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DEVELOPMENT OF LOW-COST CUSTOM HYBRID MICROCIRCUIT TECHNOLOGY

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16. ABSTRACT

The objective of this study was to develop selected potentially low cost, alternate packaging and interconnection techniques, implement them in the manufacture of specific NASA/MSFC hardware, and determine the actual cost savings achieved by their use. The hardware chosen as the test bed for this evaluation was the hybrids and modules manufactured by Rockwell International for the MSFC Flight Accelerometer Safety Cut-Off System (FASCOS). Three potentially low cost packaging and interconnection alternates were selected for evaluation.

This study was performed in three phases: hardware fabrication and testing, cost comparison, and reliability evaluation. Phase I included developing the technology for adhesive sealing and delidding FASCOS hybrid packages, fabrication/assembling and testing 32 FASCOS hybrids, designing a multiwire board functionally equivalent to the present multilayer board, and assembling and testing 2 FASCOS modules. Phase II consisted of identifying the important cost factors and ascertaining the corresponding cost deltas for the FASCOS hybrids and modules attributable to the packaging and interconnection alternates implemented. Phase III involved electrically testing adhesive sealed FASCOS hybrids after exposure to the 10-day moisture resistance test and the 1000-hour life test to determine their functional reliability, and performing mass spectrometric analyses on these and other adhesive sealed FASCOS hybrids to determine the composition of their internal atmospheres.

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CUSTOM HYBRID MICROCIRCUIT
TECHNOLOGY

By

K. L. Perkins
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ABSTRACT

The use of adhesive package sealing instead of seam welding, nickel-plated Kovar packages rather than gold-plated Kovar packages, and multiwire boards instead of multilayer boards was evaluated to determine their potential for reducing the cost of hybrid systems without degrading reliability. The evaluation was made by manufacturing specific NASA/MSFC hardware, FASCOS (Flight Accelerometer Safety Cut-Off System) hybrids and board assemblies, using the new techniques, subjecting these hybrids and board assemblies to normal screen and functional testing to determine their performance, and comparing their costs with those of the same hardware fabricated using the conventional techniques.

Effort included developing the technology for adhesive sealing and delidding FASCOS packages, fabricating/assembling and testing FASCOS hybrids, designing a multiwire board functionally equivalent to the present FASCOS multilayer board, assembling and testing multiwire board assemblies, identifying the important cost factors and determining the cost deltas due to the implemented changes, exposing adhesive-sealed FASCOS hybrids to the ten-day moisture resistance test and the 1000 hour life test, and functionally testing these hybrids and analyzing their internal atmospheres after these exposures.

The major conclusions of the study were that nickel-plated Kovar packages are recommended as a replacement for gold-plated Kovar packages, and multiwire boards are recommended as a replacement for multilayer boards, but adhesive package sealing is not recommended as a replacement for seam welding.

1.0 INTRODUCTION

1.1 STUDY OBJECTIVE

The objective of this study was to develop selected potentially low cost, alternate packaging and interconnection techniques, implement them in the manufacture of specific NASA/MSFC hardware, and determine the actual cost savings achieved by their use. The hardware chosen as the test bed for this evaluation was the hybrids and modules manufactured by Rockwell International for the MSFC Flight Accelerometer Safety Cut-Off System (FASCOS). Three potentially low cost packaging and interconnection alternates were selected for evaluation. These were:

1) adhesive package sealing instead of metallurgical package sealing (seam-welding),

2) nickel-plated rather than gold-plated Kovar packages and lids, and

3) multiwire boards instead of multilayer boards.

1.2 STUDY SCOPE

This study was performed in three phases: hardware fabrication and testing, cost comparison, and reliability evaluation. Phase I included developing the technology for adhesive sealing and delidding FASCOS hybrid packages, fabricating/assembling and testing 32 FASCOS hybrids, designing a multiwire board functionally equivalent to the present multilayer board, and assembling and testing 2 FASCOS modules. Phase II consisted of identifying the important cost factors and ascertaining the corresponding cost deltas for the FASCOS hybrids and modules attributable to the packaging and interconnection alternates implemented. Phase III involved electrically testing adhesive sealed FASCOS hybrids after exposure to the 10-day moisture resistance test and the 1000-hour life test to determine their functional reliability, and performing mass spectrometric analyses on these and other adhesive sealed FASCOS hybrids to determine the composition of their internal atmospheres.

2.0 TECHNICAL DISCUSSION

2.1 PHASE I - HARDWARE FABRICATION AND TESTING

This phase of the study involved developing the technology for adhesive sealing and delidding FASCOS hybrids; fabricating, assembling, and testing 32 FASCOS hybrids using nickel-plated Kovar packages and lids and adhesive sealing; designing a multiwire board functionally equivalent to the present FASCOS multilayer board; and assembling two FASCOS modules using multiwire boards and functionally testing them in the present FASCOS engineering system. Delidding and reworking the FASCOS hybrids and reworking the FASCOS modules was allowed as required. This effort is discussed in detail in the following sections.

2.1.1 Technology for Adhesive Sealing and Delidding FASCOS Hybrids

2.1.1.1 Selection of Package Sealing Adhesive

2.1.1.1.1 Candidate Adhesives

Two adhesives were selected for evaluation for sealing the FASCOS hybrids — Ablefilm 507 and Ablefilm 552. Ablefilm 507 consists of a DGEBA (diglycidal ether of bisphenol A) resin and a dicyandiamide curing agent. This adhesive was one of the first film adhesives produced by Ablestik Laboratories and is still widely used for sealing packages. Ablefilm 552 is relatively new and was developed expressly as an improved adhesive for sealing gold-plated Kovar packages. It is a hybrid of Ablefilm 550 and Ablefilm 529, reputedly combining the best characteristics of these adhesives, and was highly recommended by Ablestik Laboratories personnel. It consists of the nitrile modified DGEBA resin developed for Ablefilm 550 and the diaminodiphenylsulfone curing agent used in Ablefilm 529.

Film adhesives were selected rather than paste adhesives because they are easier to apply and do not run out during assembly and cure. The specific film adhesives, Ablefilm 507 and Ablefilm 552, were selected for the following reasons. Ablefilm 507 was previously evaluated under Contract NAS8-31992 and was found to be one of the four best of the ten adhesives evaluated and one of only two adhesives (the other was Ablebond 789-1) that sealed 2.54 cm (1 inch) square gold-plated Kovar packages adequately to pass the seal test after ten days exposure to 85°C/85% RH. Ablefilm 552 was selected because it contains the same resin system as Ablebond 789-1 which was also previously evaluated under Contract NAS 8-31992 and was found to be the best of the ten adhesives evaluated.

2.1.1.1.2 Adhesive Preforms

Adhesive preforms six mils thick with a two-mil thick fiberglass supporting fabric were selected for this study. These preforms have outside dimensions of 0.990 by 1.990 inches and inside dimensions of 0.890 by 1.890 inches, giving a sealing surface 50 mils wide.

2.1.1.1.3 Adhesive Evaluation and Selection

Eight empty FASCOS packages were sealed using 10-mil thick flat gold-plated Kovar lids. (15-mil thick nickel-plated Kovar lids were not available at the time.) Five were sealed with Ablefilm 552 and three with Ablefilm 507. Initially two packages were sealed with Ablefilm 552 and seal tested in accordance with Method 1014.2 of MIL-STD-883. The packages were bombed in helium for three hours at 30 psig and then fine and gross leak tested. Both packages were found to be gross leakers. Three additional packages were then sealed with Ablefilm 552 and a test performed to determine if the packages were gross leakers as sealed or if the helium bombing at 30 psig oil-cans the 10-mil lids and causes the packages to be gross leakers. These packages were gross leak tested after sealing prior to helium bombing and found to pass. They were then bombed in helium for three hours at 30 psig and again gross leak tested. Two of the three packages were found to be gross leakers. The one good package was then fine leak tested and found to have a measured leak rate of 1.0×10^{-7} atm cc/sec helium or 3.7×10^{-8} atm cc/sec air equivalent. After fine leak testing, this package was again gross leak tested and passed.

Three packages were then sealed with Ablefilm 507 and the same procedure was followed. All three packages passed the initial gross leak test. After bombing in helium for three hours at 30 psig, one of the packages failed the gross leak test and two passed. Fine leak testing of these two packages showed leak rates of 1.6 and 2.5×10^{-8} atm cc/sec helium or 6.0 and 9.3×10^{-9} atm cc/sec air equivalent. After fine leak testing, these packages also were again gross leak tested and passed.

These results show that the adhesive-sealed packages were good after sealing but that helium bombing at 30 psig damaged the seals. This is believed to be due to oil-canning of the 10-mil lids under the helium pressure.

These results also indicate that Ablefilm 507 performs better as a package sealant than Ablefilm 552. Only one of three packages sealed with Ablefilm 507 was a gross leaker after helium bombing while four of five packages sealed with Ablefilm 552 were gross leakers.

Six empty FASCOS packages also were sealed using 15-mil thick nickel-plated Kovar lids—three with Ablefilm 552 and three with Ablefilm 507. These packages were then leak tested following the same procedure previously used for the packages sealed with the 10-mil thick lids; that is, gross leak tested after sealing prior to helium bombing, gross leak tested immediately after helium bombing for three hours at 30 psig, fine leak tested, and then gross leak tested again. All packages passed all gross leak tests. The measured fine leak rates were as shown in Table 1.

Table 1. Leak Rates of FASCOS Packages Adhesive Sealed with 15-Mil Thick Nickel-Plated Kovar Lids

Package		Measured Fine Leak Rate (atm cc/sec)	
		Helium	Air Equivalent
Ablefilm 552	#1	4.3×10^{-8}	1.6×10^{-8}
	#2	1.4×10^{-7}	5.2×10^{-8}
	#3	2.7×10^{-7}	1.0×10^{-7}
Ablefilm 507	#1	1.4×10^{-8}	5.2×10^{-9}
	#2	4.0×10^{-8}	1.5×10^{-8}
	#3	2.7×10^{-8}	1.0×10^{-8}

These results show that adhesive seals passing the MIL-STD-883 Seal Test can be obtained for the FASCOS packages when the thicker (15-mil thick) lids are used. This also substantiates the validity of the speculation that the thinner (10-mil thick) lids were oil-canning under the 30 psig helium bombing pressure and damaging the seals.

These results also further indicate that Ablefilm 507 performs better as a package sealant than Ablefilm 552. As shown, the fine leak rates measured for the packages sealed with Ablefilm 507 are an order of magnitude less than those measured for the packages sealed with Ablefilm 552.

Based on these results, Ablefilm 507 was selected as the package sealing adhesive to be used for the FASCOS hybrid build for this study. Also, 15-mil thick lids were selected for use.

2.1.1.2 Selection of Type of Lids

Both stepped and flat lids were considered for the present application. Stepped lids have the advantage that the step serves as a guide to ensure proper alignment of the adhesive preforms during package assembly and restricts the flow of the adhesive during cure, but the step interferes with all conceivable delidding methods. Flat lids have the advantage that they are about 40% less expensive than stepped lids and considerably less fragile. The edges of the stepped lids are only approximately 5-mils thick and are easily bent during handling. The flatness and greater thickness of the edges of the flat lids not only simplifies delidding but makes it possible to salvage the lids for reuse if desired.

Based on these considerations, flat lids were chosen for the present application. The lids selected are made of 15-mil thick Kovar and have a nickel plating 200 to 300 microinches thick.

2.1.1.3 Development of Method for Adhesive Sealing FASCOS Packages

2.1.1.3.1 Design and Fabrication of Tooling Required for Adhesive Sealing Packages

In order to successfully adhesive seal packages, pressure must be applied while the adhesive is being cured. The amount of pressure is not particularly critical, but it must be adequate to bring the parts in intimate contact and should be uniform over the sealing area. Also, in the case of adhesive preforms, the performs must be aligned and tacked in place on either the package lid or case. This is especially true for larger-sized preforms. The larger the preform, the flimsier it is, and the more it is distorted from its intended shape.

For example, no matter how carefully the 6 mil thick, 50 mil wide, approximately 1 x 2 inch preforms required for the FASCOS hybrids are stored and handled, they are not rectangular as they should be to fit on the lids, but are slightly bowed—especially along the two-inch dimension.

Three types of tooling are essential for adhesive sealing the FASCOS packages. One to align the preform with the lid and tack it in place, another to align the lid/preform and the package case with each other, and a third to clamp the lid preform and package case together and hold them in alignment during curing.

Tooling meeting these requirements was designed and fabricated. This tooling consists of a lid/preform alignment fixture for aligning the preforms on the lids and tacking them in place, clamping plates and clips for clamping the package cases and lids/preforms together and holding them in alignment during cure, and a package assembly/ alignment fixture for assembling the clamping plates, package cases, and lids/preforms and aligning them with each other while they are clipped together. Photographs of this tooling are given in Figures 1 through 3. Note that the clamping plates are recessed on the bottom side (the side shown in the photograph) so that they only contact the outer edges of the package lids and cases. This is to ensure that they uniformly distribute the pressure and do not distort (bend) the lids.

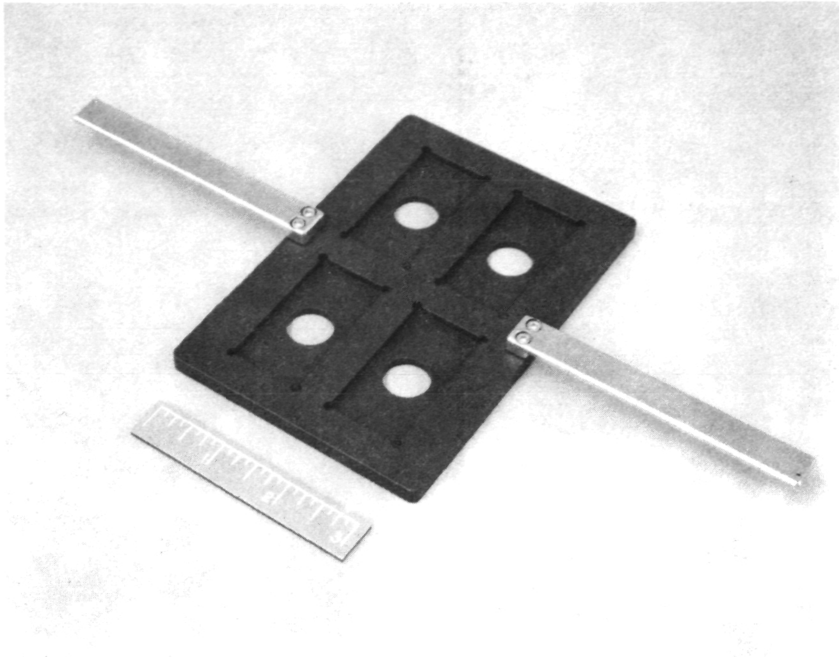


Figure 1. Lid/Preform Alignment Fixture

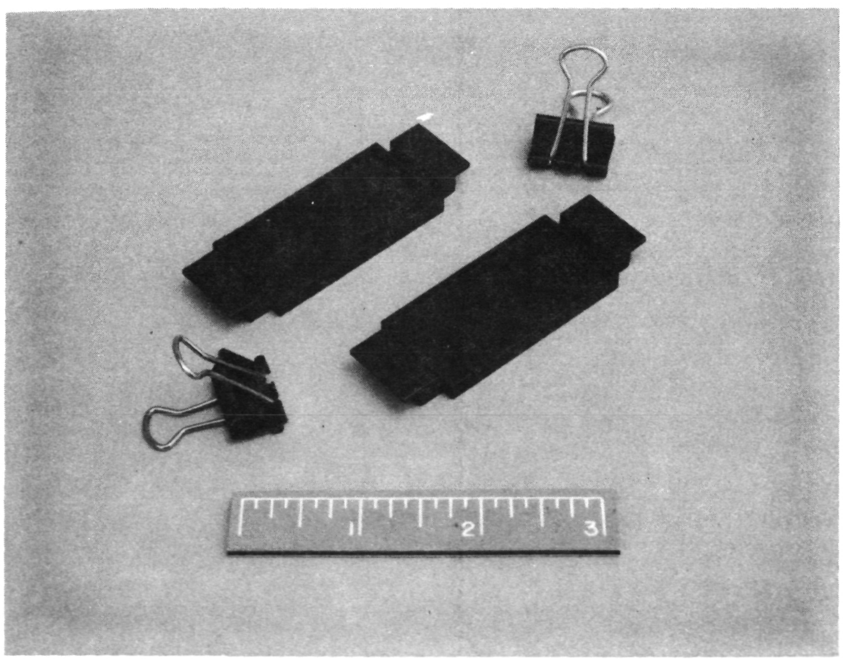


Figure 2. Clamping Plates and Clips

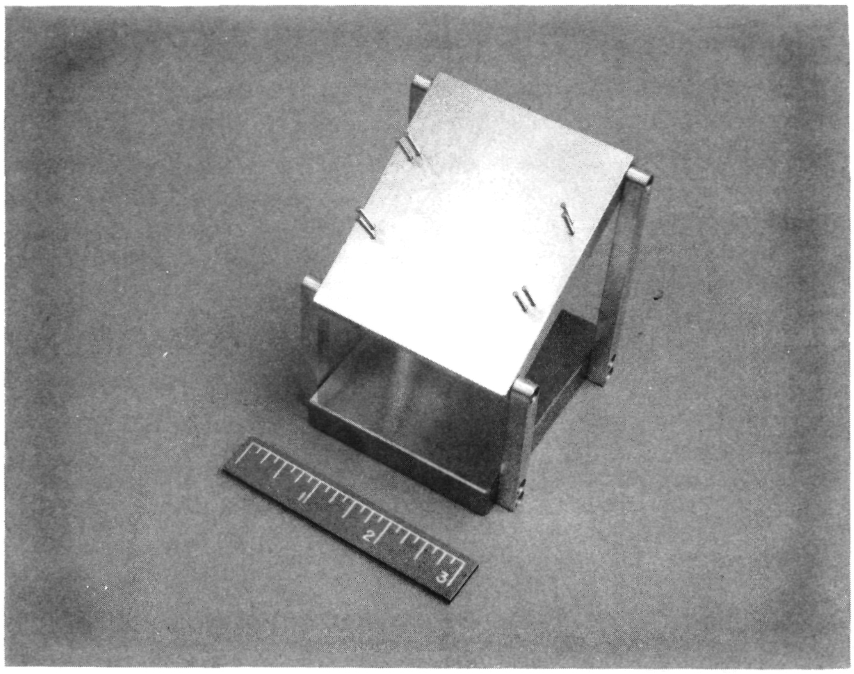


Figure 3. Package Assembly/Alignment Fixture

2.1.1.3.2 Procedure for Assembling Packages

The procedure for assembling the packages is as follows:

a) The lids are placed in the lid/preform alignment fixture, adhesive preforms are aligned on them, and then the fixture is placed on a hot plate at approximately 100^{o}C for a few minutes to tack the preforms to the lids. The fixture is then removed from the hot plate and allowed to cool to room temperature.

b) The packages are then assembled in the package assembly/alignment fixture as shown in the series of photographs of Figure 4.

Step 1 - A clamping plate is placed in the fixture with the bottom side (the side that is recessed) up.

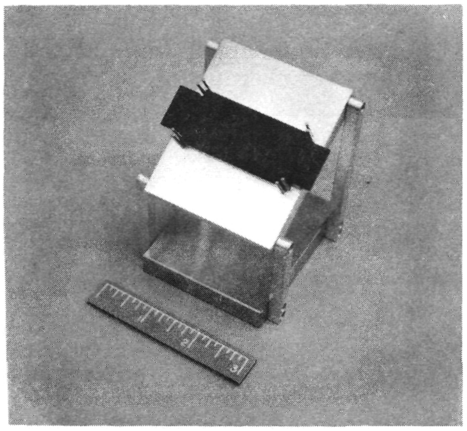
Step 2 - A lid with attached preform is placed in the fixture with the side to which the preform is attached up.

Step 3 - A package case is placed in the fixture with the bottom side up.

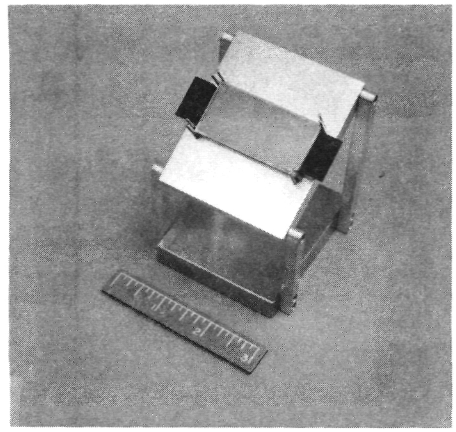
Step 4 - A clamping plate is placed in the fixture top side up.

Steps 5 and 6 - This assembly is then lightly tapped to ensure that all parts are aligned and held together tightly while the clips are installed on the ends of the clamping plates.

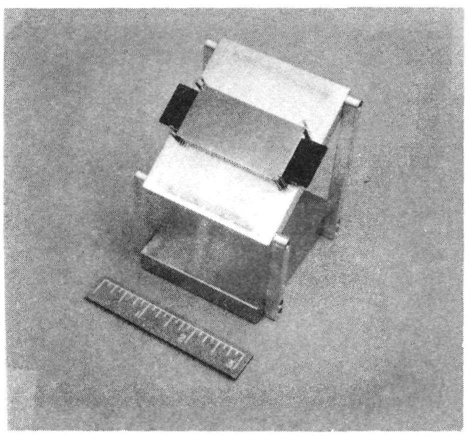
All of the assembly procedure except aligning and tacking the preforms on the lids must be performed in the sealing chamber (nitrogen dry box with attached vacuum oven). The lid/preform alignment fixture is placed in the sealing chamber and the lids with attached preforms are removed from it and placed in the package assembly/alignment fixture using a vacuum pickup tool.



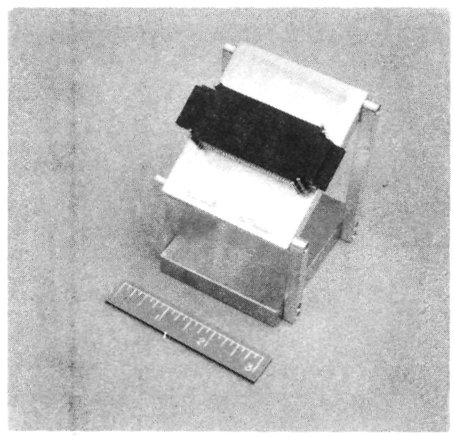
a) Step 1



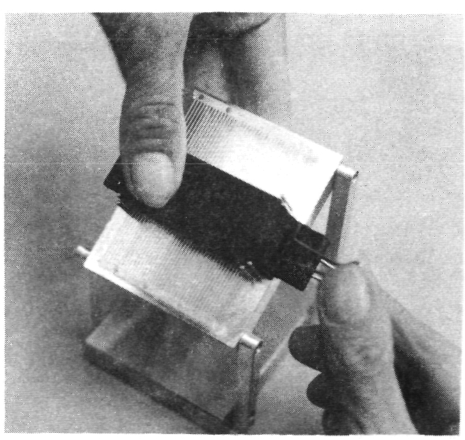
b) Step 2



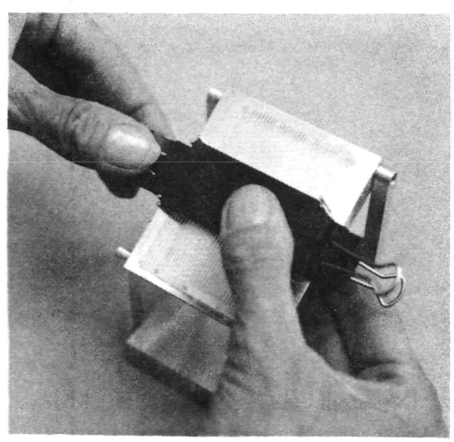
c) Step 3



d) Step 4



e) Step 5



f) Step 6

Figure 4. Procedure for Assembling Packages

Photographs of an assembled package in the package assembly/ alignment fixture and in an oven tray are given in Figures 5 and 6. Note that the oven tray is designed so that the package assembly does not rest on the edges of the clips.

2.1.1.3.3 Development of Adhesive Sealing Procedure

2.1.1.3.3.1 Evaluation and Modification of Available Sealing Facility

A dry run was made at completely processing packages in the sealing chamber (nitrogen dry box with attached vacuum oven) to reveal unanticipated problems before starting to seal the FASCOS hybrids. The complete procedure that must be performed in this chamber is as follows:

1) Bake out unlidded packages in vacuum (at <50 μm) for 4 hours at $150^{o}C$.

