused ultrasonic transducer tuned to operate at a center frequency of 5 MHz. It was driven by a Panametrics impulse generator, and returning ultrasonic echoes were handled by the matching Panametrics pulse echo receiver. The receiver contains protective diodes at its input, and has a short recovery time, so it is capable of generating a display signal with short minimum range. The elements examined, and the transducer, were mounted in a water bath, at a spacing such that the focal point of the ultrasonic beam fell approximately within the sample being examined. Figure 2 illustrates the equipment.

It is desirable to examine samples both with pulse echo reflections and with transmitted signal intensity. An ultrasonic travelling wave has stress and particle velocity forming the wave front. In a continuous medium, the ration of stress to velocity is the acoustic impedance of the medium, which varies considerably from material to material. At one extreme, the impedance of vacuum is zero--stress waves require a material for propagation--and the value of impedance increases in going from vacuum, to air, to liquids, to

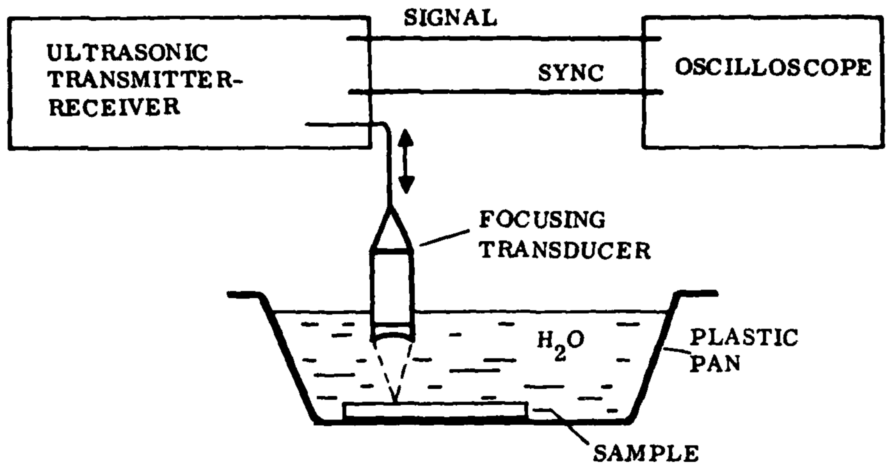


Figure 2. Test Equipment Schematic

plastics, and finally to elastic solids. Upon encountering a sudden change in medium, the wave partly reflects and partly is transmitted, with a reflection coefficient that is greatest for the greatest ratio of impedance discontinuity. Table I lists a few representative impedances for common media.

In the pulse echo tests, the object used for a target was placed in the water bath, and the water was used as an ultrasonic coupling medium between transducer and target. Since the transducer has a well-focused radiation pattern, returning echoes due to acoustic discontinuities arise almost entirely at the focal point. The data taken indicate the resolution of that effective focal point, in area and in range. Surfaces and wire cross sections in different impedance values and sizes illustrate resolution better than .005" in range, with variations in reflection coefficient clear from the corresponding strengths of reflections.

No transmission tests were run, because of the difficulty of placing a receiving transducer on the opposite side of the target from the transmitter, without adequate waterproofing procedures for the transducer cables. No detailed mapping was carried out, since no mechanical carriage was available in form suitable for moving the target or transducers accurately. However, the general techniques are those of the acoustic microscope, limited in resolution by the size of one acoustic wavelength. Velocity in water of ultrasound is 1500 meters per second, so the wavelength of 5 MHz sound in these experiments was 0.3 millimeters (.012") in water, about 3 times greater than the smallest wire diameter resolved in test. In solids, velocity of propagation for ultrasound is about 3 times higher than in water, so the limit of range resolution will be about 3 times poorer than in water

Although these tests were run with 5 MHz sound, that is not the highest frequency that can be used. Given suitable transducers, propagation can be supported in water and most solids,to frequencies an order of magnitude higher. Allowing for the higher velocity in solids, it still appears feasible to detect voids as small as .001".

TABLE I. CHARACTERISTIC IMPEDANCES

$$\text{METRIC UNIT} = \frac{\text{Newtons}/m^2}{m/s}$$

Medium	Z_o - in 10^6 units
Steam	.000242
Air - 20°C	.000415
Soft rubber	1.00
Water	1.48
Polyethylene	1.75
Lucite	3.2
Glass-Pyrex	12.9
Aluminum	17.0
Lead	23.2
Silver	39.0
Copper	44.5
Steel	47.0
Nickel	51.5
Gold	62.5
Platinum	69.7
Tungsten	103

$$\text{Stress Reflection Coefficient} = \frac{Z - Z_o}{Z + Z_o}$$

$$\text{Stress Transmission Coefficient} = \frac{2Z}{Z + Z_o}$$

Discussion of the Data

Figure 3 illustrates the pulse shape generated by the transducer when excited by an electrical impulse. This is basically a pulsed packet of 6 half-cycle oscillations of 5 MHz rate. The first echo, appearing here at 5 centimeters along the horizontal sweep, is the reflection generated when the transmitted pulse reaches the bottom of the water, at the interface with the plastic dishpan used as a water tank. Since the acoustic impedance of plastic is not greatly different from that of water, this reflection is not as large as that appearing at 6.4 centimeters, which is generated by the pulse that was transmitted into the plastic and almost totally reflects at the air interface at the bottom surface of the plastic. One more reverberation appears at the 8 centimeter mark.

Figure 4 shows a chain of echoes reverberating within a copper plate. The first reflection, at 2.6 centimeters, is strong, due to the large difference in acoustic impedance of water and copper. The remaining uniformly decaying chain of pulses represent the energy remaining within the copper except for small transmission at each arrival at the water-copper interface.

Figures 5 and 6 illustrate similar patterns for aluminum and silicon plates, for which the reverberations tend to overlap and lose identity.

In the remaining data, the copper plate was kept in the bottom of the pan, acting as a flat surface for holding other specimens. Figures 7 and 8 show, in expanded detail, the pulse echo waveforms, without and with the use of internal damping in the receiving circuits. The damping was retained for further tests, since the pulse is shorter as a result .

Figures 9 and 10 illustrate the reflections from a 7.5-mil brass shim plate, and a small projection on its surface. The echo is advanced about 0.6 microseconds by reflecting from the surface of the projection, .0135" nearer the transducer.

Figures 11 and 12 show echoes from wires, laid on the base copper plate lightly, showing both the wires and the plate positions. The .005" diameter wire is clearly displayed.