2) Transfer packages to attached nitrogen dry box, let cool, and assemble packages (cases, lids and adhesive preforms) in clamping fixtures.

3) Cure clamped packages in the attached oven in nitrogen for 1-1/2 hours at $165^{o}C$.

The following problems were encountered:

1) The vacuum oven must be used for both the vacuum bake-out and the nitrogen cure. While the oven is equipped for backfilling with nitrogen, minor modifications were required to provide the proper nitrogen flow rate to maintain a nitrogen atmosphere during adhesive cure.

2) During the course of this modification, it was realized that the location of the thermocouple provided with the oven is improper for the present application. This thermocouple simply hangs down from the top of the oven and measures the temperature established by radiation within the oven. The oven contains two trays which sit on brackets attached to the oven walls. Since, in the present case, the packages or the clamps

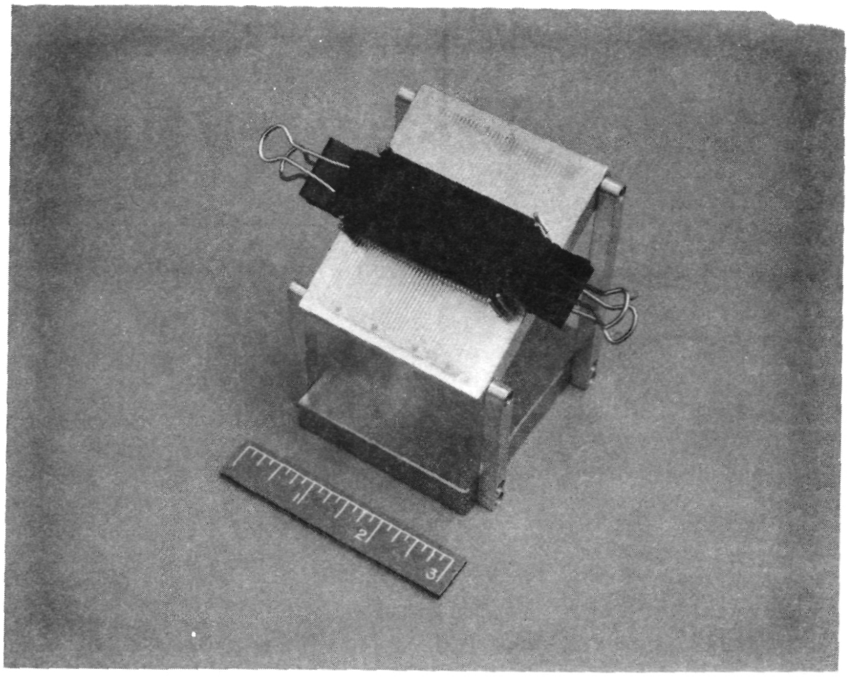


Figure 5. Assembled Package in Assembly/ Alignment Fixture

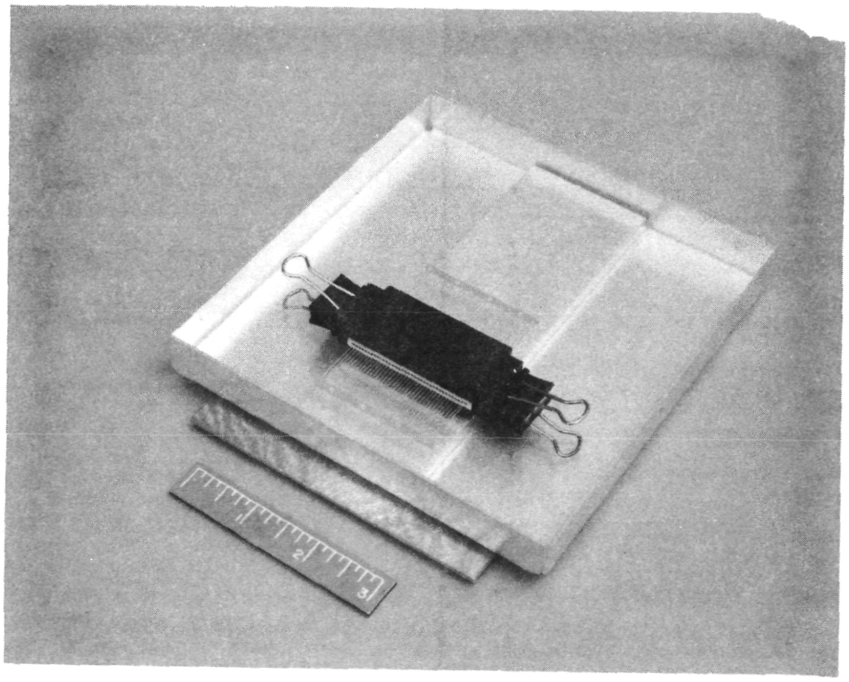


Figure 6. Assembled Package in Oven Tray Ready for Cure

holding the packages are in intimate contact with the trays, the major transfer of heat is by conduction through the trays; so a thermocouple was attached to the center of an aluminum strip spanning the oven between the brackets holding the top tray. This thermocouple is almost exactly in the center of the oven, and the top tray sits on top of the aluminum strip.

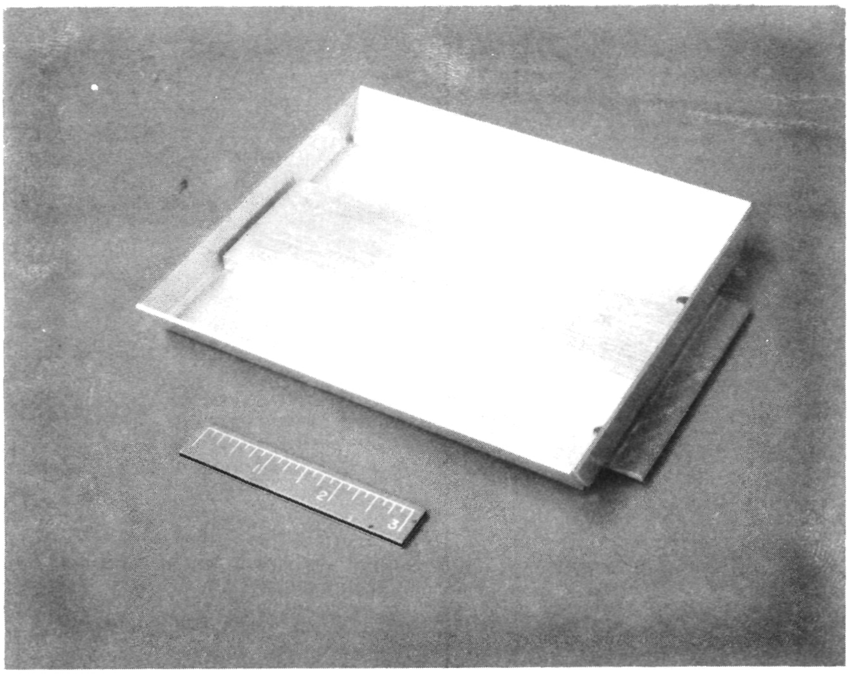
(3) Also, it was found that the trays provided with the oven were slightly undersized and were too small to hold two assembled packages. Since it is desirable to process as many packages as possible at a time, new trays, each capable of holding two assembled packages, were fabricated. These trays were made of aluminum to provide good thermal conduction, and have a strip protruding from the bottom of their front end so that they can be firmly gripped with tongs since they are heavy when loaded and must be handled while hot. Photographs of one of the trays empty and with two assembled packages in it are shown in Figure 7.

During this evaluation, it was realized that the two trays and four assembled packages constitute considerable mass for the small oven being used, so tests were run to determine the proper oven temperature-controller set-points for baking-out unlidded packages in vacuum for 4 hours at 150°C and for curing assembled packages in nitrogen for 1-1/2 hours at 165°C. Since the oven is only six inches in diameter and 8 inches long, and consequently has a volume of only 0.13 cubic feet, the nitrogen flow through the oven during cure was selected to be about 0.5 SCFH (standard cubic feet per hour).

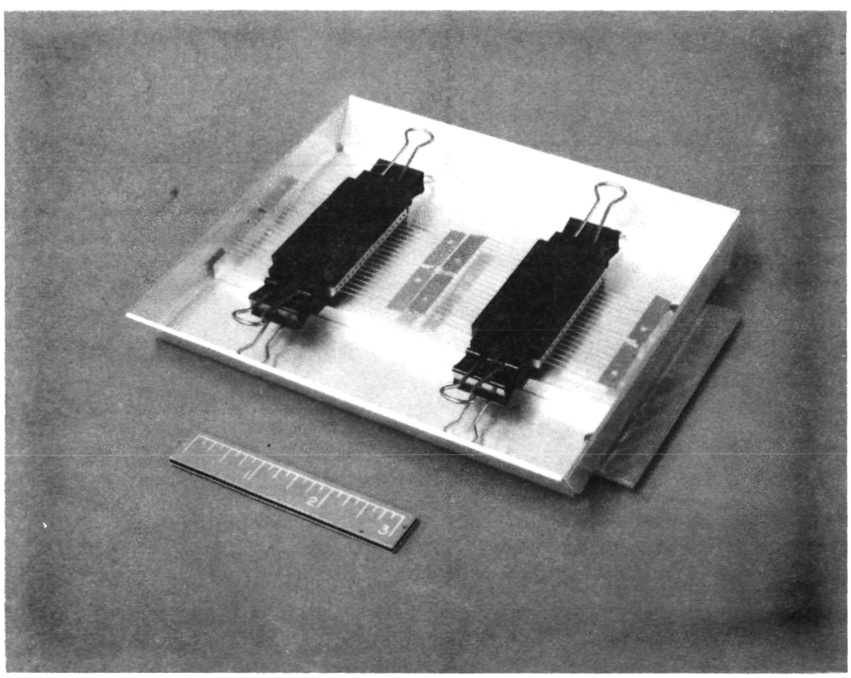
2.1.1.3.3.2 Selected Sealing Procedure

The bake-out and curing procedures selected as a result of these tests are as follows:

1) Oven Preconditioning - The oven temperature-controller set-point is always set at 175°C with the oven empty and nitrogen flowing through it at about 0.5 SCFH. At this setting, the oven stabilizes at a temperature of 170 to 172°C.



a) Empty



b) With Two Assembled Packages

Figure 7. Oven Tray

2) Vacuum Bake-Out - After the trays containing the unlidded packages are put in the oven and the oven evacuated, the temperature drops to around 85°C. The oven temperature-controller set-point is then raised to 200°C and left there until the oven temperature reaches 148°C. (This takes approximately one hour.) At this time, the oven temperature-controller set-point is lowered to 175°C. (This set-point is adequate to maintain the oven temperature at 148 to 152°C during the 4 hour bake-out at a vacuum of less than 10^{-3} Torr.)

3) Adhesive Cure - After the trays containing the clamped assembled packages are put in the oven, the temperature drops to around 75°C. The oven temperature-controller set-point is then raised to 200°C and left there until the oven temperature reaches 163°C. (This takes approximately 35 minutes.) At this time, the oven temperature-controller set-point is lowered to 175°C. (This set-point is adequate to maintain the oven temperature at 164 to 166°C during the 1 1/2 hour cure with a nitrogen flow rate of about 0.5 (0.4 to 0.6) SCFH.)

2.1.1.3.3.3 Verification of Selected Sealing Procedure

Eight empty nickel-plated Kovar packages were processed in the sealing chamber to verify the adequacy of the above procedures and to develop proper handling techniques in preparation for baking-out and sealing the FASCOS hybrids. Processing proceeded smoothly and all packages passed the fine and gross leak tests. The measured fine leak rates were as shown in Table 2. As can be seen, the leak rates of all packages were appreciably less than the 3×10^{-6} atm cc/sec air equivalent maximum leak rate specified for the FASCOS hybrids.

Table 2. Measured Fine Leak Rates for Adhesive Sealed Nickel-Plated Kovar Packages

Package	Measured Leak Rate (Air Equivalent) (atm cc/sec)
#1	1.0×10^{-7}
#2	8.2×10^{-8}
#3	9.4×10^{-8}
#4	8.0×10^{-8}
#5	8.8×10^{-8}
#6	1.2×10^{-7}
#7	9.4×10^{-8}
#8	1.0×10^{-7}

2.1.1.4 Development of Method for Delidding Adhesive Sealed Packages

2.1.1.4.1 Initial Experiments

Penetration or softening tests were performed for both Ablefilm 507 and Ablefilm 552 to establish optimum delidding temperatures. These tests were performed using a Thermal Mechanical Analyzer (TMA). In these tests, a probe with a small tip was loaded with a 10 gram weight (corresponding to a force of approximately 22 psi) and placed on the surface of cured film-laminates. The laminate was 36 mils thick in the case of Ablefilm 507 and 40 mils thick in the case of Ablefilm 552. The laminates were cured using the same curing schedules as those used for sealing packages (i.e., 1-1/2 hours at 165°C for Ablefilm 507 and two hours at 150°C for Ablefilm 552). The temperature was then increased at a rate of 10°C/minute and recordings made of both the temperature and the vertical displacement of the probe as a function of time. Results are given in Figures 8 and 9.

The glass transition temperatures were found to be 83°C for Ablefilm 507 and 92°C for Ablefilm 552. At these temperatures, the adhesives began to soften and the probe began to penetrate the laminate. The chart speed was 10 mm/minute and since the heating rate was 10°C/minute, 10 mm on the horizontal axis also corresponds to 10°C. Scaling from the Tg values, it is seen that the maximum displacement occurred around 110 or 115°C for both adhesives. The subsequent reduction in the vertical displacement of the probe as the temperature was further increased does not mean that the probe was not sinking farther into the adhesive, but rather that the adhesive laminate was expanding at a faster rate than the probe was sinking into it. The results of these tests indicate that temperatures of 100 to 150°C would be optimum delidding temperatures.

Since it would be much more convenient to delid the packages at room temperature rather than at the elevated temperatures determined above, tests were also made to determine its practicability. Two packages, one sealed with each of the adhesives, were delidded. This was done by holding the package on end and carefully positioning a razor blade along

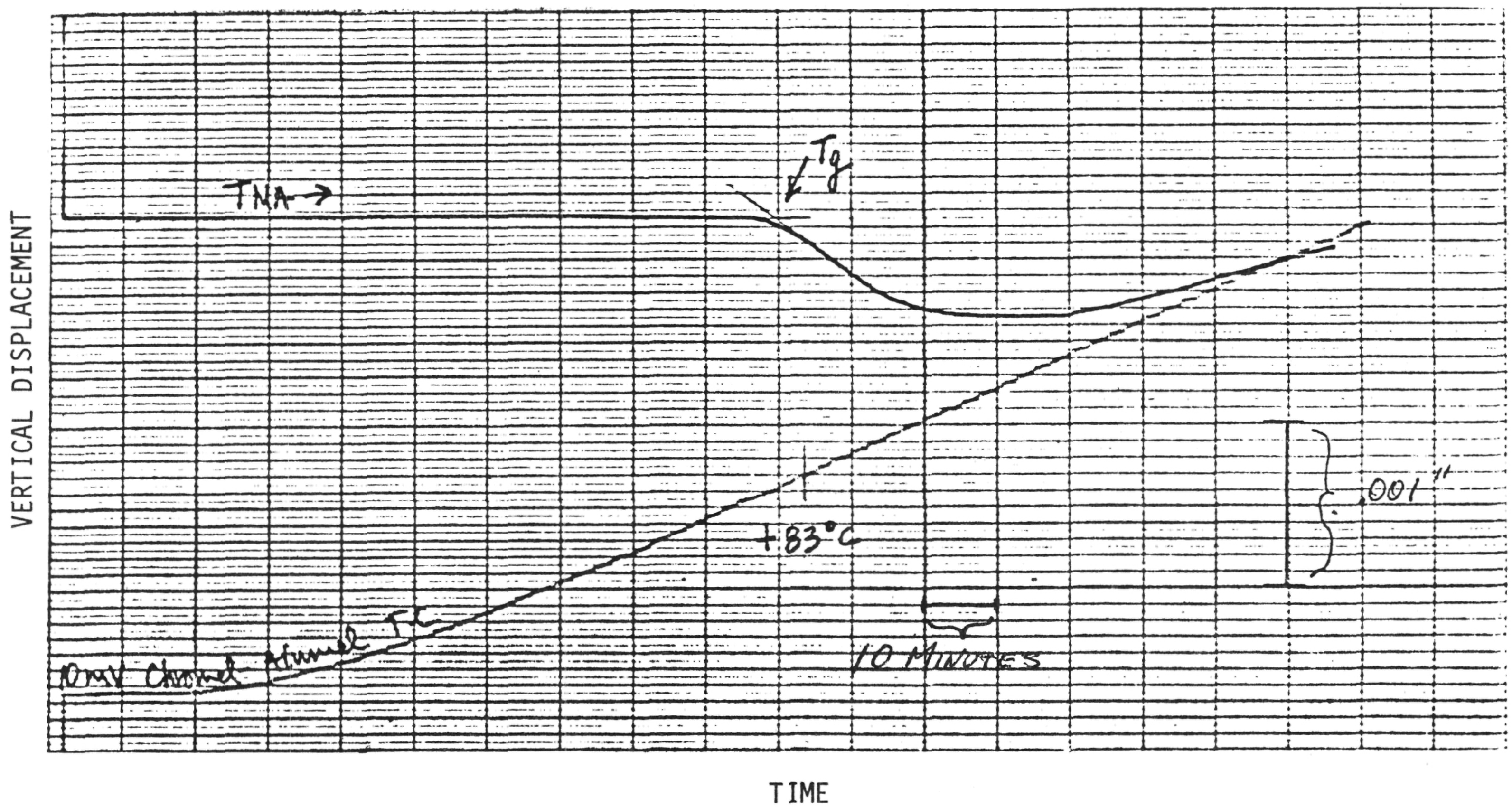


Figure 8. Results of Penetration Test for Ablefilm 507 (Laminate Thickness, 36 mils; Curing Schedule, 1-1/2 Hours at 165°C)

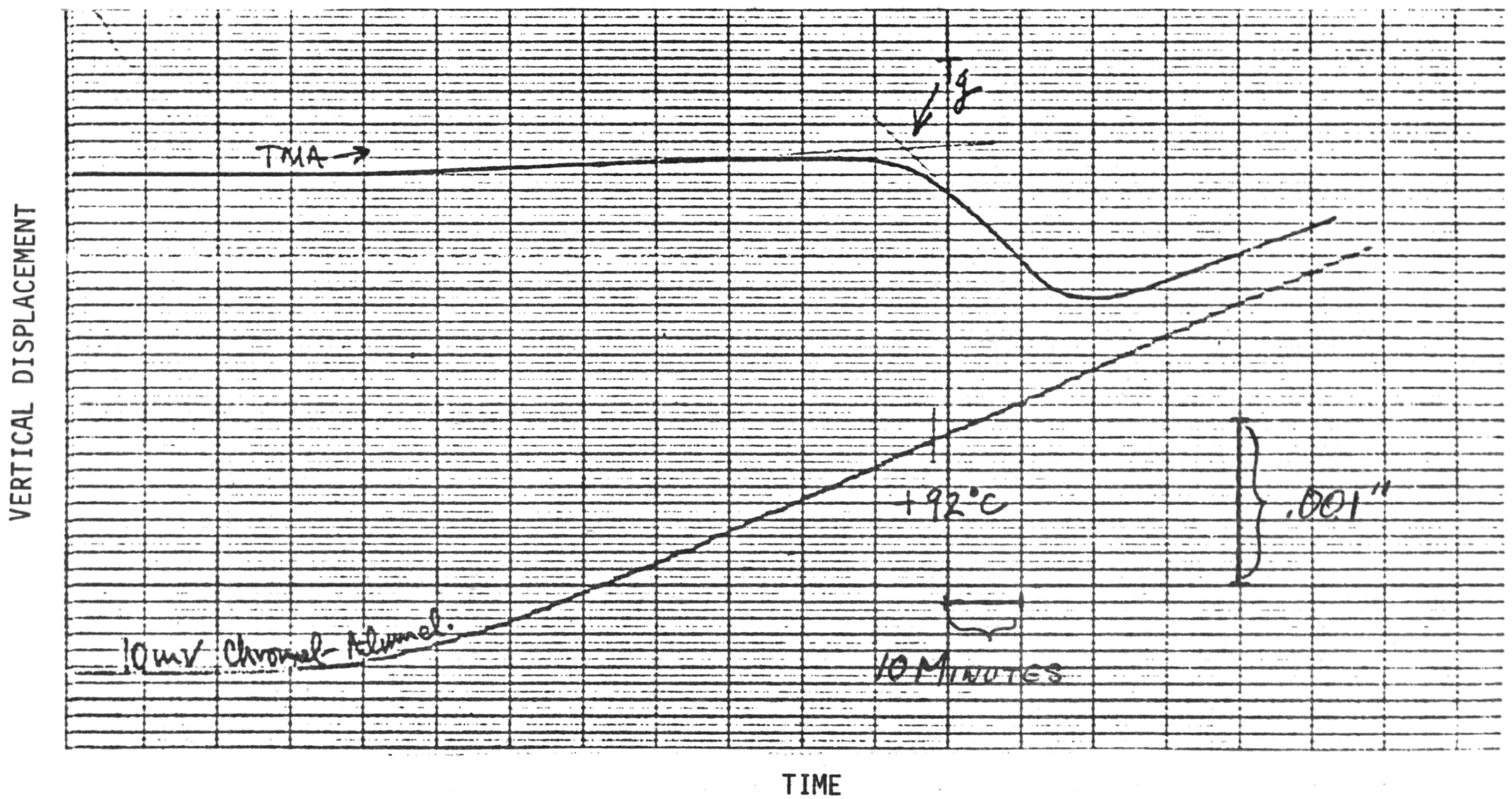


Figure 9. Results of Penetration Test for Ablefilm 552 (Laminate Thickness; 40 mils; Curing Schedule, 2 Hours at 150°C)

the bond-line at the upper right-hand corner. The razor blade was then tilted at an angle of 30 to 45^{0} while maintained in line with the adhesive bond-line and firmly pressed down. With the razor blade correctly positioned, penetration of the adhesive seal was fairly easy, and the package was then delidded by simply running the razor blade down along the rim of the package. The adhesive adhering to the rim of the package and to the lid was also removed at room temperature using a razor blade.

In removing the adhesive adhering to the rim of the package and to the lid, it was found that it was much more difficult to remove the Ablefilm 507 than it was to remove the Ablefilm 552. This supports the conclusion reached in Section 2.1.1.1.3 that Ablefilm 507 is a better package sealant than Ablefilm 552.

Hand delidding and adhesive removal as performed is not proposed as the delidding method. It not only is dangerous, but holding the razor blade in precise alignment to avoid scraping the edge of the package rim and generating metallic debris is much too difficult for a hand operation. However, this effort did establish the feasibility of delidding adhesive-sealed packages at room temperature and the desirableness of designing tooling to implement this method in a precisely-controlled manner.