Figure 13 shows greatly expanded echoes from the thin substrate of the circuit board, and the underlying copper plate. This board, shown in Figure 1, consists of solder pads approximately .013" thick, lying on the .029" thick substrate, and contains also a ceramic rail, .163" high, bonded to the substrate. Echoes from the substrate and the bottom plate are approximately 0.96 microseconds apart.

Figure 14, at a slower sweep rate, shows the strong echo generated by the top of the ceramic rail, and the smaller echoes from top and bottom of the substrate. Since the ultrasonic focal point was almost exactly on the top of the rail, very little energy passed through the water around the rail, so there is no large distinct echo from the substrate.

Figure 15, the most complex pattern generated, was obtained by moving the board so that the focused region fell in part on the rail, on the solder pad, on the substrate, and on the copper bottom plate. These are readily identified by comparison with Figure 1.

Recommendations

Further work with samples such as this is suggested, using more elaborate mounting procedures for two transducers, and including a tracking device which is electrically driven with a signal that can simultaneously position an electron beam in an image display tube. The use of higher frequencies and also incorporation of a time gate, for limiting the imaging to a selected range window, is also suggested, along with an automatic alarm circuit that can mark the positions for which pulse echoes are returned within the selected range windows.

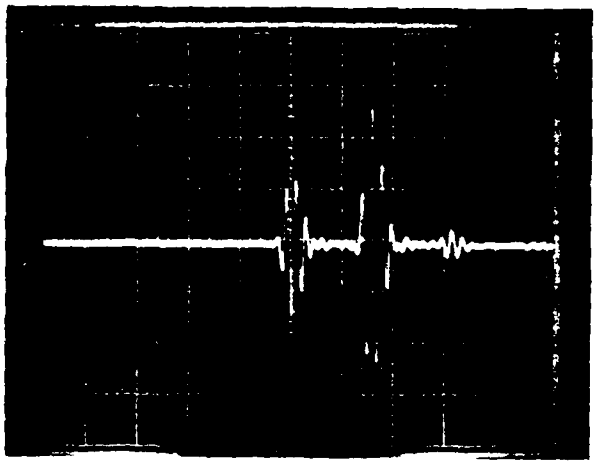


Figure 3. Echoes from Bottom of Plastic Pan. Sweep Rate is 1 $\mu s/cm$, Delayed to Display Details.

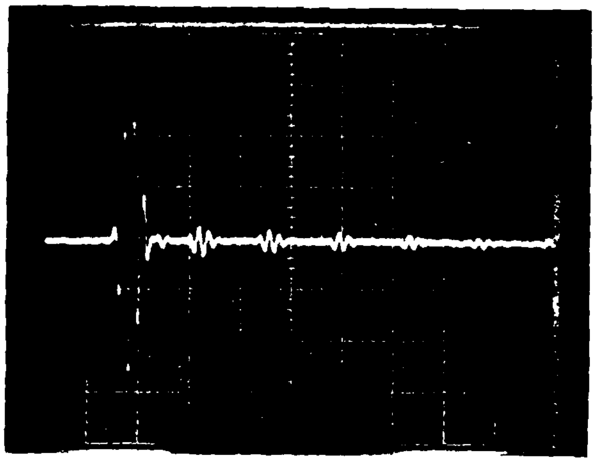


Figure 4. Echoes From .128" Thick Copper Plate, Laid on the Bottom of the Plastic Pan. Sweep Rate 1 $\mu s/cm$.

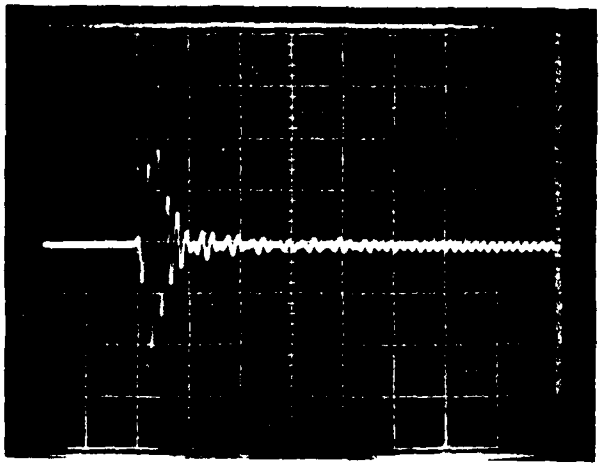


Figure 5. Echo From Aluminum Plate .0625" Thick. Sweep 1 μs/cm.

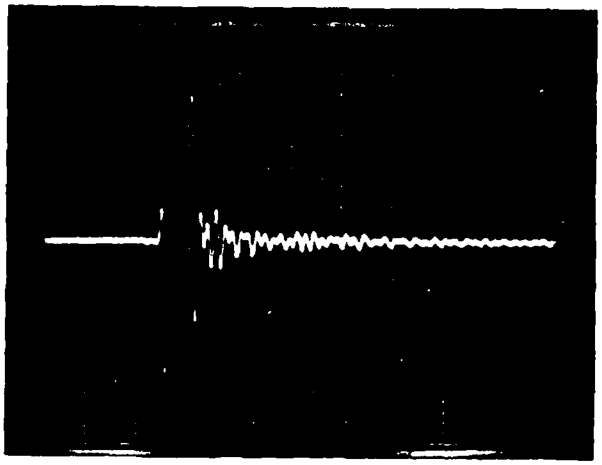


Figure 6. Echo From Silicon Crystal Wafer .0596" Thick. Sweep 1 μs/cm.

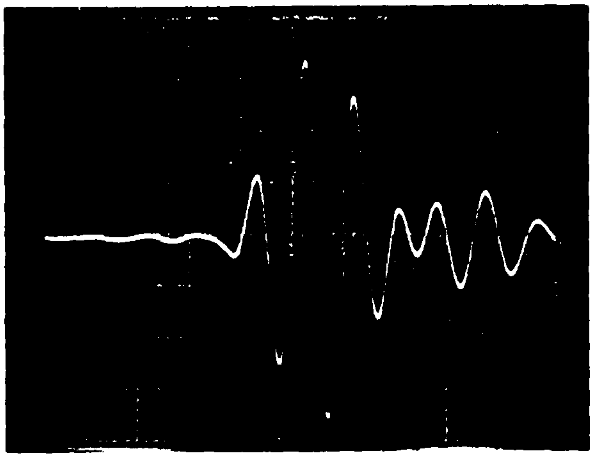


Figure 7. Expanded View of Echo From Cu Plate, at 0.2 $\mu s/cm$.

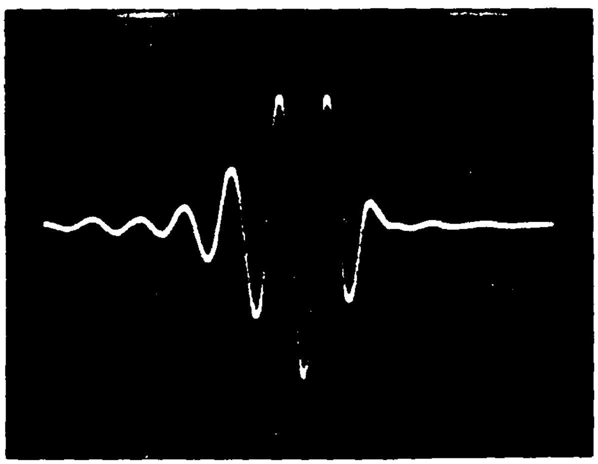


Figure 8. Same as Data in Figure 7, Except That the Parametrics Receiver damping has Been Introduced at Level "6". Gain is Increased by 10 dB to Offset the Damping Loss.

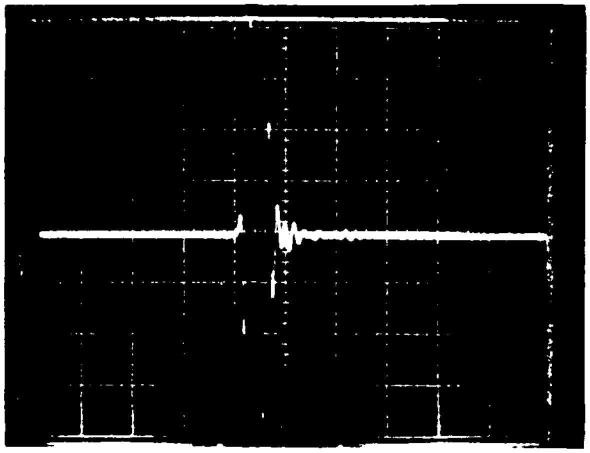


Figure 9. **Brass** Shim .0075" Thick. 1 μs cm.

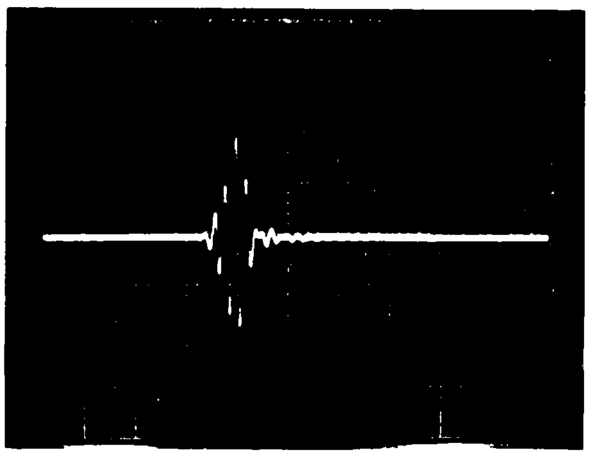


Figure 10. **Echo** From .0135" Dimpled Projection on Brass Shim. 1 **μs**/cm.
Delay has not been Altered from Test of Figure 9.

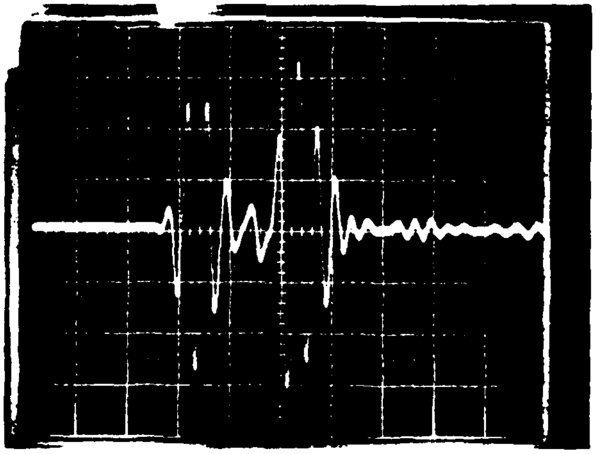


Figure 11. Echoes From .025" Dia. Wire (2.8 cm) and Supporting Cu Plate (4.8 cm). Sweep 1 $\mu s/cm$.

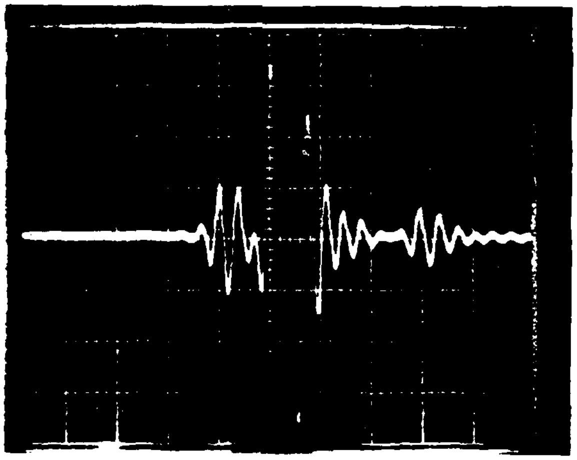


Figure 12. Echoes From .005" Dia. Wire (3.6 cm) and Supporting Cu Plate (4.8 cm). Sweep 1 $\mu s/cm$.

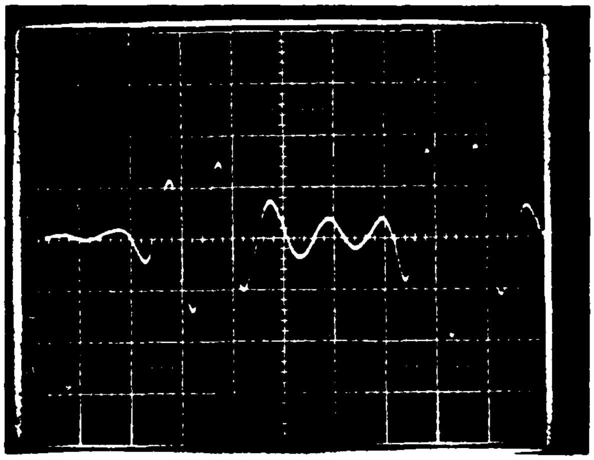


Figure 13. Echoes From Circuit Board Sample (Figure 1), Showing Thin Substrate (2.5 cm) Lying on Cu Plate (7.5 cm). Sweep Rate 0.2 $\mu s/cm$.