2.1.1.4.2 Design and Fabrication of Delidding Tool

A tool for delidding packages at room temperature was designed and fabricated. The basic component is a manually operated precision slide mechanism as shown in Figure 10. This component and a high precision micrometer were purchased. All other parts were fabricated in-house. A photograph of this tool with a partially delidded package in it is shown in Figure 11. During delidding the package is held firmly in place in a vacuum chuck. The edge of the blade is accurately positioned on the adhesive bond line by adjusting the blade height using the high precision micrometer while viewing the

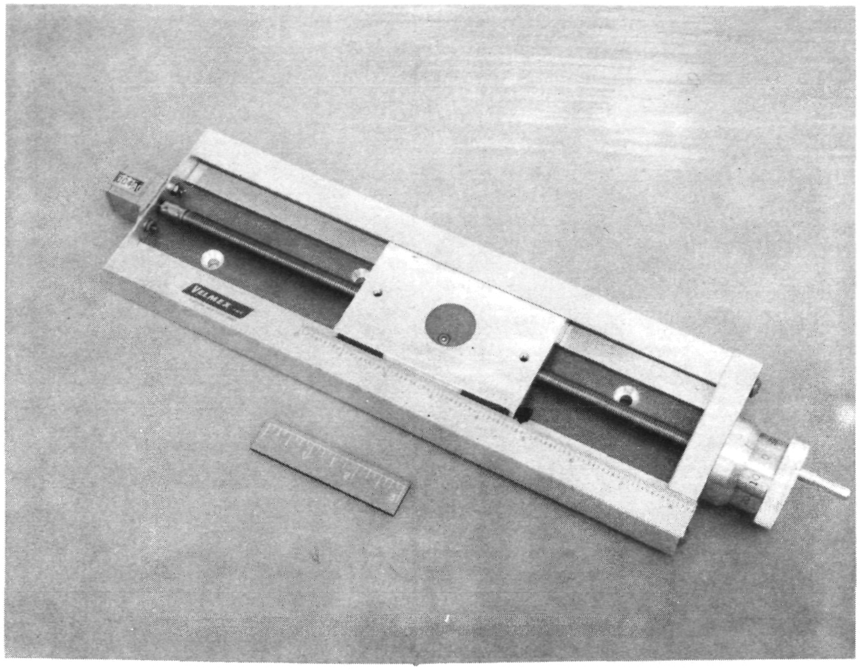


Figure 10. Manually Operated Precision Slide Mechanism for Delidding Tooling

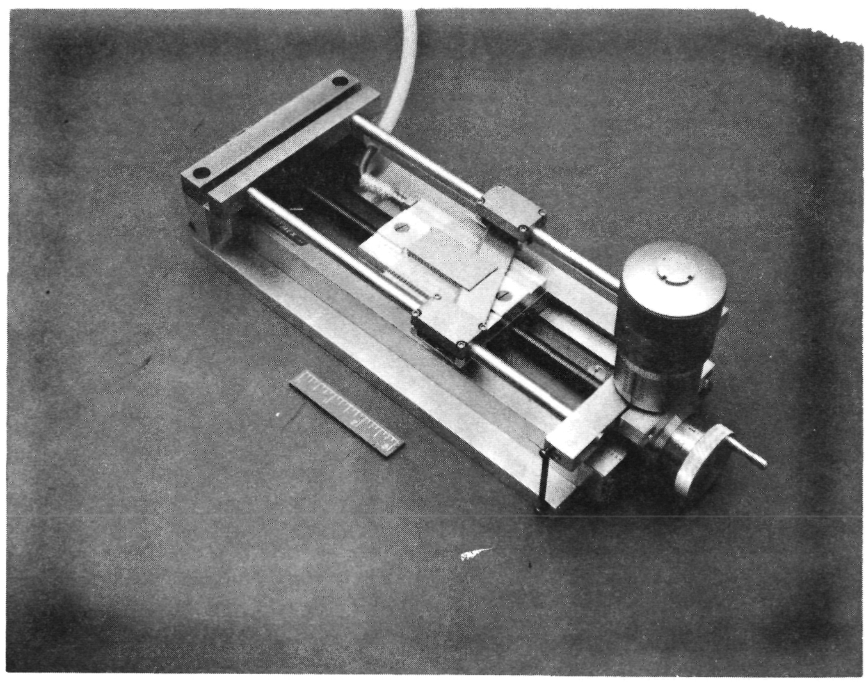


Figure 11. Delidding Tool With Partially Delidded Package

operation with an ordinary stereo microscope. The force exerted by the drive mechanism of the delidding tool is sufficient to delid adhesive sealed packages at room temperature. Photographs showing close-up views of the vacuum chuck and a partially delidded package are given in Figures 12 and 13.

Initially, a double beveled cutting edge blade (i.e., a blade beveled on both sides) was used in this tool. This blade worked satisfactory for delidding packages sealed with Ablefilm 552 but not for packages sealed with Ablefilm 507. It was determined that this was due to the fact that after initial penetration of the adhesive at the corner of the package, the bevel on the bottom side of the blade caused the height of the cutting edge of the blade to increase as it rode up on the rim of the package. This was not of consequence in the case of packages sealed with Ablefilm 552 because the seal apparently was weak enough that the flexing of the lid exerted adequate force to break the adhesive bond all the way across the package. However, in the case of packages sealed with Ablefilm 507, this was not so. The seal was strong enough that the adhesive bond had to be cut, and as the height of the edge of the blade increased as it rode up on the rim of the package, the blade cut into the package lid instead of the adhesive.

This problem was solved by using a single beveled cutting edge blade (i.e., a blade that is beveled only on one side and flat on the other) with the beveled side up so that the blade does not ride up on the rim of the package. Fortunately, these blades were manufactured by the same vendor from whom the double beveled blades were obtained and were available in the same length.

This tool has reduced the delidding of adhesive sealed packages to a simple process. However, it is incapable of removing the cured adhesive that remains on the rims of the packages. Consideration shows that this should be expected. Design of a good delidding tool requires that the cutting edge of the blade must be essentially

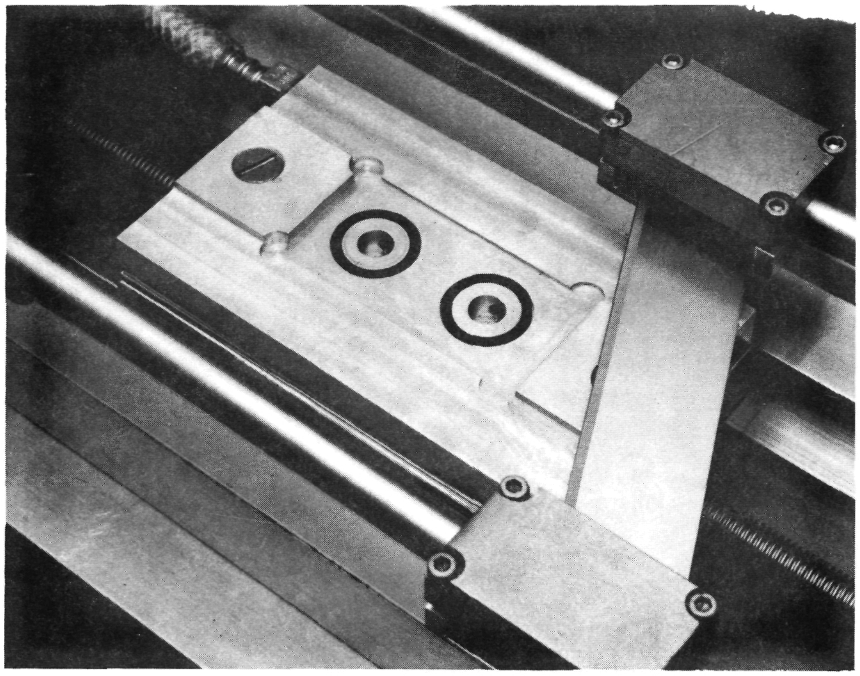


Figure 12. Close-Up View of Vacuum Chuck In Which Package Is Held During Delidding

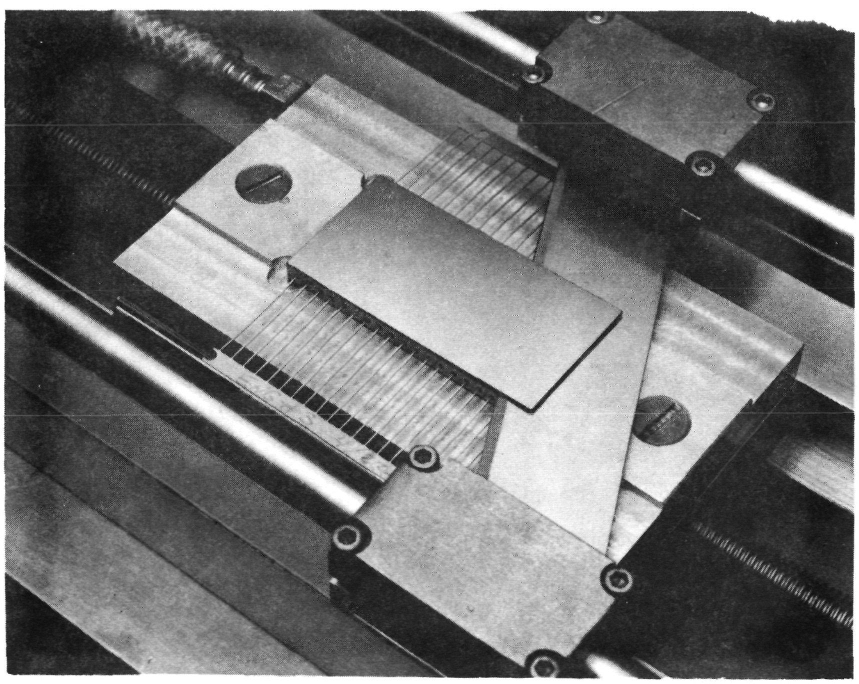


Figure 13. Close-Up View of Partially Delidded Package

parallel with the bonded surfaces (i.e., the contact angle with the package lid and rim surfaces must be essentially zero). Under this circumstance, particularly since both sides of the blade are honed, the cutting edge of the blade cannot directly contact either package surface (the lid or the rim) and consequently tries to split the adhesive. While this occurs in some cases, in general, in the case of a film adhesive, the tendency is for the adhesive to tear loose from the surface to which it is more weakly bonded in any particular area. Thus, in general, when a package is delidded, it should be expected that some of the adhesive will remain on the lid and some will remain on the package rim.

2.1.1.4.3 Removal of Cured Adhesive from Package Rims

An attempt was made to make a tool capable of removing the cured adhesive from the package rims. This tool has a rigidly supported blade and was designed to provide a fairly large, adjustable contact angle between the blade and the package rim. Since the cutting edge of the blade is honed on both sides (blades honed only on one side are not available), the contact angle of the blade must be adjusted so that the honed surface on the trailing edge of the blade is just parallel with the package rim. The optimum contact angle for removing the adhesive also appears to exist when this condition is just met. In this position, the blade just skims the package rim and removes the adhesive without cutting into the rim.

This tool was designed to be used with the delidding tool. As shown in Figure 14, the delidding blade is removed and this tool is attached in its place. A close-up view of this tool removing Ablefilm 552 from the rim of a package is shown in Figure 15.

This tool was very successful in removing Ablefilm 552 from package rims but was in general incapable of removing Ablefilm 507 because of its much greater adhesion.

The method finally selected for removing cured Ablefilm 507

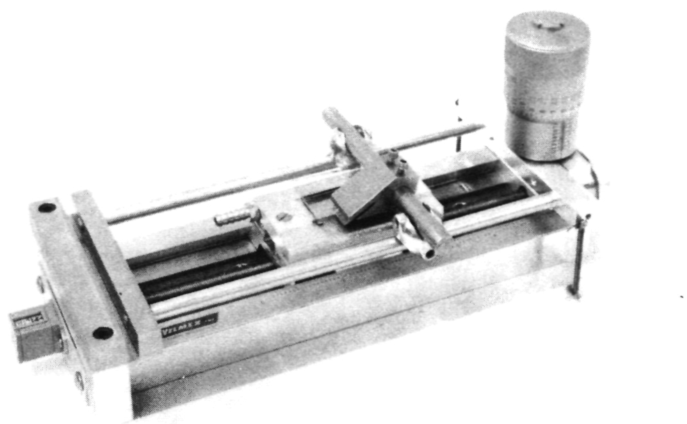


Figure 14. Delidding Tool With Adhesive-Removal-
Knife Attachment

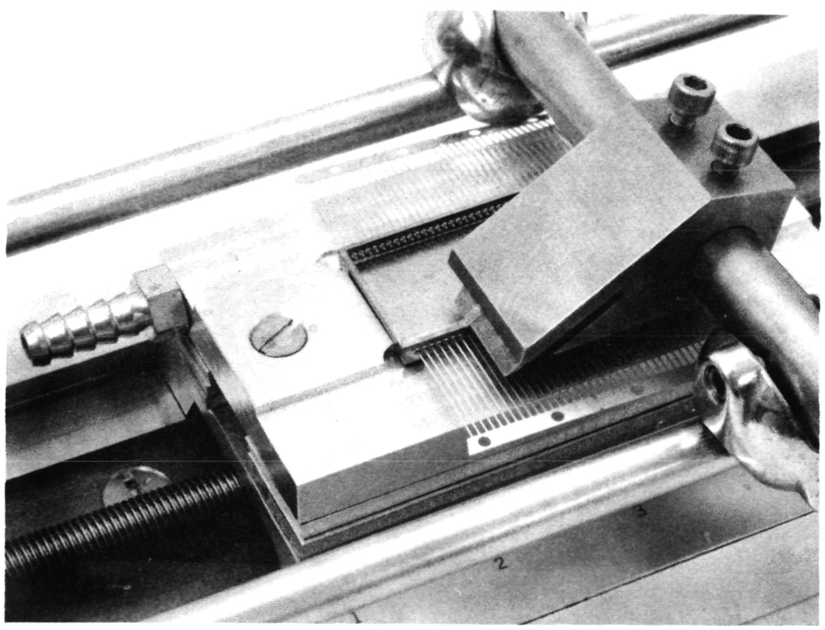


Figure 15. Close-Up View Of Adhesive-Removal-
Knife Attachment Removing Cured Adhesive
From Package Rim

from the package rims was to lightly sand them using a very fine grit (400 or 600) paper or crocus cloth. Due to the hardness of the nickel plating, if the sanding is done carefully, only the cured adhesive is removed.

2.1.2 Fabrication/Assembly and Testing of FASCOS Hybrids

2.1.2.1 FASCOS Hybrid Fabrication/Assembly

A revised version of the FASCOS assembly specification (VL 70033) was written to reflect changes pertinent to the present study. This specification (VL 70044) calls out the use of nickel-plated Kovar package cases and lids and adhesive sealing, and permits delidding. Also, the MO's (Manufacturing Orders) for the four different circuit types detailing the manufacturing processing and screen testing steps were revised to include the required changes in the production procedures. In conjunction with this and in order to avoid possible confusion with the production FASCOS circuits, new dash numbers were assigned to the circuits to be produced for this study. The part numbers assigned were as follows:

Bite Control - Part No. 10090-516-21
Analog Bite - Part No. 10091-516-21
Signal Conditioner #1 - Part No. 10092-516-21
Signal Conditioner #2 - Part No. 10093-516-21

Layouts for these hybrids are given in Figures 16 through 19 and the parts list is given in Table 3.

Thirty-two hybrids (8 of each of the 4 different types) were fabricated/assembled, tested, and reworked as required. Prior to sealing, the hybrids were functionally tested and visually inspected. After sealing, the hybrids were screen tested and functionally tested. A record of all operations performed including delidding and rework was kept on individual record cards (travelers).

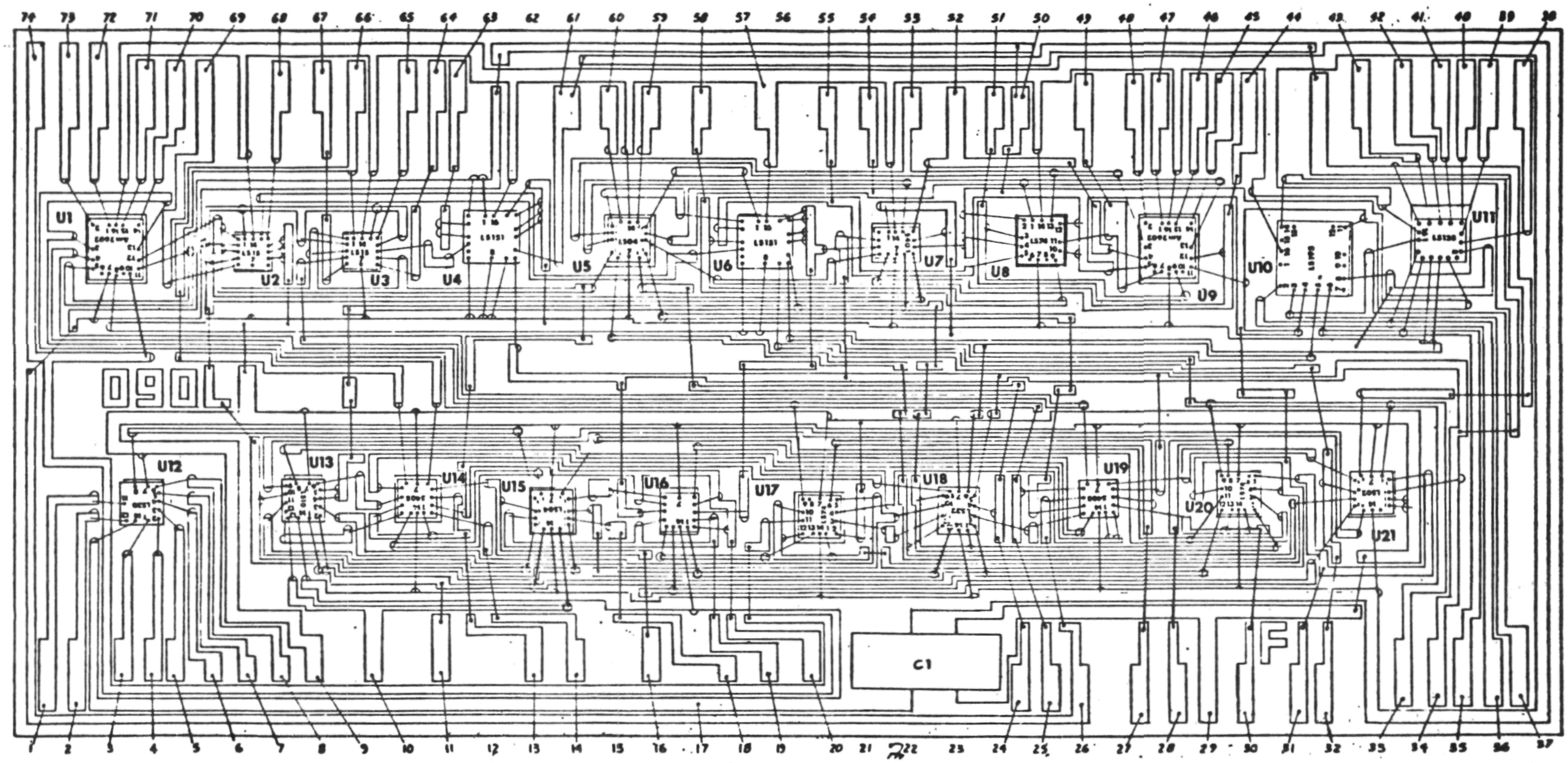


Figure 16. Bite Control, Part No. 10090-516-21

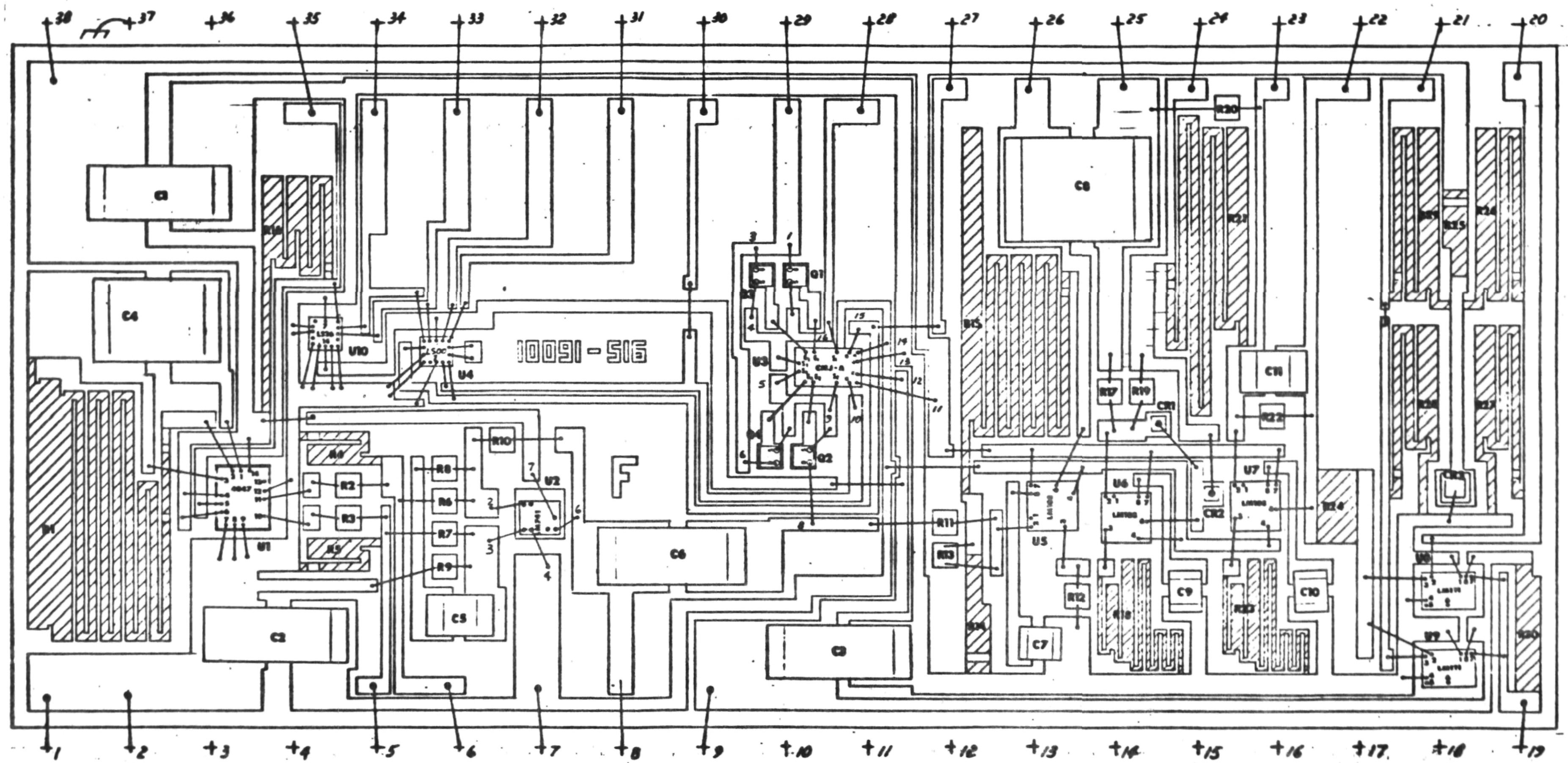


Figure 17. Analog Bite, Part No. 10091-516-21

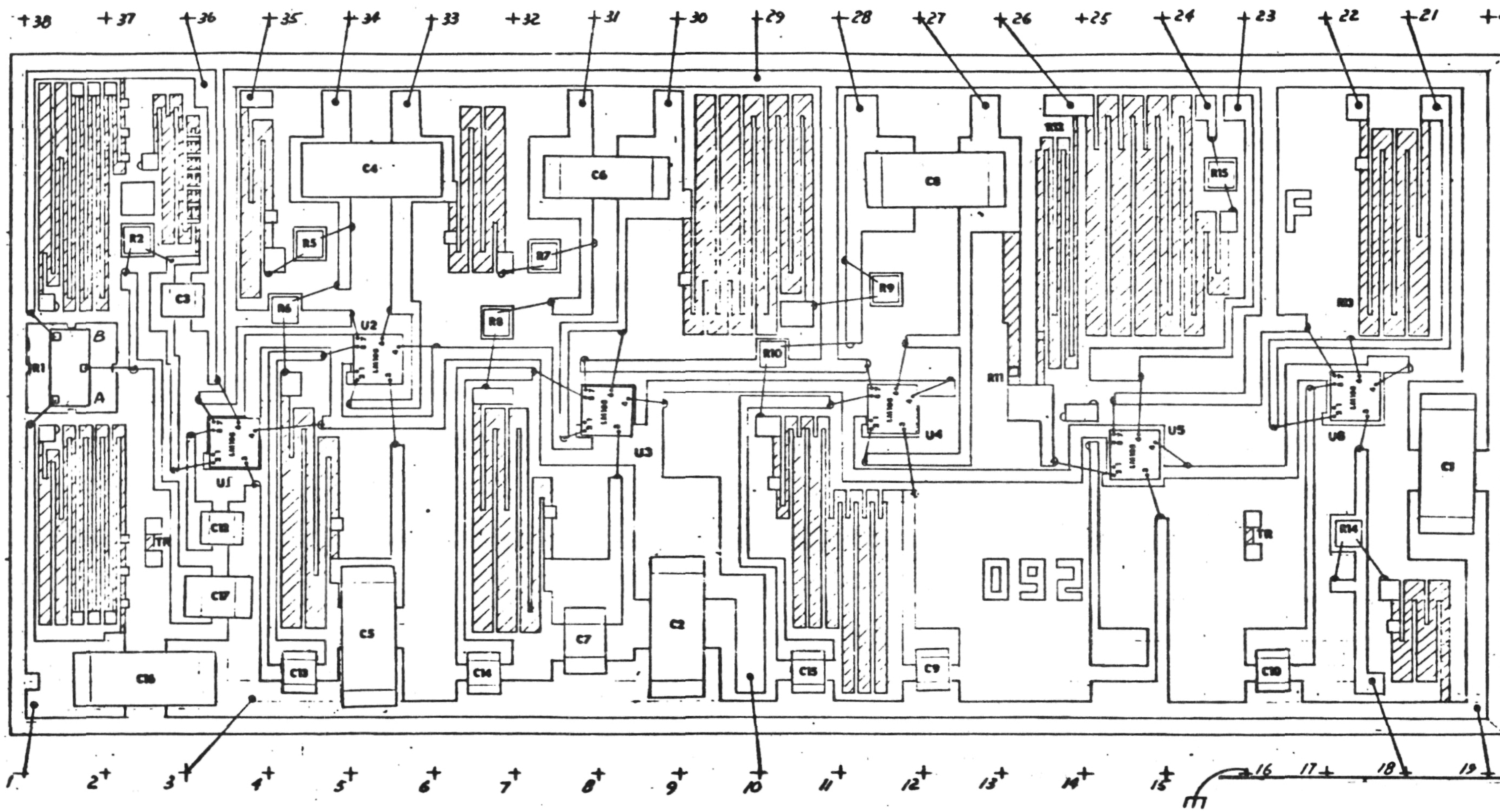


Figure 18. Signal Conditioner #1, Part No. 10092-516-21

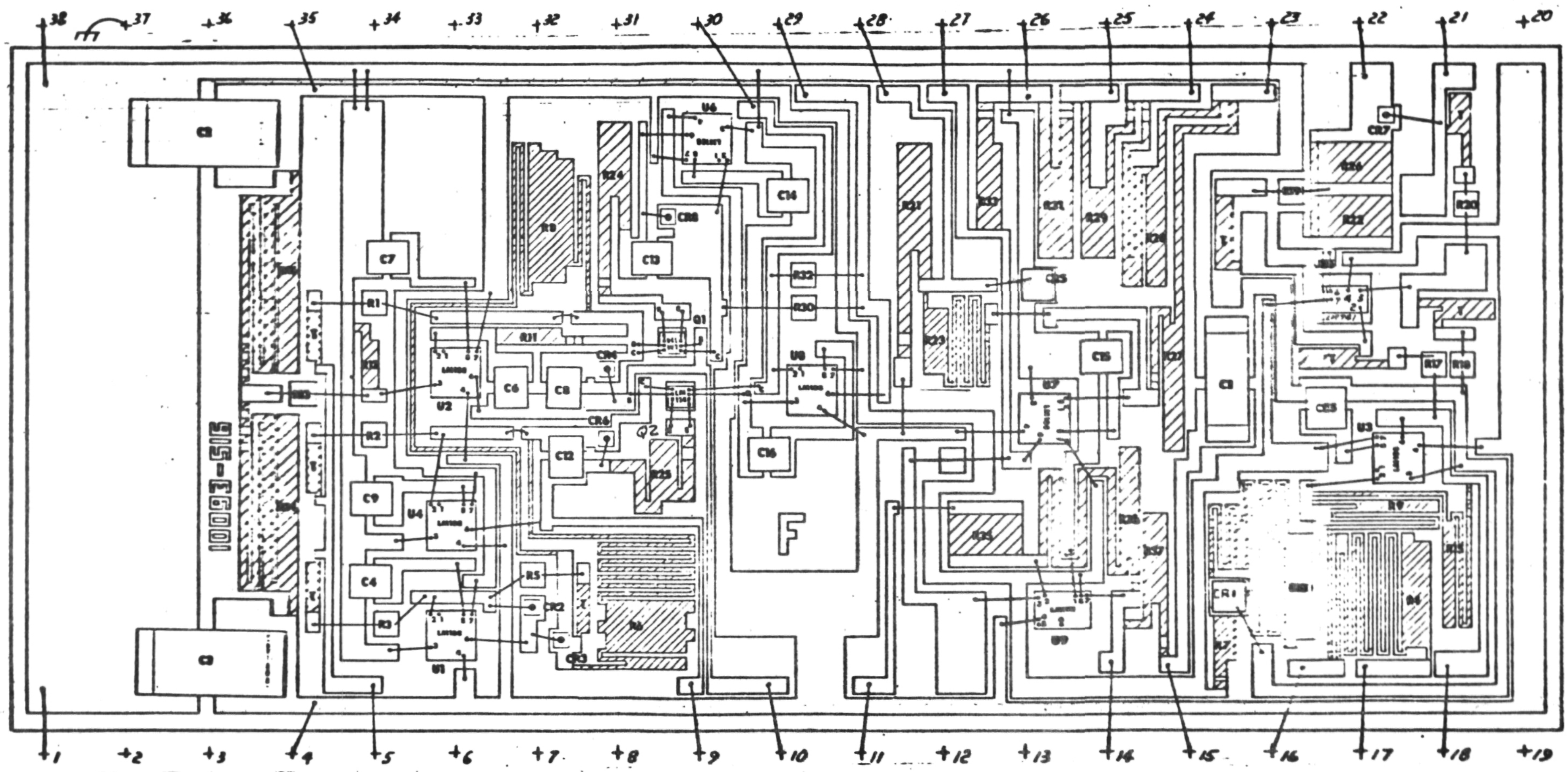


Figure 19. Signal Conditioner #2, Part No. 10093-516-21

TABLE 3. PARTS LIST FOR FASCOS HYBRIDS

Part Number	Hybrid Part Number				No. Reqd Per Hybrid Set	Total Reqd. (8 sets)
	10090	10091	10092	10093		
S1620A-15	1	1	1	1	4	32
IP1620A-2	1				1	8
10090-516-3	1				1	8
5404	1				1	8
5408	1				1	8
54LS15	2				2	16
54LS193	1				1	8
54LS10	1				1	8
54LS02	1				1	8
54LS04	2				2	16
54LS08	1				1	8
54LS11	1				1	8
54LS74	3				3	24
54LS138	1				1	8
54LS151	2				2	16
54LS30	1				1	8
54LS32	1				1	8
AM9602	2				2	16
1706X104K1P	1	3	2	2	8	64
IP1620A-1		1	1	1	3	24
10091-516-3		1			1	8
54LS00		1			1	8
1209C0G103F2P		1			1	8
0805X153K1P		1			1	8
1706C0G332F2P		1	2		3	24
0504C0G101K3P		3	5	8	16	128
250S43W474KP		1			1	8
0505X333K1P		1			1	8
1N4148		2			2	16
1N827		1		2	3	24
CD4047A		1			1	8
LM741		1		1	2	16

TABLE 3. PARTS LIST FOR FASCOS HYBRIDS (continued)

Part Number	Hybrid Part Number				No. Reqd. Per Hybrid Set	Total Reqd. (8 Sets)
	10090	10091	10092	10093		
DG185		1			1	8
LM108		3	6	7	16	128
LM111		2		1	3	24
54LS26		1			1	8
UHR-01E-500-2N		10		4	14	112
UHR-01E-162-3N		1	1		2	16
SFR-01-1004		3			3	24
10092-516-3			1		1	8
0504COG120F3P			1		1	8
1706COG272F2P			1		1	8
0805COG152F2P			1		1	8
1706COG392F2P			1		1	8
0504COG221F3P (500R15N221FP) Sub.			1		1	8
1505COG202F1P			1		1	8
UHR-01E-300-3N			1		1	8
UHR-01E-820-2N			1		1	8
UHR-01E-100-3N			2	7	9	72
UHR-01E-560-2N			1		1	8
UHR-01E-390-2N			2		2	16
SFR-01-3903			1		1	8
NET-0538			1		1	8
10093-516-3				1	1	8
1505X823K1P				1	1	8
0504COG300K3P				1	1	8
101R15N471JPS				1	1	8
1N914				5	5	40
MZC5.1B10				1	1	8
LM114				2	2	16
UHR-1S-100-2N				2	2	16
0504C101F3P				1	1	8

2.1.2.2 Screen and Final Functional Testing

During the course of this study, all hybrids including those reworked were subjected to the following tests:

a. Stabilization Bake (24 hours at 150°C)

b. Temperature Cycling (10 cycles, -55°C to +125°C)

c. Constant Acceleration (5000 gs, Y_1 axis)

d. PIND Test

e. Burn-In (160 hours at 125°C)

f. Final Functional Test

These tests were performed in accordance with the Manufacturing Orders (MO's) for the four different circuit types. During testing, one hybrid failed the PIND test (one 10093) and six failed final functional (one 10090, one 10091, three 10092's, and one 10093).

2.1.2.3 Adhesive Sealing and Seal Testing

The 32 FASCOS hybrids were baked-out and sealed with Ablefilm 507 in accordance with the procedures described in Section 2.1.1.3.3.2. These hybrids were then gross leak tested by immersing them for 30 seconds in FC-40 maintained at 125 $\pm$ 5^{0}C and checking for streams of bubbles as specified in Operation Number 47 of the MO's (Manufacturing Orders). All 32 hybrids passed this test (i.e., none of the hybrids were gross leakers).

At this point, it was decided to perform a complete seal test (both fine and gross leak tests) before proceeding to the other screen tests. Testing was performed in accordance with Operation Number 72 of the MO's. The hybrids were bombed in helium for 6 hours at 15 psig and then fine and gross leak tested. Nine hybrids failed the fine leak test (i.e., were found to have leak rates greater than 3 x 10^{-6} atm cc/sec air equivalent), and these and 5 others failed the gross leak test. Thus, a total of 14 of the 32 FASCOS hybrids failed the seal test. This result was certainly unexpected since 14 empty nickel-plated Kovar packages had previously been adhesive-sealed and all passed both the fine and gross leak tests (see sections 2.1.1.1.3 and 2.1.1.3.3.3). Six of these (those of Section 2.1.1.1.3) were even bombed at a higher pressure—30 psig.

It was suspected that the explanation for the difference in these results was the difference in the cleaning methods used in the two cases. The empty packages had been sprayed with acetone, isopropyl alcohol, and Freon TF, and then cleaned with Freon TF in the Branson cleaning console with ultrasonic agitation. The FASCOS hybrids (cases containing circuits) were simply cleaned with Freon TF in the Branson cleaning console without ultrasonic agitation, and the lids were cleaned with deionized water and with Freon TF in the Branson cleaning console with ultrasonic agitation. Since acetone is a very polar solvent, it removes contaminants such as greases that may get on the package rims by inadvertently touching them with the fingers during fabrication/assembly and/or pre-seal functional testing and visual inspection.

When the 14 hybrids that failed the seal test were delidded, almost all of the adhesive remained on the lids in all cases. This was also the case for the hybrid that failed the PIND test. However, for the hybrid that failed final functional, the adhesive was distributed about 50/50 between the lid and package rim. This supported the speculation that the seal test failures were due to the fact that the package rims were inadvertently contaminated and that the packages were not cleaned adequately prior to sealing.

As a result, the following improved cleaning procedure was selected and used for the 16 hybrids that had to be resealed:

a) Lids

1. Cleaned in deionized water with ultrasonic agitation
2. Rinsed in acetone

3. Rinsed in isopropyl alcohol
4. Cleaned in Freon TF in the Branson cleaning console with ultrasonic agitation.

b) Packages
1. Rims wiped with cotton swab dipped in acetone
2. Rims wiped with cotton swab dipped in isopropyl alcohol
3. Cleaned in Freon TF in the Branson cleaning console without ultrasonic agitation.

After sealing, these packages were bombed in helium for 6 hours at 15 psig and fine and gross leak tested. All 16 packages passed both the fine and gross leak tests. Measured fine leak rates ranged from 1.1×10^{-8} to 1.7×10^{-7} atm cc/sec air equivalent, which is well below the 3×10^{-6} atm cc/sec air equivalent requirement specified. The 100% sealing yield obtained was very encouraging and indicated that the new cleaning procedure had solved the sealing problem.

However, after all hybrids were completed, two sets of hybrids (8 hybrids—2 each of the 4 different types) selected for assembly on the multiwire boards were final seal tested (i.e., both fine and gross leak tested) as required prior to final acceptance. Five of these 8 hybrids failed. Four failed the fine leak test (could not be pumped down), and three of these and one that passed the fine leak test, failed the gross leak test. Since these hybrids had passed the gross leak test after lead forming, and had simply been stored at room ambient prior to seal testing, it was concluded that the failures were caused by the stresses imposed during fine leak testing.

This result was unexpected and disappointing since these hybrids (and all other hybrids) had passed both fine and gross leak tests immediately after sealing. Since it is felt that the hybrids are being cleaned and sealed as well as they can be, it must be concluded that adhesive sealed packages of this size (1 x 2 inches) cannot withstand the stresses imposed during the fine leak test, even at a bombing pressure of only 15 psig.

A review of the fine leak test procedure shows that the stresses exerted on the adhesive seal are substantial even for this condition (bombing at 15 psig). Initially, the hybrids are placed in a chamber that is rapidly pressurized with helium to 15 psig and then vented to the atmosphere several times (at least three) to fill it with essentially pure helium at 30 psia (15 psig). This causes relatively rapid flexing of the package lids and exerts peel-tensile stresses alternately on the outer and inner edges of the adhesive seal. The hybrids are then maintained at this condition (i.e., pressurized at 15 psig helium) for 6 hours. This causes a sustained peel-tensile stress on the outer edge of the adhesive seal and forces helium into the hybrid package. The chamber is then vented to atmospheric pressure, and the hybrids are removed and their leak rates measured. This consists of placing the hybrid packages in a chamber and evacuating it. This causes a peel-tensile stress on the inner edge of the adhesive seal proportional to the internal pressure of the hybrid package. The internal pressure is atmospheric pressure plus a delta due to the helium forced into the package during the 6 hour bombing period.

Apparently, in many cases, one or another of these stresses or the combination of all of them is adequate to weaken and finally destroy the integrity of the adhesive seals of the relatively large 1 x 2 inch packages being used in this study.

As a result of this fact and since adhesive sealed packages are not hermetic in any case, it is recommended that the fine leak test requirement be eliminated for adhesive sealed packages of this size and require only that they pass the gross leak test. This requirement is adequate to ensure that the hybrids are protected from liquid and particulate contaminants.

2.1.2.4 Summary of Test Failures and Rework Performed

The failures that occurred during production of the 32 adhesive-sealed FASCOS hybrids are shown in Table 4.

Table 4. Summary of Test Failures for Adhesive-Sealed Hybrids

Hybrids Manufactured	Initial Seal Test	PIND Test	Final Functional Test	Final Seal Test	Final Functional Test (After Rework)
10090-516-21-01E	F				
-02E*	F			F	F
-03E	F				
-04E	F				
-05E				F	
-06E	F				
-07E	F				
-08E	F				
10091-516-21-01E				F	
-02E*	F		F		F (Repeat)
-03E				F	
-04E					
-05E				F	
-06E*	F			F	
-07E					
-08E					
10092-516-21-01E*	F		F		
-02E	F				
-03E	F				
-04E					
-05E					
-06E					
-07E			F		
-08E*	F			F	F
10093-516-21-01E*	F		F		
-02E*		F		F	
-03E					
-04E					
-05E					
-06E				F	
-07E				F	
-08E					

*Indicates those hybrids that had to be reprocessed (reworked) twice.

As discussed in the previous section (Section 2.1.2.3), all 32 hybrids initially passed the gross leak test as required, but 14 (those listed in Column 2 of Table 4) subsequently failed after being bombed in helium for 6 hours at 15 psig. These hybrids were reprocessed (i.e., delidded, cleaned, visually inspected, and relidded) and reseal tested. All passed.

All 32 hybrids were then screen, final functional, and final seal tested. One failed the PIND test, four failed the final functional test, and ten failed the final seal test as shown in Columns 3, 4, and 5 respectively of Table 4. These hybrids were delidded, reworked as required, relidded, and retested. As shown in Column 6 of Table 4, three failed final functional. All passed the final seal test (gross leak test only).

A review of Table 4 shows that 22 of the 32 hybrids had to be reworked, and that 7 of them had to be reworked twice (those indicated by an asterisk). Of these required reworks, all but 5 (1 PIND test failure and 4 final functional test failures) were due to failure of the adhesive seals as discussed in Section 2.1.2.3. The 3 hybrids that failed the final functional test after being reworked (listed in Column 6 of Table 4) were not reworked again, so only 29 of the 32 FASCOS hybrids produced were functionally good.

2.1.3 Fabrication and Testing of FASCOS Modules

2.1.3.1 Brief Description of Multiwire Technology*

Basically the Multiwire process consists of writing the circuit on a dielectric substrate with insulated magnet wire. The writing is done precisely with a numerically-controlled machine. A typical Multiwire machine with computer numerical control units is shown in Figure 20 and a closeup view of a Multiwire machine head writing a circuit by laying down insulated wire on an adhesive coated substrate is shown in Figure 21. The wire used is NEMA No. 34 AWG Class 220 Polyimide Heavy Coated magnet wire (i.e., copper wire approximately 7 mils in diameter with 0.6 mil thick polyimide insulation). This wire is electrically equivalent to a 12-mil wide line of 2-ounce copper or a 24-mil wide line of 1-ounce copper. Since the wire is insulated, direct crossovers can be made without fear of shorting. A magnified view of a cross section of a typical wire crossover is shown in Figure 22. The essentially 1-mil polyimide insulation separating the wires has a minimum breakdown voltage in excess of 2000 volts. Although only single crossovers are all that are required on typical multiwire boards, the number of crossovers allowed is essentially unlimited.

The six steps involved in producing multiwire boards are shown in Figure 23 and are as follows:

Step 1. Using standard printed circuit techniques, etch copper-clad epoxy glass laminate to form power and ground plane and contact fingers as desired.

Step 2. Apply partially cured layer of thermosetting adhesive to board. Do not cover contact fingers and card-guide areas.

Step 3. Place the board on the computer controlled Multiwire wiring machine and put down wire pattern. (Each wire begins and ends at a hole location and may intersect any number of hole locations making up the net.)

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*This information and the photographs were taken from the Multiwire Reference Guide issued by the Multiwire Division of Kollmorgan Corporation.

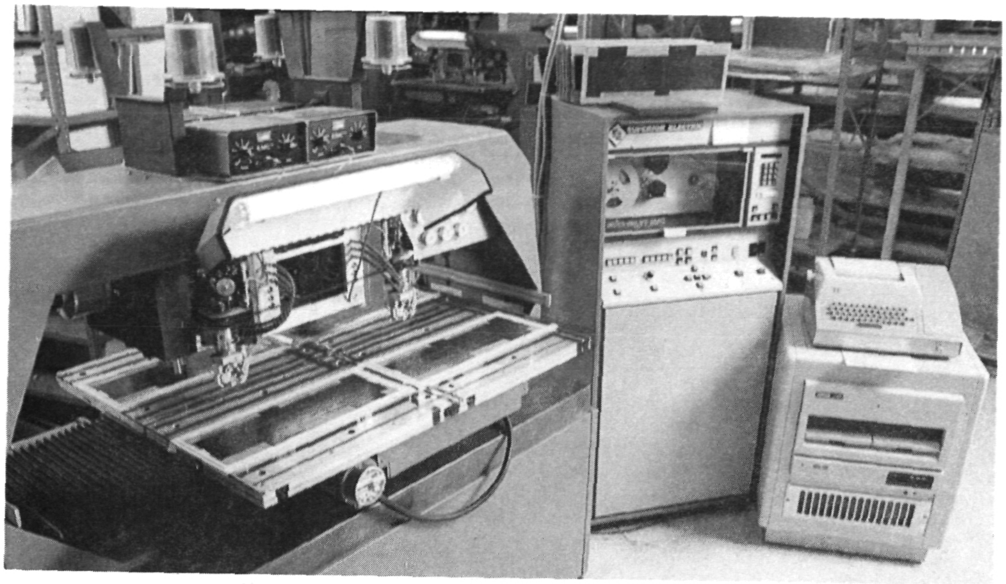


Figure 20. Typical Multiwire Machine with Computer Numerical Control Units

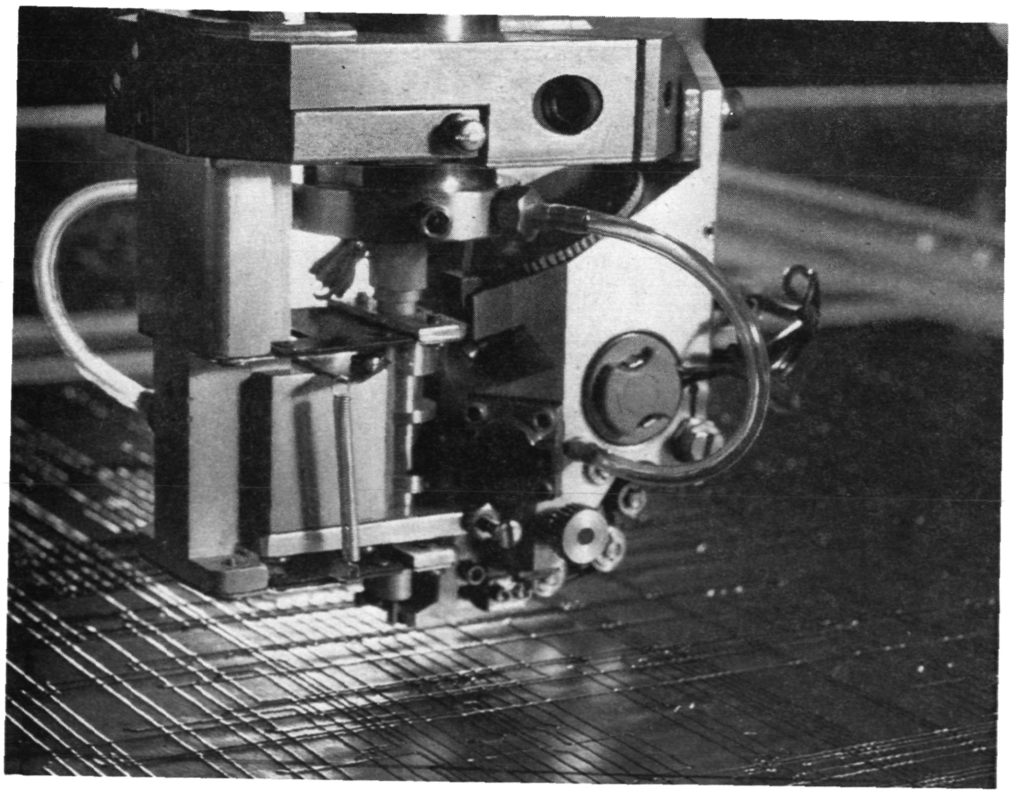


Figure 21. Close-Up View of Multiwire Machine Writing a Circuit

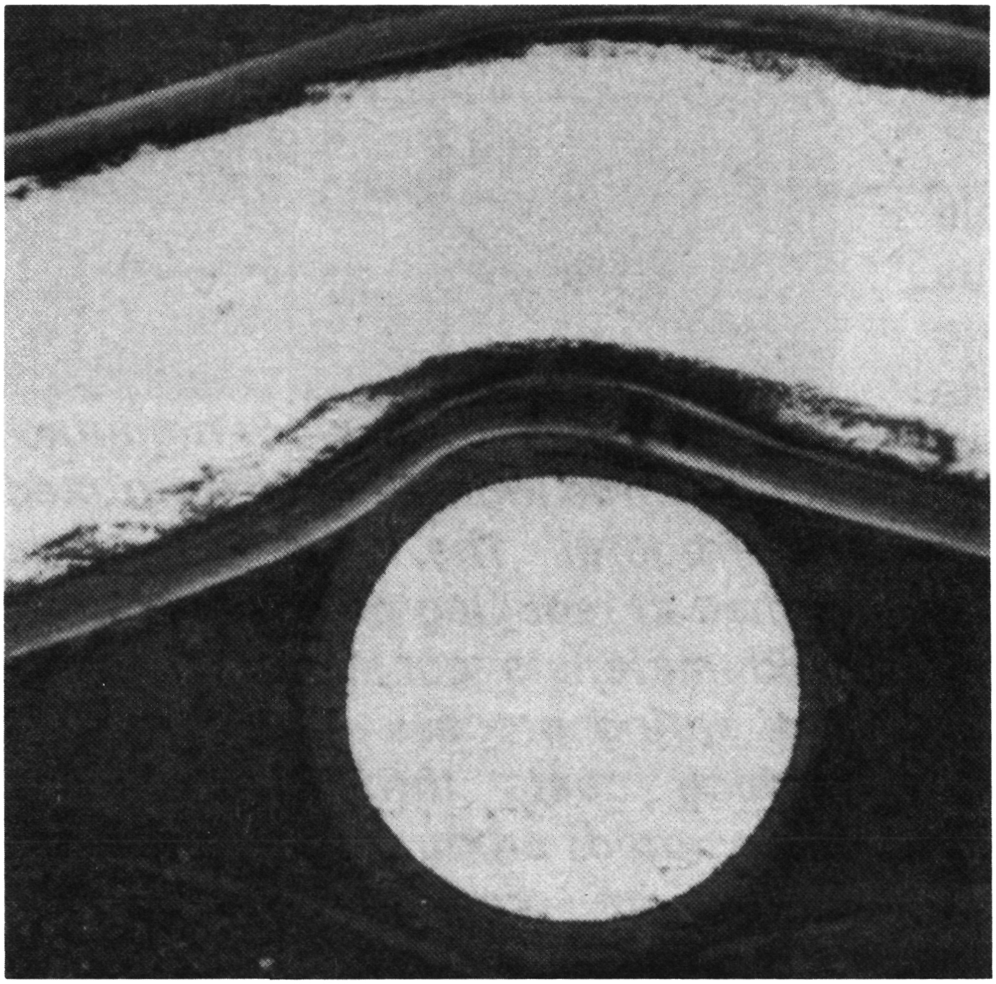
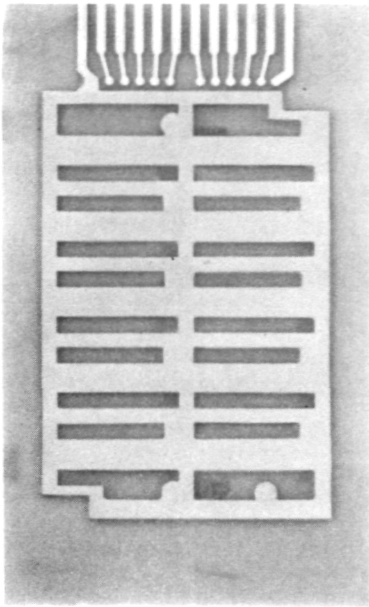
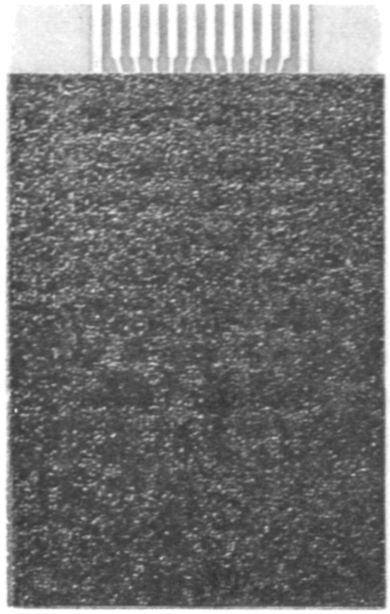