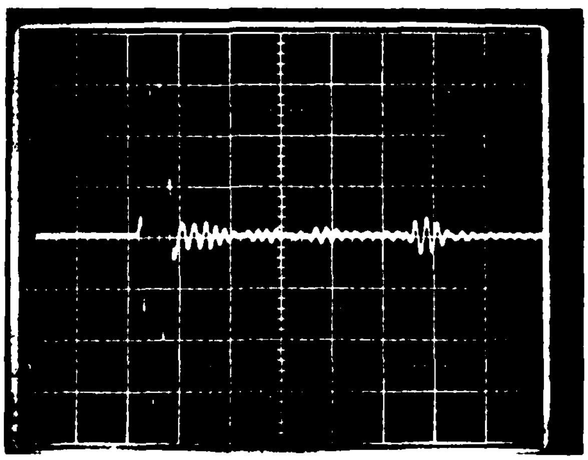


Figure 14. Echoes From Ceramic Rail of Circuit Board, (2.2 cm), Lying on Cu Plate (7.6 cm). Sweep Rate 1 $\mu s/cm$.

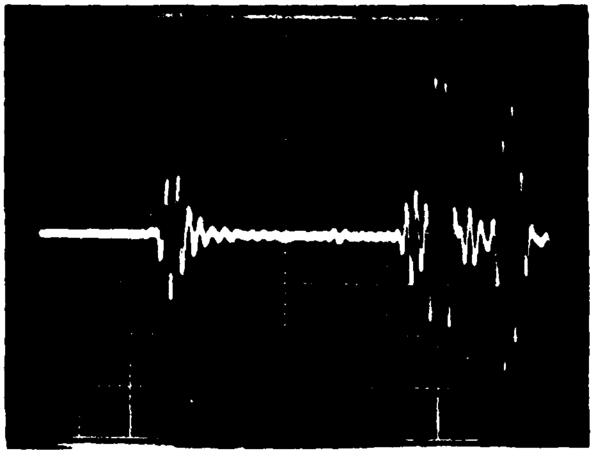


Figure 15. "Corner View" Echoes From Circuit Assembly Board, Show:
a) Rail (2.6 cm)
b) Solder pad (7.2 cm)
c) Wiring board (8 cm)
d) Tank bottom (9.4 cm)

APPENDIX K

DESCRIPTION OF "ANSYS" FINITE ELEMENT STRESS
ANALYSIS PROGRAM
(2 Pages)

ANSYS PROGRAM DESCRIPTION

The ANSYS computer program is a large scale general purpose computer program for the solution of several classes of engineering analysis problems. Analysis capabilities include static and dynamic; plastic, creep and swelling; small and large deflections; steady state and transient heat transfer and steady state fluid flow.

The matrix displacement method of analysis based upon finite element idealization is employed throughout the program. The library of finite elements available numbers more than forty for static and dynamic analyses, and ten for heat transfer analyses. This variety of elements gives the ANSYS program the capability of analyzing frame structures (two dimensional frames, grids and three dimensional frames), piping systems, two dimensional plane and axisymmetric solids, flat plates, three dimensional solids, axisymmetric and three dimensional shells and non-linear problems including interfaces and cables.

Loading on the structure may be forces, displacements, pressures, temperatures or response spectra. Loadings may be arbitrary time functions for linear and non-linear dynamic analyses. Loadings for heat transfer analyses include internal heat generation, convection and radiation boundaries, and specified temperatures or heat flows.

The ANSYS program uses the wave front (or "frontal") direct solution method for the system of simultaneous linear equations developed by the matrix displacement method, and gives results of high accuracy in a minimum of computer time. The program has the capability of solving large structures. There is no limit on the number of elements used in a problem. The number of nodes can be in excess of 2500 for three dimensional problems, and 5000 for two dimensional problems. There is no "band width" limitation in the problem definition; however, there is a wave front" restriction. The "wave front" restriction depends on the amount of core storage available for a given problem. Up to 576 degrees of freedom on the wave front can be handled in a large core. The wave front limitation tends to be restrictive only for analysis of arbitrary three dimensional solids or in the use of ANSYS on a small computer.

ANSYS has the capability of generating substructures (or super-elements). These substructures may be stored in a library file for use in other analyses. Substructuring portions of a model can result in considerable computer time savings for non-linear analyses.

Geometry plotting is available for all elements in the ANSYS library, including isometric, perspective and section views of three dimensional structures. Plotting subroutines are also available for the plotting of stresses and displacements from two and three dimensional solid or shell analyses, mode shapes from dynamic analyses, distorted geometries from static analyses, transient forces and displacements vs. time curves from transient dynamic analyses, and stress-strain plots from plastic and creep analyses.

Post processing routines are available for algebraic modification, differentiation, and integration of calculated results. Root mean square operations may be performed on seismic model results. Response spectra may be generated from dynamic analysis results. Results from various loading modes may be combined from harmonically loaded axisymmetric structures.

The input data for the ANSYS program has been designed to make it as easy as possible to define the problem to the computer. Options for multiple coordinate systems in cartesian, cylindrical, or spherical coordinates are available, as well as multiple region generation capabilities to minimize the inputs data for repeating regions.

Sophisticated geometry generation capabilities are included for two dimensional plane and axisymmetric structures and for intersecting three dimensional shell structures.

The ANSYS program capabilities are continually being enhanced by the addition of new or improved elements, new analysis capabilities and new input, output and graphic techniques. The ANSYS USER'S MANUAL is modified periodically to reflect the latest additions.

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APPENDIX L

QUALIFICATION TEST REPORT

RADIO FREQUENCY POWER MODULE
(15 Pages)

AD-A105 892 GENERAL ELECTRIC CO SYRACUSE NY MILITARY ELECTRONIC --ETC F/G 17/9
MANUFACTURING TECHNOLOGY STUDY ON RADIO FREQUENCY POWER MODULES--ETC(U)
1981 N00039-79-C-0378

UNCLASSIFIED NL

AD A
105892

END
DATE
FILMED
11-81
DTIC

QUALIFICATION TEST REPORT

R.F. POWER MODULE

SPECIFICATION G.E. 77A100244

MANUFACTURING METHODS & TECHNOLOGY PROGRAM

CONTRACT NOOO39-79-C-0378

FOR

NAVELEX, CODE ELEX 2702

REPORT DATE: August 26, 1981

PREPARED BY

HYBRID INTEGRATED CIRCUIT FACILITY

MILITARY ELECTRONICS SYSTEMS OPERATION

GENERAL ELECTRIC CO.

SYRACUSE, NEW YORK

QUALIFICATION TEST REPORT

1. PURPOSE

To report results of tests/inspections performed to meet qualification inspection requirements established in General Electric R.F. Power Amplifier Specification 77A100244 (REF. APPEND. "B") para. 4.4.

2. SCOPE

Tests were performed on "proof of process" R.F. power modules per Manufacturing Methods and Technology Program, Contract N00039-79-C-0378 for NAVELEX, Code ELEX 2702.

3. TEST PROCEDURE

Modules were tested to Quality Control Test Procedure 85.47.10.10. (REF. APPEND. "D"), Qualification Procedure, R.F. Power Amplifier 77D609955. This procedure was specifically developed to meet requirements in R.F. Amplifier Specification Appendix "B".

4. TESTS/INSPECTIONS

Tests/inspections were performed as shown in following list:

SUB GROUP	TEST	TEST QTY.
1	Physical Dimensions	5
	Thermal Shock	↓
	Temperature Cycling	

SUB GROUP	TEST	TEST QTY
1 (CONT)	Moisture Resistance Seal Test (Hermeticity) Visual Inspection Electrical Tests	5 ↓
2	Mechanical Shock Vibration, Variable Frequency Acceleration Seal Test Visual Inspection Electrical Tests	5 ↓
3	Salt Atmosphere	5
—	Life Test	10

5. GOVERNMENT WITNESS

Local DCMASMA quality inspection personnel were notified prior to initiation of each test. A mutually agreeable schedule was established to allow DCAS witness of each planned test/inspection.

6. MODULE ASSIGNMENT

A matrix depicting module serial number assignments for each test group is provided in the following listing. Module operational status is also included.

TEST STATUS

SER. NO.	SUBGROUP 1 (THERM.)	SUBGROUP 2 (MECH.)	SUBGROUP 3 (SALT)	LIFE	TEST RESULTS PASSED	FAILED ELEC.	FAILED MECH.
127	X				X		
163				X		X[1/]	
197	X				X		
202				X		X[1/]	X[5/]
207	X				X		
209		X	X				X[4/]
211		X	X				X[4/]
212		X		X		X[1/]	X[5/]
217		X			X		X[5/]
227	X				X		
228		X	X				X[4/]
235				X		X[1/]	
250				X	X		
251				X		X[1/]	
255				X		X[2/]	
256	X				X		
257		X		X		X[3/]	X[5/]
264		X	X				X[4/]
271		X		X	X		X[5/]
272		X		X	X		X[5/]
274			X		TEST NOT REQUIRED		X[5/]
311[6/]							

1/ Failed Life Test Final Electrical - Pulse Breakup @ -40°C

2/ Failed during Life Test - Cracked ceramic capacitors

3/ Failed functional test prior to Subgroup 2 Final Electrical - Cracked substrate

4/ Failed module fixture demounting - Subgroup 2 - Cracked seal glass

5/ Cracked seal glass - plastic cover removal performed incorrectly

6/ Spare unit - Not required for test

TEST RESULTS

A. SUBGROUP 1 - Module Serial Numbers 127, 197, 207, 227, 256

A.1 Physical Dimensions

Method: MIL-STD-883, Method 2016

Results: All modules passed.

A.2 Thermal Shock

Method: Cold soak non-operating module until thermally stable at -56°C or lower. Operate module until thermal stability achieved. Externally heat module to -20°C or higher. Repeat soak/operate/heat cycle for a total of 15 cycles.

Result: All modules passed. Tests performed on computer controlled automatic module test station. Heating/cooling controlled by thermo-electric temperature controller. Hard copy computer test data on file. Typical test parameters as follows:

Parameter	Approximate Value
Delta time (≥ -20°C to -56°C)	12 minutes
Delta time (≤ -56°C to stable temp.-operating)	2 minutes
Stable temp. (operating)	-50°C
Delta time (-50°C to ≥ -20°C)	1 minute
Total test time per module	3½ hours

A.3 Temperature Cycling

Method: MIL-STD-883, Method 1010, -55°C and +85°C, 100 cycles

Results: All modules passed. Test interrupted after 33rd cycle due to mechanical malfunction of cold chamber of automatic temperature cycling machine. Test resumed at point of interruption following chamber repair.

A.4 Moisture Resistance

Method: MIL-STD-883, Method 1004, 10 days

Results: All modules passed. Test included subcycle test of Step 7 (3 hours @ -10°C for any 5 of the 10 test days). A separate cold chamber was used for the subcycle test.

A.5 Seal Test

A.5.1. Fine Leak

Method: MIL-STD-883, Method 1014, Condition A2

Results: All modules passed. Modules were pressurized with helium gas @ 30 PSIG for one hour. Measured leak rate limit was $\leq 1.8 \times 10^{-7}$ atmosphere cubic centimeters per second (Helium).

A.5.2. Gross Leak

Method: MIL-STD-883, Method 1014, Condition C

Results: All modules passed.

A.6 Visual Inspection

Method: MIL-STD-883, Method 2009

Results: Serial numbers 207, 227, and 256 passed. Serial number 127 had corrosion at one spot on edge of kovar cover. Serial number 197 had three points of corrosion. Condition was caused by tiny area at edge of kovar cover exposed to high humidity during moisture resistance test. Condition is cosmetic and does not affect hermetic seal of module.

A.7 Final Electrical Test

Method: Test performed on computer controlled automatic module test station using special test program developed to perform environmental subgroup final electrical tests specified in Table 1 - test 7 of 85.47.10.10 (Qualification Procedure).

Results: All modules passed tests.

B. SUBGROUP 2

B.1 Mechanical Shock - Module Serial Numbers - 1st Group 209, 211, 217, 228, 264

2nd Group 212, 217, 257, 271, 272

Method: MIL-STD-883, Method 2002, 30G peak

Results: 1st group of modules were mounted on metal fixtures using double sided tape between bottom of module heat sink and fixture surface. Modules mechanically passed shock test and were subjected to and mechanically passed next subgroup test (vibration). Modules were demounted from blocks preparatory to Constant Acceleration Test. Visual inspection after demounting revealed glass fractures in the wall seal glass at one or both ends of 4 of the 5 modules. Fractures occurred apparently as a result of the demounting operation, not the mechanical testing. The demount process consisted of cold soaking modules/fixtures at -55°C for two hours to embrittle tape adhesive then prying between module heatsink and special slots in fixture. NOTE: Plastic covers on top of modules are attached with double sided tape also and were removed at same time for constant acceleration test. It was concluded cause of failure was due to prying heatsink from fixture. This prying resulted in a concave bowing of the heatsink and ceramic substrate thereby applying a tensile stress to the wall seal glass. The removal of the plastic cover by prying between substrate and end of cover wasnot considered as the cause since this technique was developed during early module process development without similar damage.

Retest - A module holding fixture was designed and built to mount the module using clamp screws. The surviving module (S/N 217) and 4 modules from the completed Life Test group were resubmitted to Mechanical Shock Test. All modules passed.