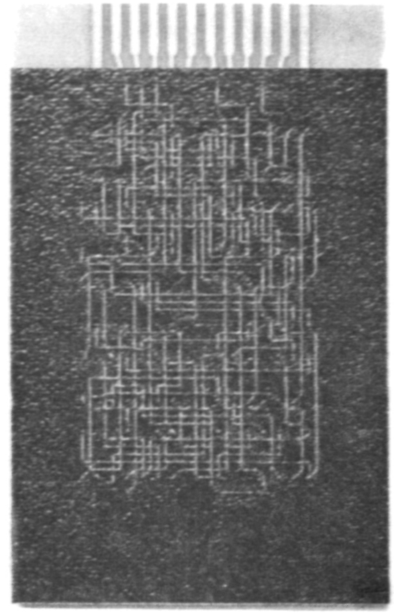
Figure 22. Magnified View of Cross Section of of Typical Wire Crossover



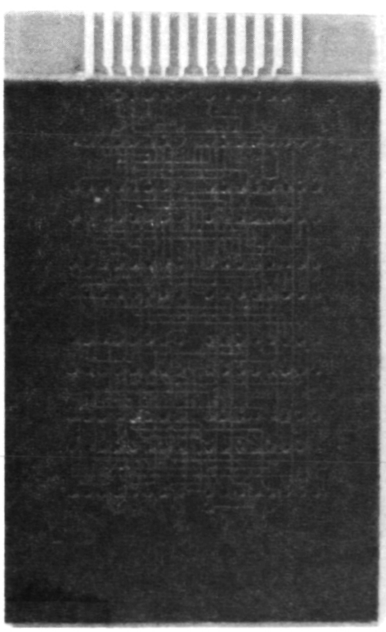
Step 1. Etch Board



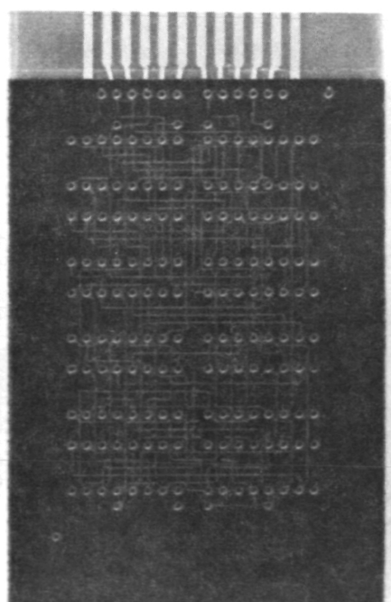
Step 2. Apply Adhesive



Step 3. Put Down Wire Pattern



Step 4. Encapsulate Wires, Drill Holes



Step 5. Deposit Copper in Holes

Step 6. Fabricate Board

Figure 23. Process for Producing Multiwire Boards

Step 4. Cover the board with a thin epoxy prepeg, press the wires into the adhesive, and cure the adhesive to encapsulate the circuit. Then drill the component holes on the computer controlled machine.

Step 5. Deposit copper in holes by electroless additive plating process. This process bonds each wire end to the wall of the hole.

Step 6. Fabricate board using routine printed circuit manufacturing methods.

The Multiwire boards are then tested for opens using a chemical discharge tester as shown in Figure 24. This test consists of placing a specially sensitized paper on the board and applying a voltage to the first hole in each wire net. If no opens exist, an image of the complete circuit will be reproduced on the paper. If an open exists in any wire net, an image of the portion of that wire net after the open will not be reproduced.

At the present time, there are three practical limitations associated with Multiwire board technology that impact the present application (i.e., replacing the present FASCOS multilayer board with a Multiwire board.) These are:

1) All components must be attached by inserting the leads in through holes. The adhesion of free standing conductor pads is insufficient for lead attachment.

2) Components can be mounted on only one side of the boards.

3) While smaller spacing is permissible, the manufacturer (Multiwire/West) recommends that holes be placed on 100-mil centers.

2.1.3.2 <u>Design and Fabrication of Multiwire Boards</u>

Since components are mounted on both sides of the present FASCOS multilayer board and can only be mounted on one side of a multiwire

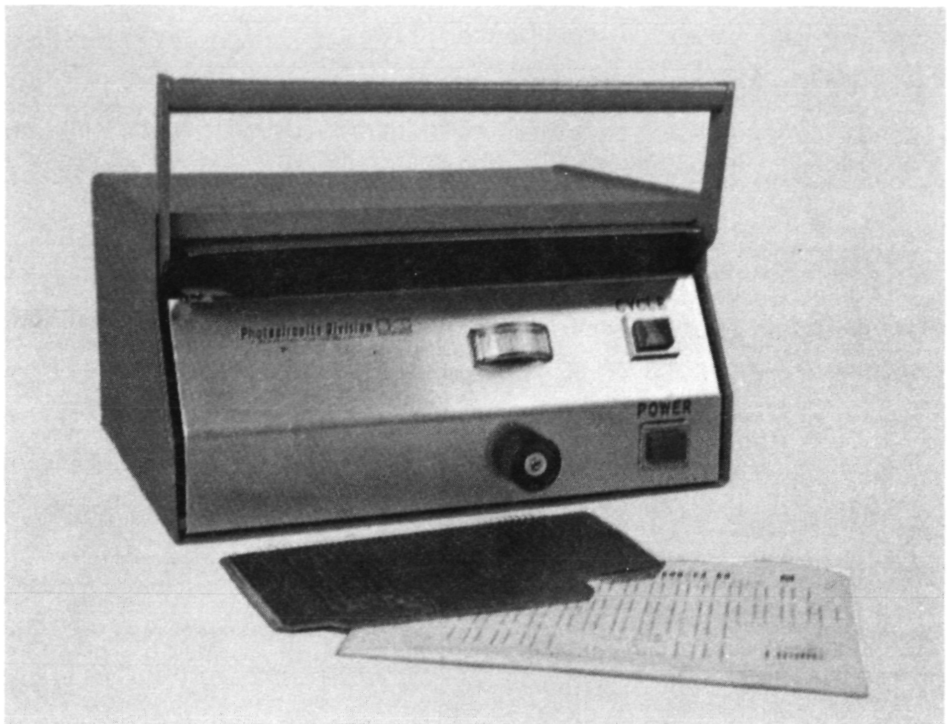


Figure 24. Chemical Discharge Tester

board, the present multilayer board constituting a FASCOS Module cannot simply be duplicated as a multiwire board. The present multilayer board contains eight hybrids (two each of the four different types) and the additional components required to comprise two control channels. The hybrids are symmetrically distributed between the two sides of the board (i.e., one hybrid of each of the four different types is mounted on each side of the board) but the additional components are not. Also, some interconnections between the hybrids are made through the multilayer board. Because of these facts, the multilayer board cannot simply be divided into two multiwire boards where one board duplicates one of its sides and the other board duplicates the other. Instead, the multilayer board had to be essentially completely redesigned. This involved relocating some components and rerouting some interconnections to divide the present multilayer board into two identical multiwire boards containing four hybrids (one each of the four different types) and the additional components required to comprise a single control channel.

The schematic for the multiwire boards is given in Figure 25. These boards are identical in size with the present multilayer board as required and two of them can be interconnected to provide the same function. The fabrication drawing showing the board dimensions is given in Figure 26 and the layout of the board showing the hole locations on the component side is given in Figure 27. Redesign of the board also required redesign of the power and ground plane as shown in Figure 28, and generation of a new list (X-Y interconnect data).

All necessary information for fabricating the multiwire boards [fabrication drawing, board layout, power and ground plane artwork (1X), net list (X-Y interconnect data), and hole coordinate drill tape] was delivered to Multiwire West.

A photograph of the finished FASCOS multiwire board as received from Multiwire West is shown in Figure 29.