B.2 Vibration, variable frequency

Method: MIL-STD-883, Method 2007, 20G

Results: 4 of 5 modules in 1st test group failed when modules demounted from holding fixture. See para. B.1, Mechanical Shock for details.

All modules in 2nd test group passed retest.

B.3 Constant Acceleration

Method: MIL-STD-883, Method 2001, 5KG, Y1 orientation

Results: No modules in 1st group submitted to test due to failures at demounting.

All modules in 2nd group passed test.

B.4 Seal Test

B.4.1 Fine Leak

Method: See para. A.5.1 (Method and Results)

Results: 4 rejects from 1st test group not submitted to test.

All modules in 2nd group passed test.

B.4.2 Gross Leak

Method: See para. A.5.2

Results: 4 rejects from 1st test group not submitted to test. All modules in 2nd test group failed test. Failures caused by cracked wall seal glass incurred during removal of plastic covers prior to seal tests.

It was found necessary to remove the plastic cover before performing either seal test for the following reasons: During fine leak testing the plastic cover absorbs helium gas during pressure bombing. During readout the helium desorbs from the plastic creating an artificially high reading which exceeds the maximum allowable leak rate. In gross leak, low boiling point electronic fluid trapped between the module and and plastic cover during pressure bombing creates a continuous stream of bubbles when immersed in high boiling point electronic fluid. This masks any true leak site.

Seventeen modules were submitted for plastic cover removal. Post removal inspection disclosed seven modules had cracked glass at one or both ends. Cause of failure was determined to be human initiated. The operator performing the task cold soaked modules at -55°C for 15 to 30 minutes instead of two hours as required by process instruction. Lack of adequate soak time allowed sufficient residual strength in the tape adhesive to transfer tensile stress to the wall glass when the cover was pryed from the substrate. Modules with marginally low glass strength broke.

As corrective action the operator was retrained to the provisions of the process instruction. The process instruction was revised to add fine and gross leak testing after cover removal to assure damaged or defective modules are removed from the lot.

B.5 Visual Inspection

Method: See para. A.6

Results: 4 damaged modules from 1st test group not inspected with this Subgroup. All modules in 2nd test group failed due to wall seal glass cracks on one or both ends of wall.

B.6 Electrical Tests

Method: See para. A.7

Results: All modules passed test except S/N 257. S/N 257 failed functional test after Seal Test prior to Final Electrical Test. Failure was manifested by drop in output power to approximately half level. Failure analysis revealed one group of cells in output transistor Q3 burned-out plus a crack in the substrate in the input drive region. It was postulated the crack caused a phase change in the input drive circuit. The resulting change in output power and load characteristics caused Q3 to burn-out. Q3 is considered to be an induced failure. S/N 257 suffered seal glass damage during improper plastic cover removal prior to Seal Test (see para. B.4.2 - Results). The substrate crack may have been induced during cover removal, seal test pressure bombing, or from thermal stress during immersion into +125°C electronic liquid for Gross Leak Testing.

C. SUBGROUP 3 - Module Serial Numbers 209, 211, 228, 264, 274

C.1 Salt Atmosphere

Method: Requirement MIL-STD-883, Method 1009, 24 hours. Method used: MIL-STD-202, Method 101 , 24 hours. Modules were tested in a salt chamber of MESO's Standards Engineering Laboratory. The chamber is used to evaluate a variety of electronic and electrical components and is adjusted to meet MIL-STD-202 requirements. Salt concentration is approximately seven times greater when chamber is set to test to -202 method.

Results: External solder coated copper conductor runs were dull gray due to reaction to salt environment. Discoloration is cosmetic only since solder coating is used to prevent oxidation of copper runs. Gold plated R.F. and D.C. contacts passed test with no evidence of corrosion.

D. <u>LIFE TEST</u> - Module Serial Numbers 163, 202, 212, 235, 250, 251, 255, 257, 271, 272

<u>Method</u>: Test in SSR Burn-In Test Rack under conditions specified in R.F. Power Module Specification 77A100244, Table II, Step 7 except test for 1000 hours minimum. After Life Test completed test modules per 77A100244, Table III, except tests 4, 5, 6, 7, 8, 9 and 20 not required.

<u>Results</u>: Three (3) modules passed all tests performed (S/N's 250, 271, and 272). Module S/N 255 failed just prior to termination of Life Test. Module S/N 257 failed electrical test at end of Subgroup 2 (Mechanical S.G.) and was not subjected to Life Test final electrical testing (see para. B.6 - Results).

NOTE: Output Pulse Rise Time (Test17), and Output Pulse Fall Time (Test 18) from Table III test requirements were not performed on any Life Test modules. The maximum allowed time for both tests is 0.15 microseconds. This limit exceeds the short pulse measurement capability of the automatic test equipment.

S/N 255 failed during the last week of Life Test after more than 800 test hours had accrued. Failure cause was determined to be cracked bias line filter capacitors. One (C6) failed catastrophically by short circuit to 28 VDC. Two ceramic chip capacitors (C6 and C7) were butt mounted end to end on a common substrate solder pad. Thermal expansion during operation created mutual mechanical stress on the capacitors causing eventual capacitor failure. This condition was also noted in production modules. Corrective action has been implemented on production modules using a small hairpin shaped loop on buss wire under the common terminal of each capacitor. This tilts each capacitor upward on the common substrate solder pad and separates the capacitors. A restricted amount of solder is used to form a solder fillet between each capacitor terminal, its portion of the buss wire and the solder pad. An angled air gap is formed between the common capacitor terminals to accommodate thermal excursions.

Modules 163, 202, 212, 235, and 251 failed Final Electrical Test due to pulse breakup at -40°C. The first four modules exhibited pulse breakup at VSWR of 1.3 to 1. S/N 251 failed catastrophically at VSWR of 2.0 to 1. Since the special test program to perform final electrical tests on Life Test units was only developed as part of the Qualification Test Program, none of the Life Test modules were tested for low temperature pulse breakup prior to Qualification testing. Therefore, the capability of the "failed" modules to initially pass low temperature pulse breakup testing is not known.

APPENDIX M

SAFETY STATEMENT FOR
MANUFACTURING TECHNOLOGY STUDY
ON RF POWER MODULE PACKAGING TECHNIQUES

(4 Pages)

SAFETY STATEMENT FOR
MANUFACTURING TECHNOLOGY STUDY
ON RF POWER MODULE PACKAGING TECHNIQUES

1.0 Introduction

This safety statement covers the safety engineering aspects of a Manufacturing Technology Study, Contract N-00039-79-C-0378. These safety aspects covered both proposed and actually implemented designs, materials, processes, and tests.

2.0 System

This study program was performed to improve the manufacturability of the RF Power Modules and was broken into the following sub-tasks:

1. Improve the direct bond copper process.
2. Improve the glass sealing process.
3. Develop a lid sealing process for non-kovar lids.
4. Fabricate a sample lot of improved RF power modules and test them with improved test equipment.
5. Debug software/hardware for module test and complete test procedures.

3.0 Conclusions

The general results of this study show that the RF module's design is inherently safe to manufacture, to test, and to use.

A special warning label has been designed and is affixed to the finished RF modules. This label advises operating and maintenance personnel that the module contains small amounts of Beryllia (BeO).

Twenty-five (25) Material Safety Data Sheets (MSDS) were submitted for all new or potentially hazardous materials used during the manufacturing sub-tasks. These MSDS's detailed all necessary safety criteria for each material.

4.0 Discussion

The potentially hazardous materials used during the study are listed with their MSDS file numbers in Exhibit A. The individual MSDS's were submitted as part of the referenced progress reports.

For convenience these materials are grouped in accordance with the most significant sub-task applicability. That is, there are ten MSDS's applicable to sub-task 1, the development of the direct bond copper process. These are further divided into three used in alumina substrate processing, five used in copper processing, and the last two in copper bonding.

The personnel using all these materials have been informed of the correct use, handling and disposal procedures.

A special warning label was prepared for the RF power module stating that it contained BeO (Beryllia). This was done because beryllium compounds have been identified as potentially carcinogenic. In normal RF module handling the BeO carrier cannot be contacted by personnel. So the warning label is intended to caution maintenance or failure analysis personnel who might attempt to take the sealed RF module apart.

5.0 References

Progress Reports #1 through #18 inclusive.

J. Balko
TPS-59 Safety Engineer

EXHIBIT A

MATERIAL SAFETY DATA SHEETS
SUBMITTED IN PROGRESS REPORTS

Sub-Task Item No.	MSDS File No.	Material Designation	Primary Usage in Sub-Task	Report No.
1	81-J	Methylene Chloride	Alumina Substrate Processing	4
1	XVII-27-Is	Isopropyl Alcohol	" " "	4
1	221-M	Turko Dy Check #2	" " "	6
1	1-4-Ni	Nitric Acid	Copper Processing	4
1	94-A	Sulfuric Acid	" "	4
1	XV-10-Ne	Neutra Clean #68	" "	4
1	XVII-59-Ch	Chlorothene Nu	" "	4
1	235-E	Enplate MB #08025	" "	6
1	IV-10-Ni	Nitrogen Gas	Copper Bonding	4
1	236-Q2	Firebrick K23	" "	6
2	XVII-40-To	Toluene	Thick Film Glass Seal	4
2	243-Q2	CV-111 Borosilicate Paste	" " " "	6
3	78-F	Alpha 611 Flux	Soldering	4
3	VIII-46-So	Solder (60/40)	"	4

(Sheet 1 of 2)

EXHIBIT A (Continued)

Sub-Task Item No.	MSDS File No.	Material Designation	Primary Usage in Sub-Task	Report No.
3	208-Q1	Kovar	Module Lid Material	6
3	227-2	Phenolic (Glass Filled)	Plastic Outer Cover	6
3	265-Z	Copper Paste Comp. 9922	Thick Film Printed Copper	7
3	32-C	Oakite #31	" " " "	13
4	38-Q2	Alumina T-61	Ceramic Capacitors & Substrates	4
4	III-9-Al	Allros #100	Gold Wire Flux	4
4	XIII-2-Be	Beryllia (BeO)	Transistor Carrier	4
4	132-Q	Ammonium Chloride	Thick Film Resistor Paste	4
4	I-10-Fl	Fluoboric Acid	" " " "	4
4	266-R	Resistor Paste (E-21569-4)	" " " "	7
-	13-C	4053 Micromet Crystals	(Not Used)	4

Sub-Tasks:
1 - Direct bond copper process
2 - Glass sealing process
3 - Lid sealing process
4 - Fabrication of sample lot of improved RF modules

(Sheet 2 of 2)

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APPENDIX N

MFG. CONTROL DOCUMENT PIA #77D609398
NEW OXIDE REMOVAL PROCESS

THICK FILM **PIA SHEET** **Date:** 8-14-81 **Rev.** 20 **File:** 9955 (C2)

Circuit: Power Module **System:** S.S.R. **WA:** ______

SK/Dwg: 77D609398 **Rev.** A **Pkg:** ____

Substrate Mat'l Al_2O_3 (circled) 96% (circled) BeO 99%

DIRECT BONDED S.S. PER 9955 (B)

PRINTED WALL PER 939 W (C1)

INPUT REQD [ ]

OUTPUT REQD [ ]

*1.1.232 (1.2.230), 1.1.245, 1.1.250

These substrates Serialized ______ **thru** ______

*** 1.1.232, 1.1.245, 1.1.251

S.S. REF. NO. ______ **PRINT REFERENCE CORNER** Holes Q1,Q2/Q3

WALL REF. NO. ______ PRINT DIRECTION TOWARDS – Left

NO.	OPERATION NAME	MPI/ES/QC	ART 9398	MESH	EMULSION	SQUEEGE FORCE	SQUEEGE SPEED	PASTE	PASTE LOG	PROFILE NO.	OPER	DATE	QUANTITY IN	QUANTITY OUT
10														
20														
25	PDF Cond	*	L1 A	280	.2-.3 (Dwg. Notes 5 & 7)	(1)		0922	C	900/6				
30	PDF Cond	*	L 2A	280	.2-.3			0922	c	900/6				
33														
34	Measure & Record Bias Line Res. Note 8													
35	Check Line Widths per Dwg. Note# 7 (1)													
40 (3)	PDF Res.	*	L 4A	280	.2-.3	(2.7-3.5 Ω)		Blend (9)	C	900/6				
50	Measure & Record Res. 100% (Largest element only)							(2.7-3.5 Ω)						
60	PDF Diel	***	L 5A	105	4.0	(DWG. (2) (1))		MVD 6111	G	400/6				
70	Measure THK	(5.0-8.0 mils.)												
80	Seal	1.1.251 (Dwg. Note # 10 (1))(Note (5))							F	500/6				
90	DYE Check	1.1.403 Part 7												
100														
105	Paint D. Resist			(Note # (6))				2005		75/1 HR.				
110	Remove Oxidée	1.1.126 (Must be done same shift as step 120)												
115	Remove Resist	1.1.142 Part C												
117	Cut Copper Tabs See Note (7) on back of sheet.													
120	Solder Tin	1.1.748B												
130														
140	Clean	1.1.104B												
150	Q.C. Audit	82.99.90.12, 8247.1059 Para 7.1.4,5,7,11												
155	Serialize	1.1.652 Proc. F.												
160	Route To Stock													
More	(1) All Dwg. Ref. Notes Refer to 9398 Rev. A													
NOTES	(2) Print Wall Paste .030" ± .010" from edge of Input Pad.													
On BACK	(3) Print Resistor so lower contact is exposed to leave .015" bare conductor or More.													
	(5) See 1.1.251 Procedure Para. 4.													
	(6) Paint Resist to protect resistors and as noted in note # (3).													