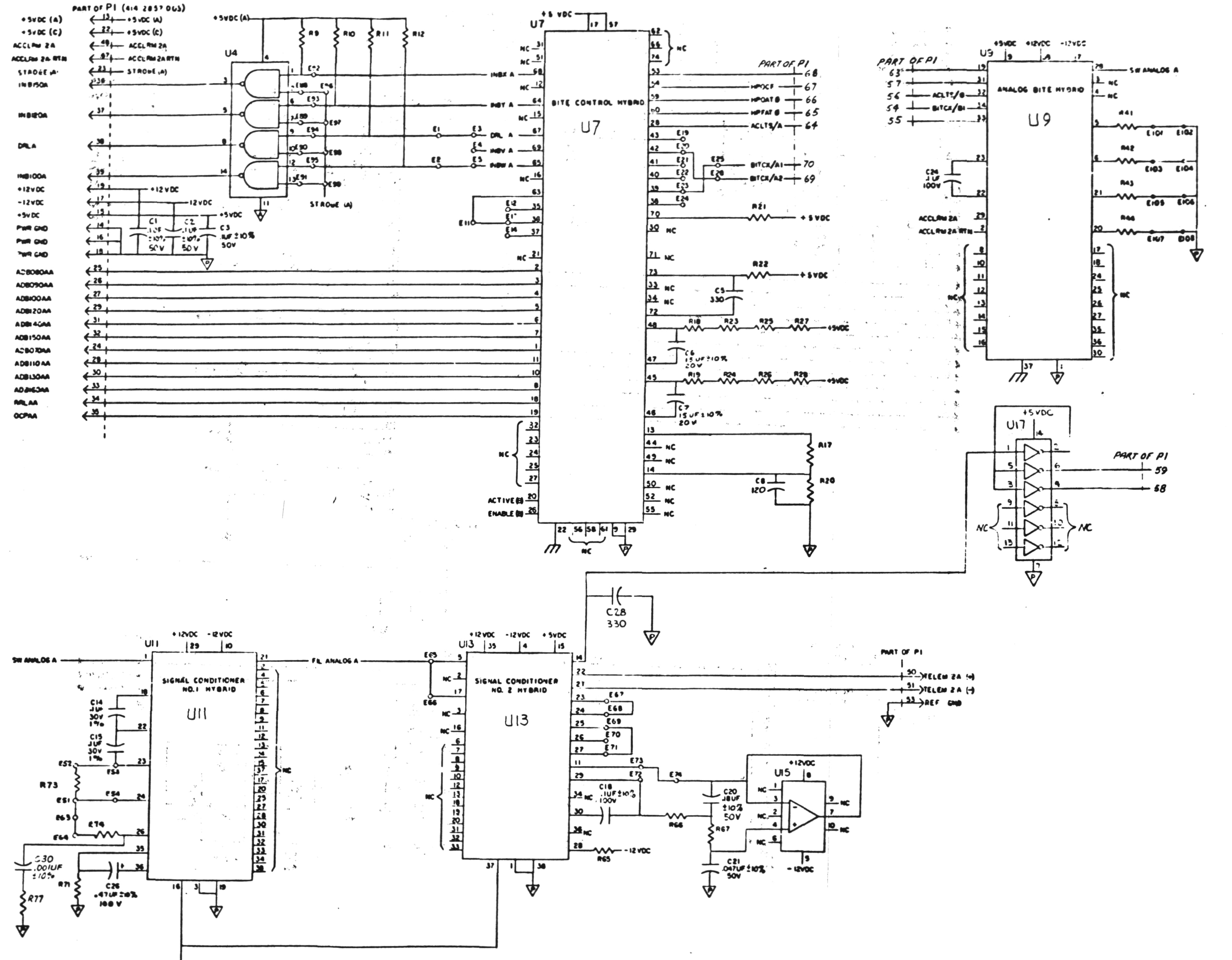


Figure 25. FASCOS Multiwire Board Schematic

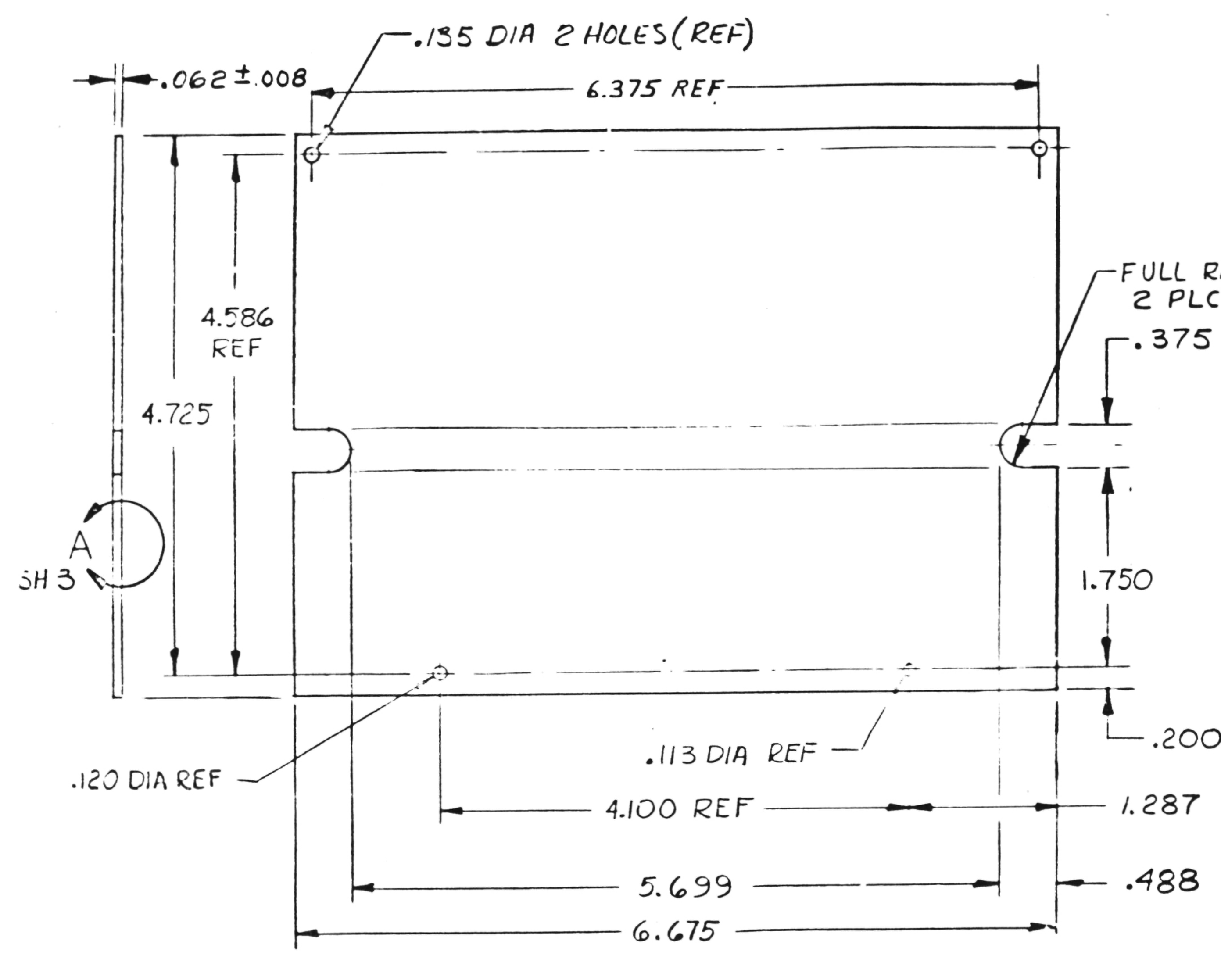


Figure 26. Fabrication Drawing of FASCOS Multiwire Board

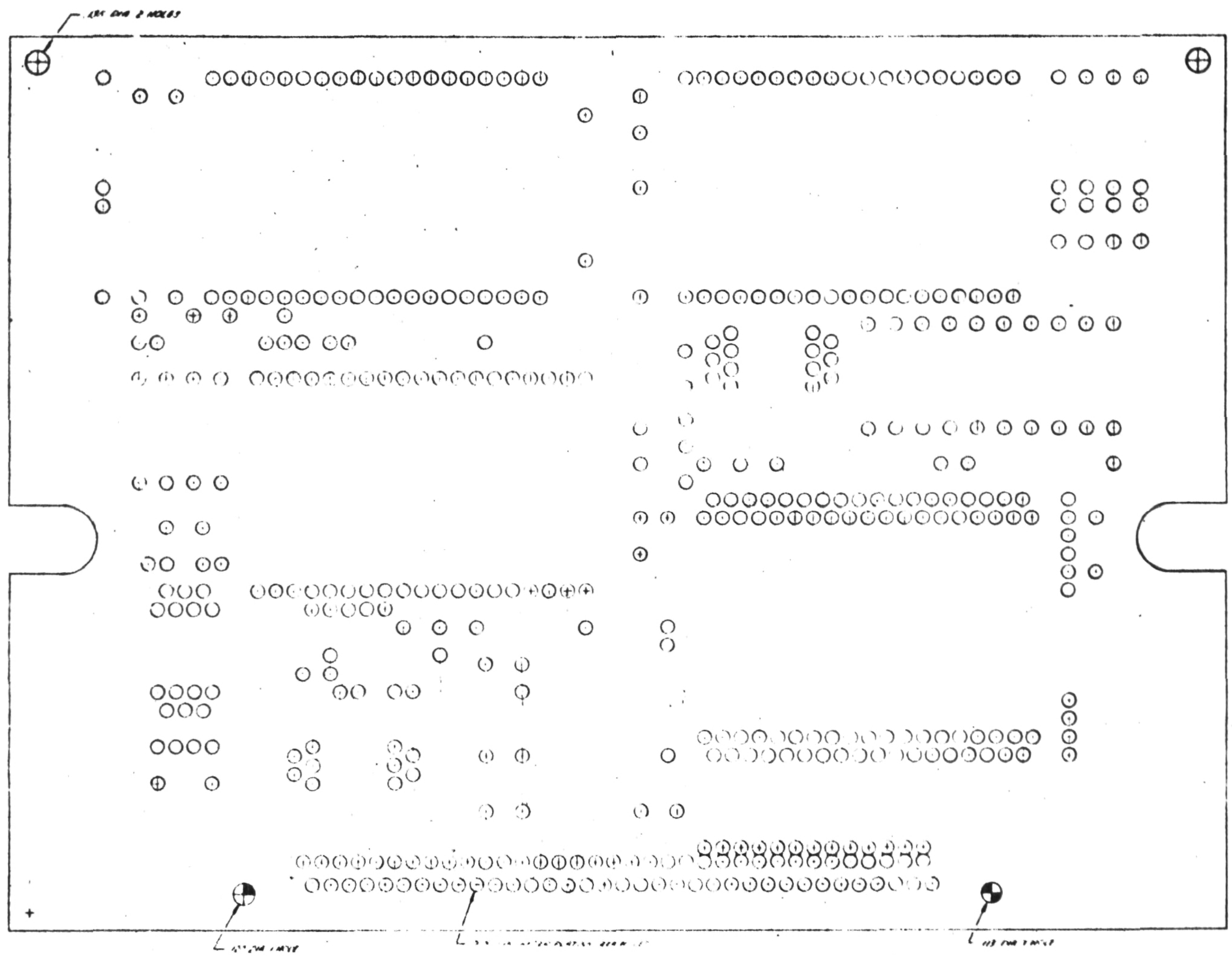


Figure 27. Layout of FASCOS Multiwire Board - Component Side

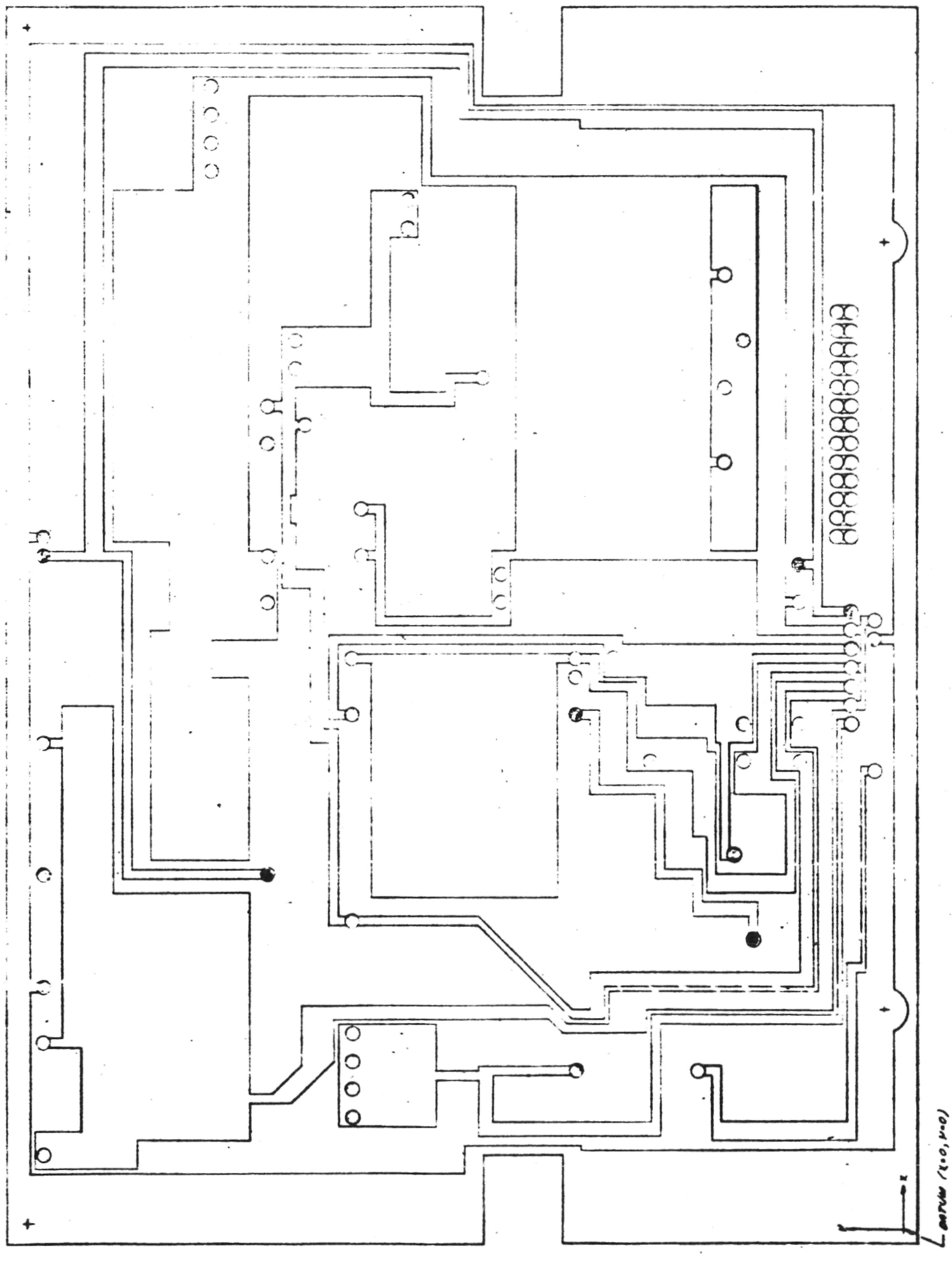
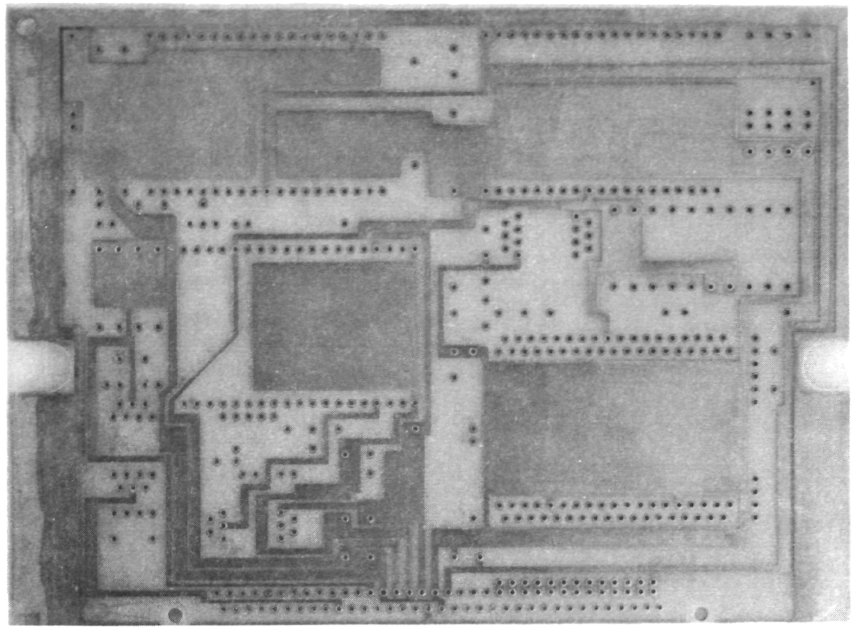
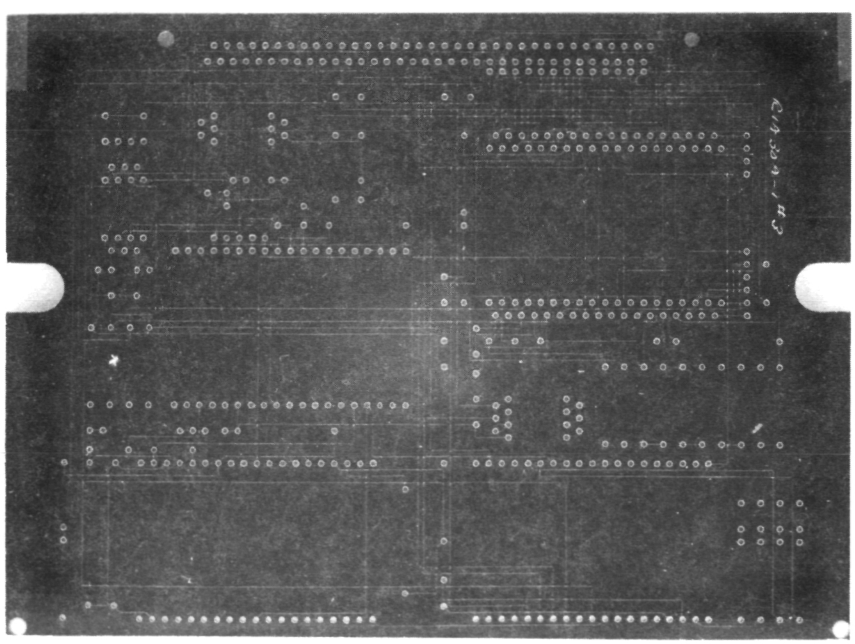


Figure 28. Layout of Power and Ground Plane for FASCOS Multiwire Board



a. Front - Component Side



b. Back - Wiring Side

Figure 29. FASCOS Multiwire Board

2.1.3.3 Design and Fabrication of Lead Forming Tool

A tool to form the leads of the FASCOS hybrid packages as required so that they can be inserted in the multiwire boards was designed and fabricated. An expanded view of this tool and a 74 lead FASCOS package is shown in Figure 30. This tool was designed for use with both the 38 lead and the 74 lead FASCOS packages.

The leads of the 38 lead packages are on 100 mil centers while those of the 74 lead packages are on 50 mil centers. The multiwire board was designed with holes on 100 mil centers as recommended by the manufacturer (Multiwire West). All that is required to form the leads of the 38 lead packages is that the packages be clamped in the fixture and the leads bent over as shown in Figure 31. For the 74 lead packages, the leads must be staggered to give two rows of leads on 100 mil centers. This is done as shown in Figure 32. First, the tool is used as for the 38 lead packages and every other lead is bent over as shown in Figure 32a. Then the side plates of the tool are added and the remaining leads are bent over as shown in Figure 32b.

2.1.3.4 Assembly and Testing of Multiwire Boards

Two multiwire boards were assembled and tested. Component placement is shown in the assembly aid given in Figure 33 and the components are identified in the parts list (Table 5). A photograph of one of the assembled multiwire boards is shown in Figure 34.

A special wiring harness was fabricated to interconnect the two multiwire boards so that they functionally duplicated a FASCOS multilayer board and could be tested in the FASCOS engineering system. A photograph of the two multiwire boards connected together by the wiring harness is shown in Figure 35, and a photograph of the boards being tested on the ADIT Console (Analog-Digital Tester) is shown in Figure 36.

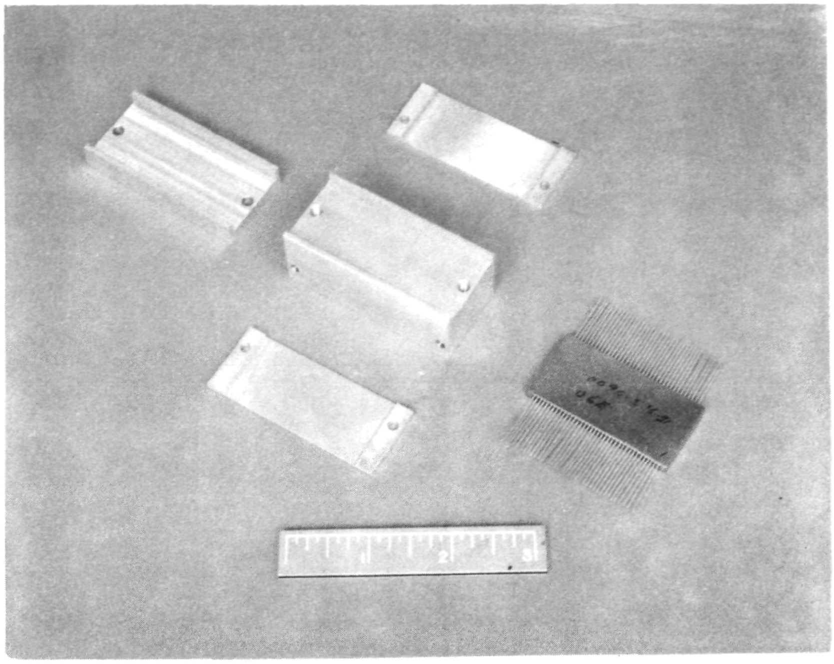


Figure 30. Expanded View of Lead Forming Tool

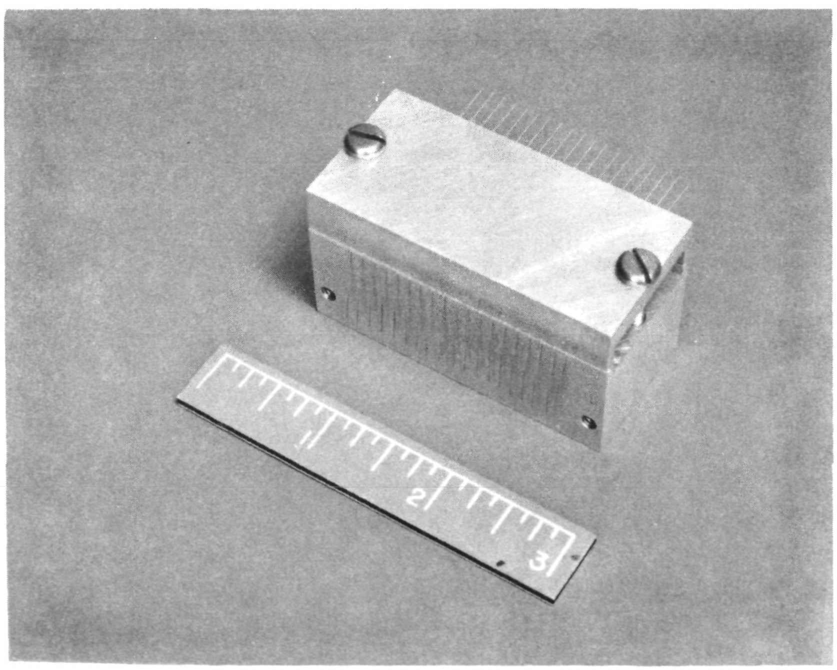
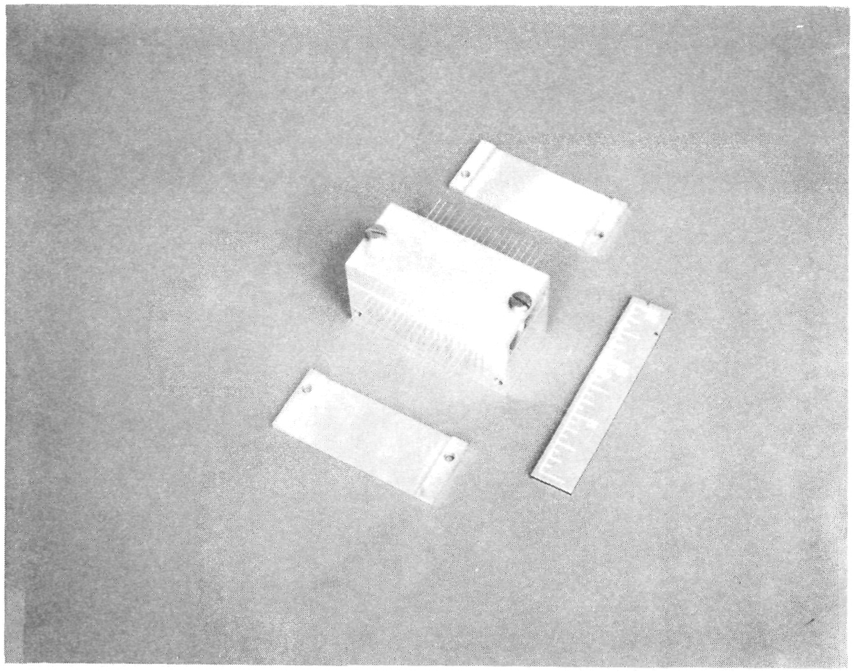
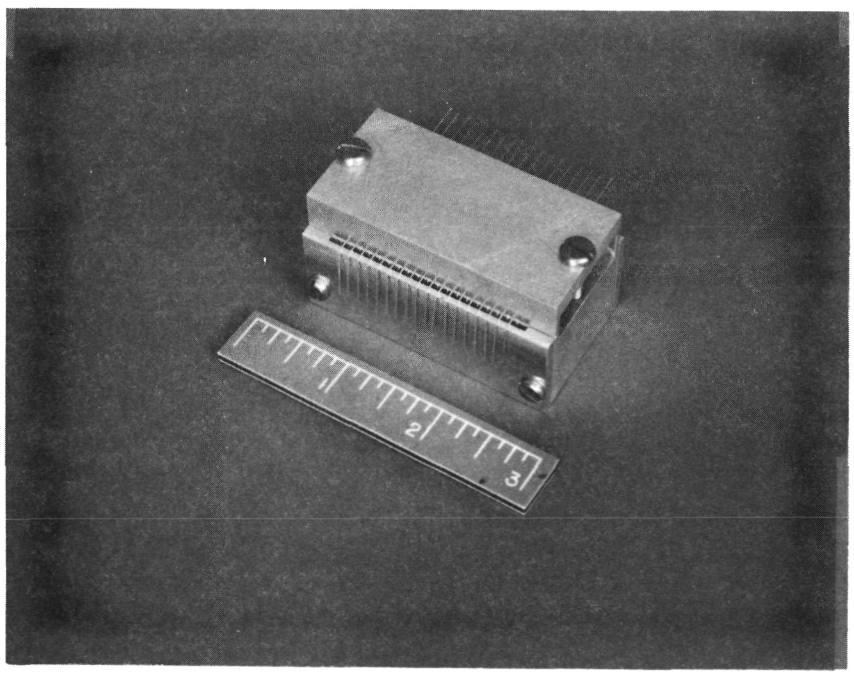


Figure 31. Lead Forming Tool with 38 Lead Package



a) Lead Forming First Row of Leads



b) Lead Forming Second Row of Leads

Figure 32. Lead Forming Tool with 74 Lead Package

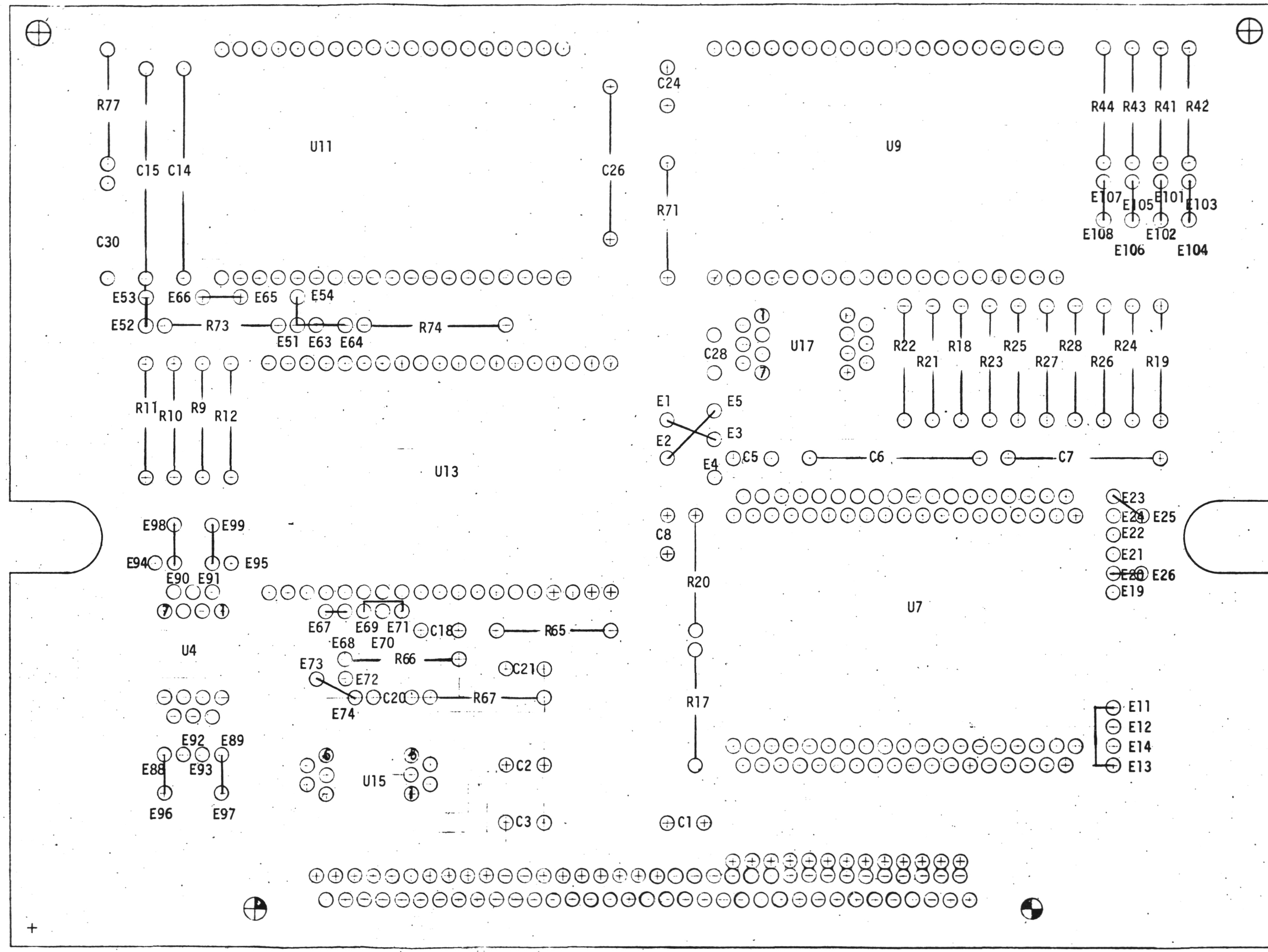


Figure 33. Component Placement - Multiwire Board

Table 5. Parts List for Multiwire Boards

Ident. Number	Ref. Designation	Qty.	Remarks
5401	U4	1	I.C.
741	U15	1	I.C.
54LS04	U17	1	I.C.
M39014/01-1593	C1,C2,C3,C30	4	Capacitor
M39014/01-1341	C8	1	Capacitor
M39014/02-1350	C18,C24	2	Capacitor
M39014/01-3009	C6,C7	2	Capacitor
M39014/01-2769	C6,C7	Sub	Capacitor
M39014/01-1348	C5,C28	2	Capacitor
CK05BX331K	C5,C28	Sub	Capacitor
M83421/01-1171P	C14,C15	2	Capacitor
M39003/01-3179	C26	1	Capacitor
M39003/01-2350	C26	Sub	Capacitor
M39014/02-1355	C20	1	Capacitor
M39014/01-1587	C21	1	Capacitor
RNR55C1212FS	R77	1	Resistor
RNR55C2871FS	R9,R10,R11,R12	4	Resistor
RN55D2871FS	R9,R10,R11,R12	Sub	Resistor
RNR55C9091FS	R20,R73	2	Resistor
RNR55C1001FS	R41,R42	2	Resistor
RNC55H1001FS	R41,R42	Sub	Resistor
RNR55C3481FS	R43	1	Resistor
RNR55C5622FS	R44	1	Resistor
RNC55H5622FS	R44	Sub	Resistor
RNR60C2004FS	R74	1	Resistor
RNR55C1003FS	R71	1	Resistor
RNR55C1271FS	R65	1	Resistor
RNR55C4992FS	R66,R67	2	Resistor
RNR55C6811FS	R17	1	Resistor
RNR55C1302FS	R22	1	Resistor
RNR55C1962FS	R21	1	Resistor
RNR55C1332FS	R18,R19	2	Resistor
10090-516-21	U7	1	Hybrid
10091-516-21	U9	1	Hybrid
10092-516-21	U11	1	Hybrid
10093-516-21	U13	1	Hybrid

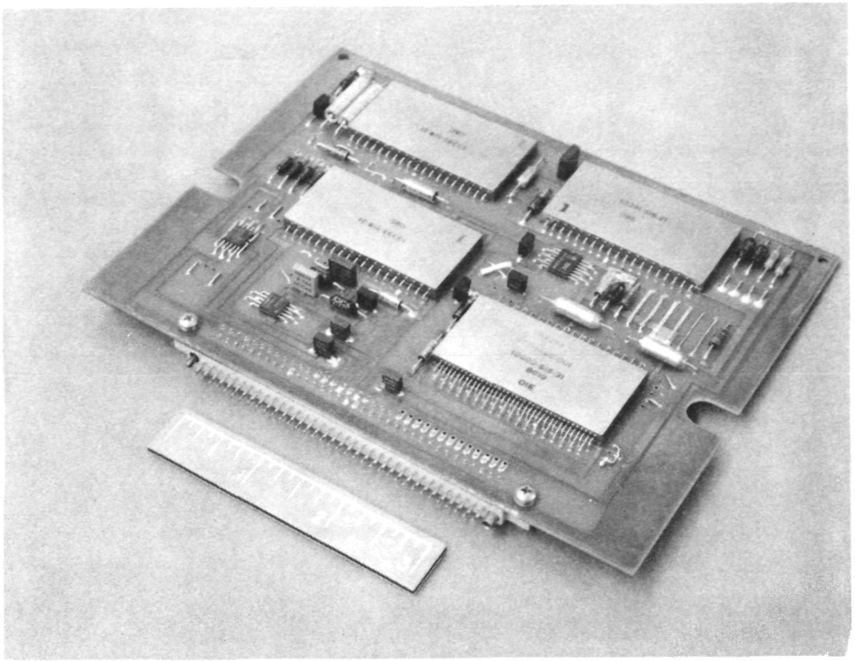


Figure 34. Assembled Multiwire Board

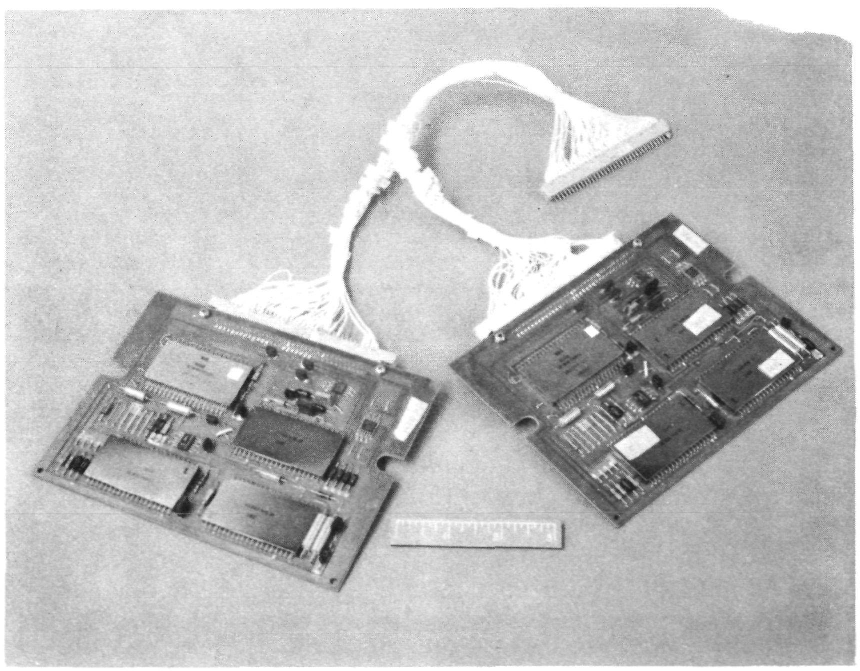


Figure 35. Multiwire Boards Connected Together to Functionally Duplicate a FASCOS Multilayer Board

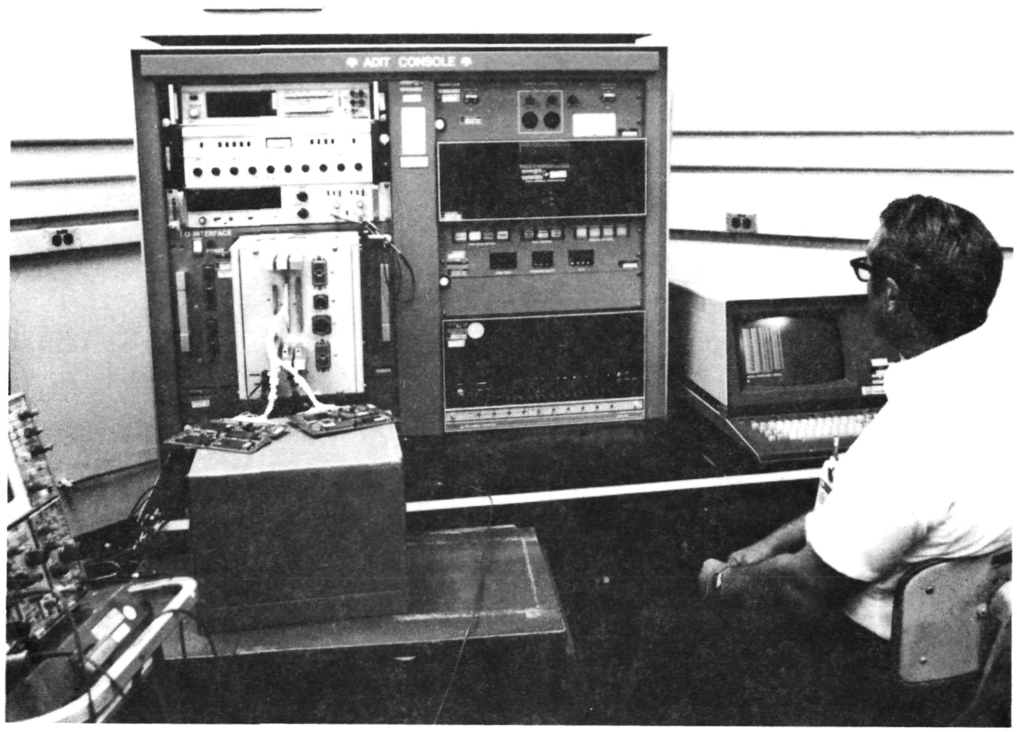


Figure 36. Multiwire Boards Being Functionally Tested on ADIT Console

Initial testing revealed that one of the boards had a high resistance short on the fuel cutoff (FCO) line. After correcting this problem by simply cutting the board wire and soldering in an external wire, the multiwire boards passed the complete functional test with all parameters well within the specified tolerances.

The engineer performing the testing indicated that the multiwire boards were much easier to troubleshoot and repair than the multilayer boards.

2.2 PHASE II - COST COMPARISON

The hybrid-packaging approach investigated in this study using adhesive package sealing, nickel-plated Kovar packages and lids, and multiwire boards was compared to the conventional hybrid-packaging approach using metallurgical package sealing (seam welding), gold-plated Kovar packages and lids, and multilayer boards to determine the cost savings achieved. Separate comparisons were made for the FASCOS hybrids and for the FASCOS modules. In these comparisons, no attempt was made to determine the total costs but only to identify the potentially important cost factors and to ascertain the corresponding cost deltas attributable to these three specific changes. For the FASCOS hybrids, the potentially important cost factors were identified to be (1) the packages and lids, (2) the sealing procedure, (3) sealing yields, and (4) delidding/relidding. For the FASCOS modules, the potentially important cost factors were identified to be (1) design and board costs, (2) implementation of design changes, and (3) board rework/repair. These cost factors are discussed below.

2.2.1 FASCOS Hybrids

2.2.1.1 Packages and Lids

Current prices (June 1981) for the types of packages and lids used for the FASCOS hybrids were obtained from Isotronics for two different quantities (25 to 49 and 100 to 249). Prices for the two package types (IP-1620A-1 and IP-1620A-2) are given in Table 6, and prices for both stepped and flat lids (15 mils thick) are given in Table 7. Prices are given for both gold-plated and nickel-plated Kovar packages and lids. In the case of packages, "selective plated" means that the package cases are nickel plated and the leads are gold plated.

Isotronics quotes their prices by giving the base price and a factor for gold over $500/oz. Package and lid prices for gold prices of $500, $600, $700, and $800/oz have been calculated and are included in Tables 6 and 7 for convenient reference. At the present time, the price of gold is approximately $500/oz.

Table 6. Current Price (June, 1981) of FASCOS Type Packages (from Isotronics)

Package	Quantity	Type	Base Price	Gold Factor*	Package Price Vs. Gold Price $500/oz	$600/oz	$700/oz	$800/oz
IP-1620A-1 (38 Leads)	25 to 49	Gold Plated (50 μin)	83.64	0.0137	83.64	85.01	86.38	87.75
		Gold Plated (100 μin)	92.20	0.0274	92.20	94.94	97.68	100.42
		Selective-Plated	63.38	0.0068	63.38	64.06	64.74	65.42
	100 to 249	Gold-Plated (50 μin)	43.73	0.0137	43.73	45.10	46.47	47.84
		Gold-Plated (100 μin)	52.29	0.0274	52.29	55.03	57.77	60.51
		Selective-Plated	33.14	0.0068	33.14	33.82	34.50	35.18
IP-1620A-2 (74 leads)	25 to 49	Gold-Plated (50 μin)	83.64	0.0163	83.64	85.27	86.90	88.53
		Gold-Plated (100 μin)	93.83	0.0326	93.83	97.09	100.35	103.61
		Selective-Plated	63.38	0.0111	63.38	64.49	65.60	66.71
	100 to 249	Gold-Plated (50 μin)	43.73	0.0163	43.73	45.36	46.99	48.62
		Gold-Plated (100 μin)	53.92	0.0326	53.92	57.18	60.44	63.70
		Selective-Plated	33.14	0.0111	33.14	34.25	35.36	36.47

*Gold Factor is multiplied by the price of gold over $500/oz and added to base price.

NOTE: Selective-Plated means that the case is nickel-plated and the leads are gold-plated.

Table 7. Current Price (June, 1981) of FASCOS Type Lids (from Isotronics)

Lid	Quantity	Type	Base Price	Gold Factor*	Lid Price Vs. Gold Price $500/oz	$600/oz	$700/oz	$800/oz
Stepped (15 mils)	25 to 49	Gold-Plated (50 μin)	27.04	0.0085	27.04	27.89	28.74	29.59
		Gold-Plated (100 μin)	32.35	0.0170	32.35	34.05	35.75	37.45
		Nickel-Plated	13.86	Zero	13.86	13.86	13.86	13.86
	100 to 249	Gold-Plated (50 μin)	14.14	0.0085	14.14	14.99	15.84	16.69
		Gold-Plated (100 μin)	19.45	0.0170	19.45	21.15	22.85	24.55
		Nickel-Plated	7.25	Zero	7.25	7.25	7.25	7.25
Flat (15 mils)	25 to 49	Gold-Plated (50 μin)	21.69	0.0085	21.69	22.54	23.39	24.24
		Gold-Plated (100 μin)	27.00	0.0170	27.00	28.70	30.40	32.10
		Nickel-Plated	8.50	Zero	8.50	8.50	8.50	8.50
	100 to 249	Gold-Plated (50 μin)	11.34	0.0085	11.34	12.19	13.04	13.89
		Gold-Plated (100 μin)	16.65	0.0170	16.65	18.35	20.05	21.75
		Nickel-Plated	4.45	Zero	4.45	4.45	4.45	4.45

*Gold Factor is multiplied by the price of gold over $500/oz and added to the base price.

Comparison of the prices given in Table 6 for 50-μinch gold-plated packages and selective-plated packages and in Table 7 for stepped 50-μinch gold-plated lids and flat nickel-plated lids gives the following:

(a) For 25 to 49 parts, the cost savings is $20.26 per package and $18.54 per lid.

(b) For 100 to 249 parts, the cost savings is $10.59 per package and $9.69 per lid.

In either case, the combined cost of a nickel-plated Kovar package and lid is 35-percent less than the combined cost of a gold-plated Kovar package and lid, or, stated differently, the combined cost of a gold-plated Kovar package and lid is 54-percent more than the combined cost of a nickel-plated Kovar package and lid.

2.2.1.2 Sealing Procedure

The present package-sealing procedure is very simple. The package cases containing the hybrid circuits and the lids are vacuum baked overnight (16 hours) at 150°C and then transferred to an attached nitrogen dry box and seam welded using a Solid-State Equipment Corporation seam sealer. The time required to seal a package varies, depending on the size of the package, but is certainly no more than three to six minutes. Moisture/gas analysis of the internal atmospheres of the sealed packages shows that they are very clean and dry.

The procedure required for adhesive sealing packages is more complex, takes longer, requires special fixturing, and is more labor intensive. The procedure used in this study is as follows:

(a) The adhesive preforms are aligned on the lids in a special fixture and heated on a hot plate at approximately 100°C for a few minutes to tack them in place. This procedure is unnecessary for small packages (1 x 1 inch or less) but is essential for larger packages such as those used for the FASCOS hybrids (1 x 2 inches).

(b) The lids with attached adhesive preforms are then placed in the nitrogen dry box attached to the oven in which the package cases containing the hybrid circuits are being vacuum baked.

(c) After the package cases have completed vacuum bake and cooled, the packages are assembled in a fixture to ensure alignment of the package cases and lids and then clamped together to hold them in alignment during adhesive cure.

(d) The clamped packages are then returned to the oven and baked in a nitrogen atmosphere at 165°C for 90 minutes to cure the adhesive.

Moisture/gas analysis of the internal atmospheres of the sealed packages immediately after sealing shows that, while they contain approximately 93-percent nitrogen, they also contain large amounts of hydrogen, methane, water vapor, carbon dioxide, acetone, and MEK, and small amounts of oxygen and methanol.

As is obvious from this discussion, it is very difficult to determine the exact cost difference between seam welding and adhesive sealing the FASCOS hybrids, but adhesive sealing is certainly more labor intensive and, consequently, at least as costly as seam sealing. Other factors may justify the use of adhesive sealing in particular applications, but reduction of the cost of sealing does not.

2.2.1.3 Sealing Yields

The sealing yield during FASCOS hybrid production using seam welding was approximately 92 percent. Since delidding/relidding was not allowed, this contributed an increase of approximately 9 percent to the cost of the FASCOS hybrids.

For the first group of adhesive-sealed FASCOS hybrids, 14 of 32 failed the seal test immediately after sealing after being bombed in helium for six hours at 15 psig. Thus, the sealing yield was only approximately 56 percent. As a result of this very disappointing experience, an improved method of cleaning the lids and the rims of the package cases prior to sealing was developed, and 16 hybrids were resealed and seal tested immediately after sealing. A 100-percent sealing yield was obtained; that is, all 16 of these hybrids passed both fine and gross leak tests after being bombed in helium for six hours at 15 psig. Consequently, it was assumed that the sealing problem had been solved. However, after screen testing, the eight hybrids (two each of the four different types) selected for assembly on the multiwire boards were final seal tested. Five of these eight hybrids failed, giving a yield of only 37.5 percent.

Of the five hybrids that failed, two had been resealed using the improved cleaning method, and three had been sealed using the original cleaning method. Of the three hybrids that passed, two had been sealed using the original cleaning method, and one had been sealed using the improved cleaning method. So the failure rate was three of five (60 percent) for the hybrids sealed using the original cleaning method and two of three (67 percent) for the hybrids sealed using the improved cleaning method. This showed that the cleaning method was not the important factor that it was originally thought to be.

Since it is felt that the hybrids are being cleaned and sealed as well as they can be, it must be concluded that, due to their size (1 x 2 inches), adhesive-sealed FASCOS hybrids are unable to withstand the stresses imposed during the fine leak test, even for a bombing pressure of only 15 psig. As a result of this fact, and since adhesive-sealed packages are not hermetic in any case, it is suggested that the fine leak test requirement for adhesive-sealed packages of this size be eliminated and that only the gross leak test be required. Experience indicates that, under this condition, essentially a 100-percent sealing yield can be expected.

2.2.1.4 Delidding/Relidding

Data for the FASCOS production hybrids and the yields obtained are given in Table 8. The yields in percent are calculated by dividing the number delivered by the sum of the number delivered and the number scrapped and multiplying by 100. Due to the complexity of the hybrids and the fact that they cannot be delidded and reworked, the yields are low as shown.

Table 8. Data for FASCOS Production Hybrids

	Part Number				Combined
	10090	10091	10092	10093	
Delivered to Test	69	67	74	88	298
Scrapped	23	17	30	36	106
Delivered	46	50	44	52	192
Yield	67%	75%	59%	59%	64%

Production Operations personnel feel that if only one delidding and rework were allowed, the scrap rate could be reduced by approximately 70 percent. If this is true, then the yields would be increased from 67 to 90 percent for Part No. 10090, from 75 to 92 percent for Part No. 10091, from 59 to 88 percent for Part Nos. 10092 and 10093, and the combined yield would be increased from 64 to 89 percent. Assuming that delidding, reworking, relidding, and retesting the hybrids would cost only approximately 25 percent of making new hybrids, the cost savings if only one delidding were allowed would be approximately 21 percent. Further savings would be achieved if more than one delidding and rework were allowed. For example, if the same assumptions are made as previously, allowing two deliddings would increase the combined yield to 97 percent and result in a cost savings of approximately 26 percent.

Essentially, this same cost savings would be achieved if the FASCOS packages were adhesive sealed and delidding were allowed. Delidding adhesive-sealed packages and cleaning the adhesive from the rims of the package cases require essentially the same effort as delidding seam-sealed packages and refinishing the rims of the package cases.

As shown in the above discussion, allowing delidding of the FASCOS hybrids would result in substantial savings—reducing the cost by 21 to 26 percent. If the present average cost of a FASCOS hybrid is $1,000, allowing delidding would reduce the cost to $740 to $790. Based on these results and the present level of success achieved in delidding seam-welded packages, the permissibility of delidding seam-welded FASCOS packages should be reconsidered.

2.2.2 FASCOS Modules

2.2.2.1 Design and Board Costs

The multilayer version of the FASCOS Signal Conditioner/Logic Control board was designed by Algorex Corporation (Syosset, New York) and fabricated by Cirtel, Inc. (Irvine, California). During the design phase, close liaison was maintained between Rockwell engineering personnel and Algorex design personnel, and drawings were checked by Rockwell engineering personnel at various stages of the design to ensure that the final board would meet Rockwell requirements. This effort required approximately 160 man-hours of Rockwell engineering time, and charges by Algorex totaled approximately $12,500 of which approximately half ($6,000) was due to Rockwell-initiated design changes. Initial fabrication of seven prototype boards by Cirtel cost approximately $10,500 including a nonrecurring charge of approximately $1,000 and $1,350 each for the boards. The fabrication of 14 heat sinks (two per board) costing approximately $100 each was included in this charge. Subsequent charge for 24 production boards was approximately $800 each.

The multiwire version of this board was designed by Rockwell engineering personnel. The total effort required was approximately 120 man-hours. Two boards were fabricated by Multiwire/West for a total cost of $1,185. This cost included a nonrecurring charge of $785 for digital and graphic tooling and $200 each for the boards. For a production run of 48 boards (which is equivalent to the production run of 24 multilayer boards since two multiwire boards are required to perform the same function as one multilayer board), Multiwire/West quoted a price of approximately $70 per board.

The above cost information for the design and fabrication of the multilayer and multiwire boards is summarized in Table 9 for convenient reference. In both cases (i.e., for both the multilayer and the multiwire boards), it was assumed that the circuit schematic and parts list were available and their generation is not included in the design costs.

As is evident from this discussion, the design and fabrication costs are much less for the multiwire board than for the multilayer board. This is generally true, just as it is true that a single-sided printed circuit board is less expensive than a double-sided printed circuit board and that

Table 9. Design and Fabrication Costs of FASCOS Signal Conditioner/Logic Control Board

	Multilayer	Multiwire*
Design	160 Man-Hours and $12,500	120 Man-Hours
Fabrication		
1) Prototype		
Nonrecurring Costs	$ 1,000	$ 785
Cost/Board	$ 1,350**	$ 200
2) Small Quantity Production Cost/Board	$ 800***	$ 70***

*Two multiwire boards are required to replace one multilayer board.

**Cost includes approximately $200 for heat sinks that are not included in multiwire board cost.

***Prices in late 1979/early 1980; current prices should be expected to be approximately 20 percent higher.

a double-sided printed circuit board is much less expensive than a multilayer board. It is a generally accepted fact that multilayer boards are expensive; however, it also is a generally accepted fact that, in spite of this, total system requirements sometimes dictate their use. For example, in the present case, it has been shown that the FASCOS Signal Conditioner/Logic Control board which is presently an expensive eight-layer multilayer board with components mounted on both sides can be replaced by two inexpensive multiwire boards with components mounted on only one side. This apparently would result in considerable cost savings. However, before this conclusion is established as fact, the compatibility of such a change with the size, weight, and performance (reliability) requirements of the FASCOS system should be determined.

In conclusion of this discussion, it is apparent that multiwire boards are a highly competitive alternate to multilayer boards and probably also to most double-sided printed circuit boards and should be seriously considered as a substitute for them to reduce overall system cost and improve system reliability.

2.2.2.2 Implementation of Design Changes

Design changes that do not affect the power and ground plane are easily made for multiwire boards. All that is required is that appropriate changes be made in the computer programs that control the wiring head and drilling machine. Design changes are much more difficult to make and are substantially more expensive for multilayer boards. Changes must be made on the master drawings and new artwork generated. Even changes that appear to be relatively minor may require extensive changes in interconnection routing on the various layers to avoid crossovers.

The ease with which design changes can be made is unquestionably the greatest advantage of multiwire technology over multilayer technology. Any wire routing change can be made with minimum effort and is of no concern since the wires used are insulated and may cross over each other without fear of shorting. In multilayer technology, changes in interconnection routing must be carefully considered and can entail substantial effort and expense.

2.2.2.3 Board Rework/Repair

In general, two types of rework/repair problems occur: 1) the removal and replacement of a failed component and 2) the rerouting or replacement of a wire (interconnection). Both of these types of rework/repair are more easily performed on a multiwire board than on a multilayer board.

Since the component leads are attached in plated-through holes on the multiwire boards, components can be removed by unsoldering their leads just as is done for a two-sided printed circuit board. The plated-through holes of the multiwire board can tolerate this procedure just as well as the plated-through holes of regular printed circuit boards. For multilayer boards when a soldering iron is applied to remove a lead from a surface mounted pad, the pad often is detached from the board and a more difficult repair problem is created.

Wire rerouting or replacement can also be performed more easily on a multiwire board than on a multilayer board since all the wires are visible on a multiwire board. The wire that is to be rerouted/replaced is simply cut with an X-acto knife and a very small section removed. A small wire is then soldered between the desired terminals to complete the correction. While a repair of this type is not allowed on deliverable boards, it is a valuable feature and can result in substantial cost and time savings during the prototype system stages.

2.3 PHASE III - RELIABILITY EVALUATION

During this phase of the study, the reliability of the adhesive-sealed FASCOS hybrids was evaluated by subjecting them to the ten-day moisture resistance test and the 1000-hour life test and then electrically testing them to determine if their functional performance was within specification. Mass spectrometric analyses were also performed on these hybrids and others to determine the composition of their internal atmospheres. The results of these tests follow.

2.3.1 Reliability of Adhesive-Sealed FASCOS Hybrids

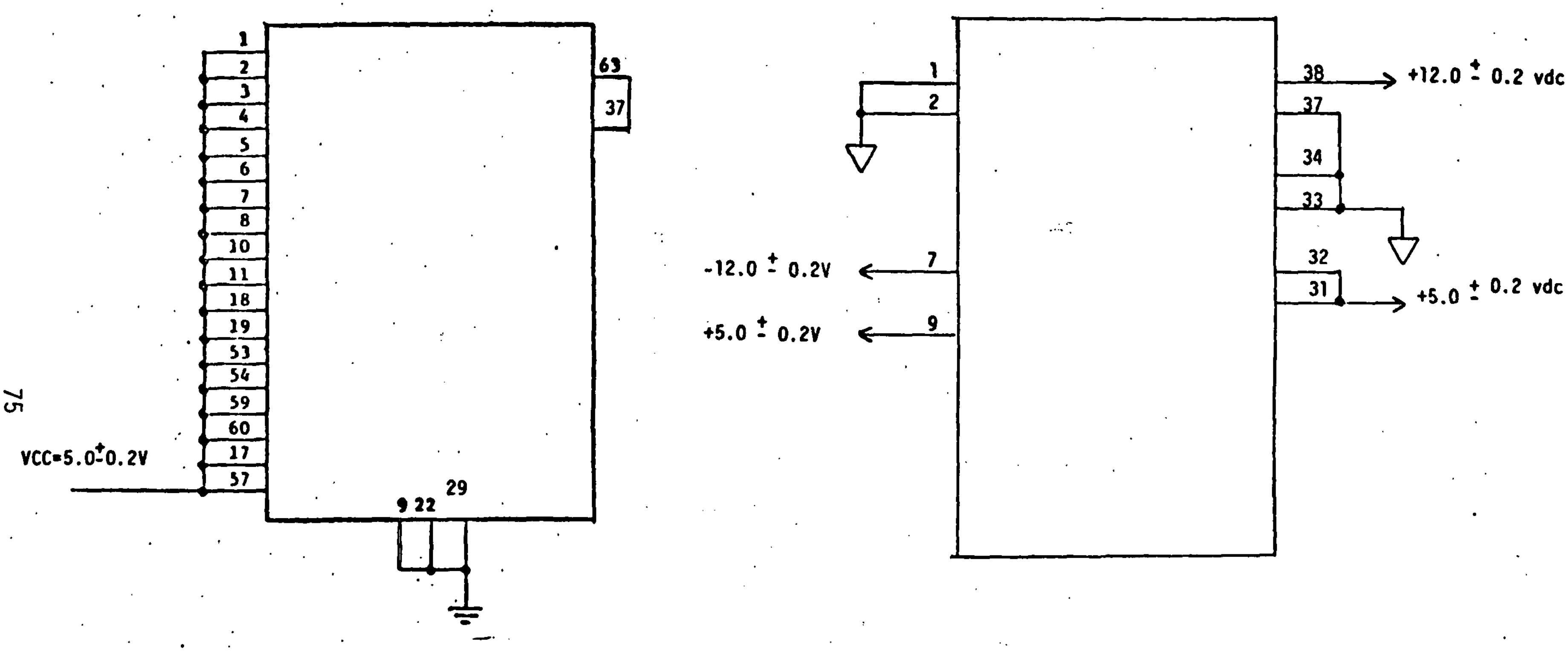
2.3.1.1 Ten-Day Moisture Resistance Test

Four adhesive-sealed FASCOS hybrids were subjected to the ten-day moisture resistance test per Method 1004.2 of MIL-STD-883 to determine the effect of high temperature/humidity on their functional performance. One hybrid of each of the four different types were tested (Part Nos. 10090-516-21-03E, 10091-516-21-03E, 10092-516-21-07E, and 10093-516-21-07E). After exposure, all four hybrids passed the electrical functional performance requirements well within specified tolerance at both test temperatures (0°C and 60°C) and the continuity and isolation test at 25°C.

2.3.1.2 1000-Hour Life Test

Eight adhesive-sealed FASCOS hybrids (two of each of the four different types) were life tested for 1000 hours at 125°C ± 5°C with steady-state power applied to them as specified in the Functional Test Specifications (VL00257, VL00258, VL00259, and VL00260) and as shown in Figure 37. Part Numbers of the hybrids used for this test were as follows: 10090-516-21-04E, 10090-516-21-06E, 10091-516-21-01E, 10091-516-21-06E, 10092-516-21-01E, 10092-516-21-02E, 10093-516-21-01E, and 10093-516-21-06E.