HIC, Manager HIC, Engineer 5/14/80 Process Engr 5/9/80 QC Engineer 5/14/80

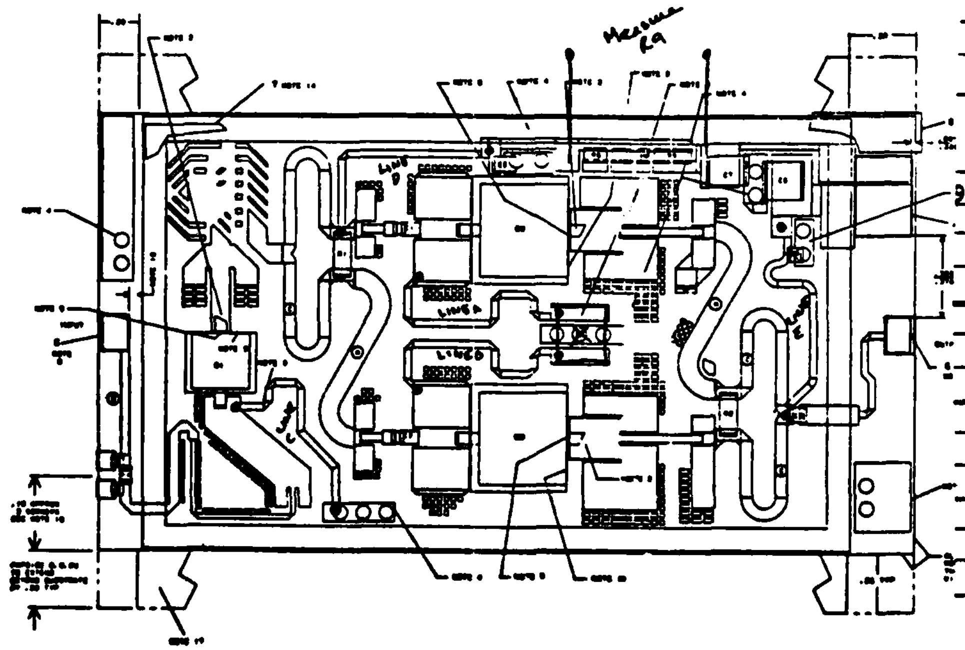
Note: ⑦ Direct Bond Copper Flange On left end to be cut.
Where indicated & Bend Tabs up & over Pads in lower left corner.

FIRED FILM THICKNESS

⑧ See Attached Sketch, Use Kelvin Probes Where Indicated.

OPER. #=	⑨ Blend 4317/4238 to get value required
LOCATION	
	9922 = G.E. Pt. No. 7840584P36
	4317 = G.E. Pt. No. 7840580P64
	4238 = G.E. Pt. No. 7840580P63
	MMD6111 = G.E. Pt. No. 7840582P18

R #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NOM															
TOL															
SAMPLES. FIRST															
SAMPLES. SECOND															



9	30

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APPENDIX O

MFG. CONTROL DOCUMENT PIA #7244612P1
NEW COPPER SPHERE PROCESS

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COPPER OXIDATION
PTA SHEET

Date: 1-22-81 **Rev.** – **File:** 9955 S (A)

Circuit: COPPER SPHERES **System:** S.S.P. **WA:**

Dwg: 7244612P1 **Rev.** – **Pkg:** –

INPUT REQD	
OUTPUT REQD	

NO.	OPERATION NAME	MPI/ ESI/ QCI/									OPER	DATE	QUANTITY	
													IN	OUT
10	Oxidize Copper 1.1.121													
20	Route To Bonding Room Stock Cabinet													

HIC,Manager

HIC,Engineer 2/19/81

Process Engr 1/22/81

QC Engineer 2/…/81

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APPENDIX P

MFG. CONTROL DOCUMENT PIA #7248543P1
NEW COPPER CERAMIC WALL BLANK PROCESS

COPPER OXIDATION
PIA SHEET

Date: 8-19-81 **Rev.** 2 **File:** 039 W (A)

Circuit: COPPER SHEET PREFORM **System:** S.S.R. **WA:**

DWG. : 7248543P1 **Rev.** – **Pkg:** –

INPUT REQD [ ]
OUTPUT REQD [ ]

NO.	OPERATION NAME	MPI/ ESI/ QCI/									OPER	DATE	QUANTITY IN	QUANTITY OUT
10	Anneal Copper	1.1.403 Part 3												
20	Oxidize Copper	1.1.121												
30	Flatten Copper	1.1.403 Part 8												
40	Route To Bonding Room Stock Cabinet													

HIC, Manager HIC, Engineer 2-6-81 Process Engr 8/19/81 5/9/81 1/23/81 QC Engineer 2/9/81

FIRED FILM THICKNESS

OPER. #=														
LOCATION														

R #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NOM																
TOL																
SAMPLES	FIRST															
	SECOND															
	THIRD															

R #		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
NOM																
TOL																
SAMPLES	FIRST															
	SECOND															
	THIRD															

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APPENDIX Q

MFG. CONTROL DOCUMENT PIA #7248571P1
NEW COPPER GROUND PLANE BLANK PROCESS

COPPER OXIDATION
PIA SHEET

Date: 8-19-81 **Rev.** 2 **File:** 0955 (A)

Circuit: Copper Sheet Preform **System:** S.S.R. **WA:**

DWG. 7248571P1 **Rev.** - **Pkg:** -

INPUT REQD
OUTPUT REQD

NO.	OPERATION NAME	MPI/ ES/ QC/								PROFILE NO.	OPER	DATE	QUANTITY IN	QUANTITY OUT
10	Anneal Copper	1.1.403 Part 3												
20	Oxidize Copper	1.1.121												
30	Flatten Copper	1.1.403 Part 8												
40	Route To Bonding Room Stock Cabinet													

MTC Manager

MTC Engineer 3-6-81

Process Engr 8/19/81

QC Engineer 2/11/81

FIRED FILM THICKNESS

OPER. #=														
LOCATION														

R #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NOM															
TOL															
SAMPLES FIRST															
SECOND															
THIRD															

R #	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
NOM															
TOL															
SAMPLES FIRST															
SECOND															
THIRD															

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