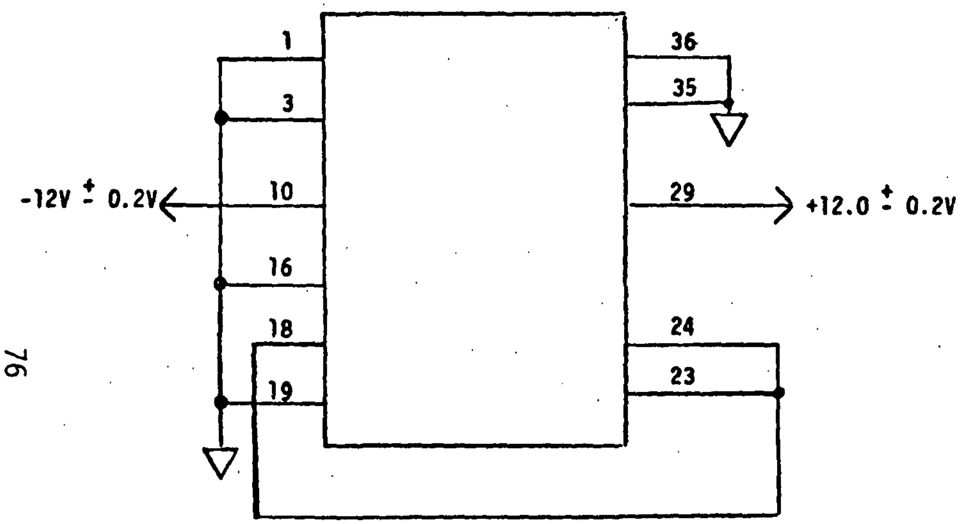
After life testing, six of the hybrids passed functional testing and two failed. Functional testing was performed at two different temperatures, 0°C (+0, -5°C) and 60°C (+5, -0°C), and a continuity



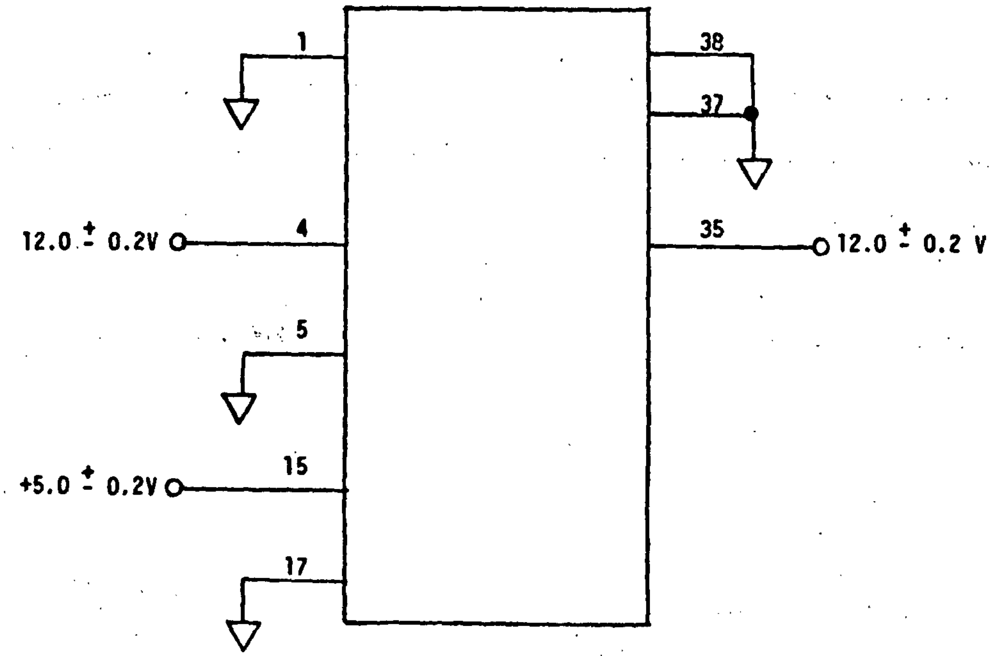
a) Part No. 10090-516-21

b) Part No. 10091-516-21

Figure 37. Circuit Connections for Life Testing of FASCOS Hybrids



c) Part No. 10092-516-21



d) Part No. 10093-516-21

Figure 37. Circuit Connections for Life Testing of FASCOS Hybrids (continued)

and isolation test was performed at 25°C (±5°C). The two hybrids that failed were Part Nos. 10092-516-21-02E and 10093-516-21-01E. Both of these hybrids are signal conditioners; 10092 processes the accelerometer signals and 10093 processes the telemetering signals. The failures were as follows: the output of the first op-amp of the 10092 was saturated, and the output of the rms-to-dc-converter portion of the 10093 was essentially zero. Previous experience with metallurgically sealed (seam-welded) FASCOS hybrids of these types has shown that these are commonly occurring failure modes after only 168-hour burn-in. Consequently, it is felt that these failures were not attributable to the fact that these hybrids were adhesive-sealed and contained larger amounts of water vapor.

2.3.2 Mass Spectrometric Analyses of the Internal Atmospheres of FASCOS Hybrids

2.3.2.1 Immediately After Adhesive Sealing

Mass spectrometric analyses were made of the internal atmospheres of four empty nickel-plated Kovar FASCOS packages and two FASCOS hybrids immediately after adhesive sealing. Results are given in Tables 10 and 11, respectively.

As shown in Tables 10 and 11, the packages and hybrids were removed from the nitrogen dry box and installed in the mass spectrometer carrousel for overnight pumpdown, in preparation for moisture/gas analysis the next day, either on the same day they were sealed or on the day after. This is indicated by the "0" or "1" entries under "Days Stored (Dry Nitrogen)." In either case, the only exposure of the packages to room air was for the brief interval of time it took to move them from the nitrogen dry box and install them in the mass spectrometer carrousel (approximately 15 minutes). As expected, comparison of the data for packages stored for 0 or 1 day in dry nitrogen certainly does not indicate that this made any difference.

These empty packages and hybrids and all other adhesive-sealed FASCOS hybrids were sealed in a dry-nitrogen atmosphere (approximately 760 Torr) at 165°C and punctured in a high vacuum at 100°C. Assuming

Table 10. Results of Mass Spectrometric Analysis of the Internal Atmospheres of Empty FASCOS Packages Immediately After Adhesive Sealing

AMU	Specie	Package #1	Package #2	Package #3	Package #4
2	Hydrogen	0.374	0.434	0.256	0.269
4	Helium	N.D.	N.D.	N.D.	N.D.
15	Methane	2.523	3.043	1.928	2.180
18	Water Vapor	1.802	1.914	1.463	1.532
29	Nitrogen	93.038	91.838	94.270	93.882
31*	Unidentified Alcohol*	0.024	0.029	0.016	0.022
32	Oxygen	N.D.	0.027	0.011	0.020
40**	Argon**	0.079	0.091	0.075	0.083
44	Carbon Dioxide	0.572	0.584	0.488	0.524
58	Acetone	1.249	1.692	0.667	0.669
72	MEK	0.339	0.348	0.826	0.819
Days Stored (Dry Nitrogen)		0	0	0	1
Approximate Package Pressure When Punctured		832 Torr	825 Torr	804 Torr	797 Torr

*Probably methanol

**Almost certainly hydrocarbon fragments, not argon.

Table 11. Results of Mass Spectrometric Analysis of the Internal Atmospheres of FASCOS Hybrids Immediately After Adhesive Sealing

AMU	Specie	Package #1	Package #2
2	Hydrogen	0.326	0.304
4	Helium	N.D.	N.D.
15	Methane	2.351	2.020
18	Water Vapor	2.319	2.256
29	Nitrogen	93.125	93.253
31*	Unidentified Alcohol*	0.023	0.018
32	Oxygen	0.013	0.005
40**	Argon**	0.079	0.072
44	Carbon Dioxide	0.489	0.468
58	Acetone	0.672	1.025
72	MEK	0.603	0.579
Days Stored (Dry Nitrogen)		0	1
Approximate Package Pressure When Punctured		780 Torr	772 Torr

*Probably methanol

**Almost certainly hydrocarbon fragments, not argon.

no internal outgassing and no permeation of gases into or out of the packages, a simple calculation using P(100°C) = P(165°C) T(100°C)/T(165°C) shows that P(100°C), the puncture pressure of the package, should be approximately 647 Torr. As shown in Tables 10 and 11, the puncture pressures are substantially higher, indicating that the sealing adhesive continues to outgas substantially after it has cured adequately to seal the packages.

The results given in Tables 10 and 11 show that all packages contained very substantial amounts of water vapor; large amounts of hydrogen, carbon dioxide, acetone, and MEK; very large amounts of methane; small amounts of an unidentified alcohol (probably methanol); fairly large amounts of some constituent with an AMU of 40 (probably hydrocarbon fragments resulting from interactions due to the large amounts of acetone and MEK present, not argon); and very small amounts of oxygen.

When the method used to lid the packages is considered, all of the constituents detected during the analysis of their internal atmospheres are expected. The package case, adhesive preform, and lid are clamped together in a dry-nitrogen environment and then placed in a nitrogen oven to cure the adhesive. Since there is no vent hole in the lid, a portion of the solvents outgassed from the adhesive (methanol, acetone, and MEK), and the various products released by the adhesive during cure (hydrogen, methane, carbon dioxide, and water vapor) will be retained inside the package.

The only major difference between the results obtained for the adhesive-sealed empty nickel-plated Kovar packages and the hybrids is that the hybrids contained somewhat more water vapor. This could be due to desorption of water vapor from the ceramic substrate or mounting adhesive, indicating that the pre-seal vacuum bake-out for four hours at 100°C is inadequate, particularly since the packages are subsequently sealed at 165°C.

In conclusion of this section, due to the fact that undesired constituents such as acetone and MEK are outgassed by the adhesive during cure, it is recommended that lids containing a small vent hole be used. After lidding, the packages should be baked out as required and a very small amount of adhesive used to seal the small vent hole.

2.3.2.2 After Extended Storage at Room Ambient

Mass spectrometric analyses were made of the internal atmospheres of four adhesive-sealed FASCOS hybrids that had simply been stored at room ambient after screen and functional testing. One hybrid of each of the four different types was used for these analyses (Part Nos. 10090-516-21-02E, 10091-516-21-02E, 10092-516-21-08E, and 10093-516-21-03E). Results are given in Table 12.

Comparison of these results with those obtained for the hybrids analyzed immediately after adhesive sealing shows that they are much the same. The major difference is that these hybrids contained substantially more water vapor and perhaps a little more carbon dioxide.

The presence of the larger quantities of water vapor and carbon dioxide was not surprising, considering the history of these hybrids. They not only were stored at room ambient for extended intervals of time, but also were subjected to a stabilization bake at 150°C for 24 hours and a burn-in at 125°C for at least 160 hours. Certainly these high temperature exposures could account for the higher carbon dioxide content and some increase in the water-vapor content, and permeation during extended storage at room ambient could account for the rest of the increase in the water-vapor content. What was surprising was the lack of oxygen in the hybrids. It was expected that oxygen would also permeate into the hybrids during extended storage at room ambient. This obviously was not the case.

Table 12. Results of Mass Spectrometric Analysis of the Internal Atmospheres of Adhesive-Sealed FASCOS Hybrids After Storage at Room Ambient

AMU	Specie	10090 516-21-02E	10091 516-21-02E	10092 516-21-08E	10093 516-21-03E
2	Hydrogen	0.421	0.282	0.408	0.441
4	Helium	N.D.	N.D.	N.D.	N.D.
15	Methane	2.792	2.005	2.852	2.842
18	Water Vapor	3.518	5.256	4.413	10.973
29	Nitrogen	89.887	91.047	89.738	84.266
31*	Unidentified Alcohol**	0.040	0.027	0.043	0.038
32	Oxygen	N.D.	0.002	0.001	0.002
40**	Argon**	0.098	0.066	0.096	0.075
44	Carbon Dioxide	0.655	0.501	0.663	0.802
58	Acetone	0.350	0.391	0.674	0.488
72	MEK	2.239	0.423	1.112	0.072
82	Unidentified Compound	N.D.	N.D.	N.D.	0.001
Days Stored at Room Ambient		66	46	64	260
Approximate Package Pressure When Punctured		692 Torr	775 Torr	821 Torr	776 Torr

*Probably methanol

**Almost certainly hydrocarbon fragments, not argon.

The explanation lies in the nature of gas-polymer systems which will now be reviewed by quoting from an internal document generated some years ago ("The Permeation of Gases Through Solids," Technical Memorandum 3041-94-1, K. L. Perkins, 7 December 1959).

"As in the case of gas-glass systems, the results of experimental investigations show that in general the permeation of gases through polymers is due to nonspecific activated diffusion. The permeation rate, J, is therefore given by the following equation.

$$J = KA \cdot \frac{P_2 - P_1}{d}$$

with $K = K_0 e^{-E/RT}$. The qualification of the diffusion process as being of nonspecific activation means that every gas of sufficiently small molecular dimensions will diffuse and that diffusion occurs as a molecular process. This is in contradistinction to the diffusion of gases through metals which occurs as an atomic process and is specific to certain gases and certain metals with which the gas can react chemically or form an alloy.

"Since the permeation of gases through polymers is a diffusion-associated process of nonspecific activation, the processes of major importance in such systems are those of absorption or solution of the gas in the polymer and diffusion of the gas through the polymer. The nature of the diffusion process and a qualitative discussion of the peculiarities of the solubility process as pertains to gas-polymer systems will now be given.

"Motion of the gas molecules through the bulk material of the polymer occurs as a result of the kinetic energy of the gas molecules and the molecules of the polymer. Those gas molecules possessing an energy corresponding to the activation energy, which has to be supplied to separate the molecular chains of the polymer a sufficient distance, will move through the polymer. As expected from the fact that larger openings should be required for the diffusion of larger gas molecules, requiring that the polymer molecules be separated a greater distance and over a greater length; it is found that the required activation energy is greater, the larger the gas molecule. Also, as expected, the activation energy depends on the nature of the polymer. It is found that the stronger the secondary valences by which the polymer molecules are interlinked, the greater is the required activation energy.

"The solubility of a gas in a polymer is also dependent on the nature of the gas and the polymer. Experiment shows that the solubility of a gas in a polymer is larger, the higher the critical temperature or boiling point of the gas. It is also found that the presence of polar groups in a polymer reduces the solubility of a nonpolar gas, and that polar gas molecules will dissolve more readily in a polymer with polar molecules than in a polymer without polar molecules. This is due to the fact that two polar molecules have greater mutual attraction than a polar and a nonpolar molecule, and, as a result, the nonpolar molecule is more or less expelled from the polymer."

Applying this information to the present case of oxygen, water vapor, and an epoxy adhesive, it is seen that water vapor should readily permeate (diffuse) through the epoxy adhesive and oxygen should not. The solubility of water vapor in the epoxy adhesive is much greater than oxygen for two reasons. The critical temperature of water vapor is much higher than that of oxygen (374.0°C versus -118.8°C) and water vapor and the epoxy adhesive are polar while oxygen is not.

2.3.2.3 After Exposure to the Ten-Day Moisture Resistance Test

Mass spectrometric analyses were made of the internal atmosphere of three of the four adhesive-sealed FASCOS hybrids subjected to the ten-day moisture resistance test (Section 2.3.1.1). Results are given in Table 13.

Table 13. Results of Mass Spectrometric Analysis of the Internal Atmospheres of Adhesive-Sealed FASCOS Hybrids After Exposure to the Ten-Day Moisture Resistance Test

AMU	Specie	10090 516-21-03E	10091 516-21-03E	10092 516-21-07E	10093 516-21-07E
2	Hydrogen	Package was gross leaker, precluding meaningful analysis	0.274	0.304	0.197
4	Helium		N.D.	0.006***	N.D.
15	Methane		1.854	2.115	0.973
18	Water Vapor		12.322	12.345	12.550
29	Nitrogen		84.515	83.937	85.620
31*	Unidentified Alcohol*		0.025	0.032	0.011
32	Oxygen		0.003	0.004	0.002
40**	Argon**		0.069	0.088	0.048
44	Carbon Dioxide		0.414	0.679	0.348
58	Acetone		0.384	0.451	0.220
72	MEK		0.140	0.039	0.031
Days Stored at Room Ambient After Completing Ten-Day Test Before Being Analyzed		10	10	11	11
Approximate Package Pressure When Punctured		12 Torr	825 Torr	794 Torr	846 Torr

*Probably methanol

**Almost certainly hydrocarbon fragments, not argon.

***This hybrid was helium bombed on 08-07-80 and tested on 03-06-81. The other hybrids were not helium bombed.

The puncture pressure of one of the hybrids (Part No. 10090-516-21-03E) was only approximately 12 Torr, indicating that this hybrid was a gross leaker and its internal atmosphere was essentially exhausted during overnight pumpdown. No analysis was made for this hybrid since the composition of the remaining sample cannot be representative of the original internal atmosphere.

Comparison of the results obtained for these three hybrids with those previously obtained for the four hybrids that had simply been stored at room ambient shows that they are much the same except for the much larger water-vapor contents of the present hybrids. Note that while considerable water vapor permeated into the hybrids during this test, oxygen did not.

2.3.2.4 After 1000-Hour Life Testing

Mass spectrometric analyses were made of the internal atmospheres of seven of the eight FASCOS hybrids subjected to the 1000-hour life test (Section 2.3.1.2). Results are given in Table 14. One hybrid (Part No. 10092-516-21-01E) was not analyzed because its puncture pressure was only approximately 76 Torr, indicating that it was a gross leaker and its internal atmosphere was essentially exhausted during overnight pumpdown. The composition of the remaining sample cannot be representative of the original internal atmosphere.

Review of the data for the seven hybrids indicates that their water-vapor content increased with the length of time that they were stored at room ambient before they were analyzed after life testing. The hybrids that were analyzed after only one or two days storage contained between 2 and 2.5 percent water vapor, essentially the same as that previously found for hybrids analyzed immediately after adhesive sealing. The hybrids that were analyzed after nine days storage contained slightly more water vapor (approximately 2.7 and 3.3 percent), and those that were analyzed after 22 days storage contained approximately 5 percent. This is very comparable to that

Table 14. Results of Mass Spectrometric Analysis of the Internal Atmospheres of Adhesive-Sealed FASCOS Hybrids After Exposure to the 1000-Hour Life Test

AMU	Specie	10090 516-21-04E	10090 516-21-06E	10091 516-21-01E	10091 516-21-06E
2	Hydrogen	0.180	0.191	0.168	0.112
4	Helium	N.D.	N.D.	N.D.	N.D.
15	Methane	2.183	2.216	1.983	1.122
18	Water Vapor	3.326	2.730	2.042	2.479
29	Nitrogen	92.315	92.839	93.210	94.801
31*	Unidentified Alcohol*	0.023	0.025	0.023	0.012
32	Oxygen	0.017	0.037	0.026	0.024
40**	Argon**	0.139	0.118	0.115	0.083
44	Carbon Dioxide	1.467	1.512	2.227	1.236
58	Acetone	0.350	0.332	0.206	0.131
Days Stored at Room Ambient After Completing Life Test Before Being Analyzed		9	9	2	2
Approximate Package Pressure When Punctured		737 Torr	733 Torr	725 Torr	785 Torr

*Probably methanol

**Almost certainly hydrocarbon fragments, not argon.

Table 14. Results of Mass Spectrometric Analysis of the Internal Atmospheres of Adhesive-Sealed FASCOS Hybrids After Exposure to the 1000-Hour Life Test (continued)

AMU	Specie	10092 516-21-01E	10092 516-21-02E	10093 516-21-01E	10093 516-21-06E
2	Hydrogen	Package was gross leaker, precluding meaningful analysis	0.074	0.098	0.184
4	Helium		N.D.	N.D.	N.D.
15	Methane		1.064	1.137	2.168
18	Water Vapor		5.048	5.262	2.335
29	Nitrogen		88.699	90.265	93.371
31*	Unidentified Alcohol*		0.012	0.013	0.026
32	Oxygen		0.166	0.003	N.D.
40**	Argon**		0.455	0.102	0.094
44	Carbon Dioxide		4.132	2.685	1.627
58	Acetone		0.350	0.435	0.195
Days Stored at Room Ambient After Completing Life Test Before Being Analyzed		1	22	22	1
Approximate Package Pressure When Punctured		76 Torr	736 Torr	804 Torr	769 Torr

*Probably methanol

**Almost certainly hydrocarbon fragments, not argon.

found for three of the four hybrids analyzed after they had simply been stored at room ambient for extended periods of time. This indicates that water vapor permeates out of the hybrids through the adhesive seal during the 1000-hour life test at 125°C and subsequently permeates back into them during exposure at room ambient.

Further comparison of the results obtained for these hybrids with those obtained for the hybrids that were simply stored at room ambient for extended periods of time after screen and functional testing and those that were analyzed immediately after sealing shows that the major difference is that these hybrids contained substantially more carbon dioxide. This indicates that substantial further outgassing of the adhesive (due either to further curing or slow decomposition) occurred during the 1000-hour exposure at 125°C. Also, these hybrids contained slightly less hydrogen and no MEK, but the concentrations of the other constituents were essentially the same.

3.0 SUMMARY AND CONCLUSIONS

In this study, three alternate hybrid packaging and interconnection techniques were evaluated to determine their potential for reducing the cost of hybrid systems without degrading reliability. These were the use of 1) adhesive package sealing instead of metallurgical package sealing (seam welding), 2) nickel-plated Kovar package cases and lids rather than gold-plated Kovar package cases and lids, and 3) multiwire boards instead of multilayer boards. The evaluation was performed by manufacturing FASCOS (Flight Accelerometer Safety Cut-Off Systems) hybrids and board assemblies using these alternate techniques, subjecting them to normal screen and functional testing to evaluate their performance, and comparing their costs with those of similar hybrids and board assemblies fabricated using conventional techniques.

The study was performed in three phases: 1) hardware fabrication and testing, 2) cost comparison, and 3) reliability evaluation. The first phase included developing the technology for adhesive sealing and delidding FASCOS hybrids, fabricating/assembling and testing 32 FASCOS hybrids using nickel-plated Kovar package cases and lids and adhesive sealing, designing a multiwire board functionally equivalent to the present FASCOS multilayer board, and assembling two FASCOS modules using the multiwire boards and functionally testing them in the present FASCOS engineering system. The second phase consisted of identifying the important cost factors related to the implementation of the new techniques and ascertaining the corresponding cost deltas for both the FASCOS hybrids and the FASCOS modules. The third phase involved electrical testing of the adhesive-sealed hybrids to determine their functional performance after they were subjected to the ten-day moisture resistance test and the 1000-hour life test, and performing mass spectrometric analyses of these and other hybrids to determine the composition of their internal atmospheres.

The major conclusions of this study are:

1. Nickel-plated Kovar packages are a desirable replacement for gold-plated Kovar packages. Selective-plated cases (i.e., package cases with nickel-plated case bodies and gold-plated leads) should be used. For FASCOS packages (1 x 2 inches), the cost of nickel-plated packages is 35 percent less than the cost of gold-plated packages.

2. Adhesive package sealing is not recommended as a replacement for metallurgical package sealing (seam welding). Adhesive-sealed packages are not hermetic, and, at least for FASCOS packages (1 x 2 inches), adhesive sealing does not result in a cost savings either for sealing the packages or delidding them.

3. Multiwire boards are a desirable replacement for multilayer boards, especially for small quantity applications. Design costs are substantially lower, boards are less expensive, design changes are much easier to make and less expensive, and board rework/repair is simpler. Design costs for the FASCOS multiwire board were approximately 25 percent of those for the multilayer board. The cost of the two multiwire boards required to replace a multilayer board was only approximately 35 percent of the cost of the multilayer board for the prototype boards and would be less than 20 percent of the cost of the multilayer board in small quantity production (24 multilayer boards and 48 multiwire boards) as required for the FASCOS build.

Additional results and conclusions or recommendations are:

1. Nickel-plated Kovar packages can be adhesive sealed; however, adhesive sealing the large

(1 x 2 inch) FASCOS packages is more labor intensive than seam welding them.

2. Adhesive-sealed FASCOS packages cannot withstand the stresses imposed during the fine leak test, even for a bombing pressure of only 15 psig. Since the packages are being cleaned and sealed as well as they can be, it is felt that this is due to their relatively large size (1 x 2 inches). As a result, since adhesive-sealed packages are not hermetic in any case, it is recommended that, if adhesive sealing is used, the requirement for fine leak testing be eliminated for packages of this size or larger and it be required only that they pass the old C_1 gross leak test. This test is adequate to ensure that the hybrid circuits are protected from the direct intrusion of liquid and particulate contaminants.

3. A tool was developed during this study that makes the delidding of adhesive-sealed packages a very simple process; however, this tool cannot remove the cured adhesive that remains on the rims of the package cases. Attempts to develop a tool for this purpose were unsuccessful. The method finally selected for removing the cured adhesive from the package rims was to invert the package cases and lightly rub them on a very fine grit paper or crocus cloth. Due to the hardness of the nickel plating, if this sanding is done carefully, only the cured adhesive is removed.

4. Delidding adhesive-sealed packages and removing the cured adhesive from the rims of the package cases require essentially the same effort as delidding seam-welded packages and refinishing the rims of the package cases.

5. Allowing delidding of the FASCOS hybrids could result in substantial savings—reducing their cost by 20 to 25 percent. Based on this fact and the present level of success achieved in delidding seam-welded packages, it is recommended that delidding be allowed.

6. Mass spectrometric analysis of the internal atmospheres of adhesive-sealed FASCOS packages performed immediately after sealing showed that, while they contained approximately 93 percent nitrogen, they also contained other constituents such as solvents outgassed from the sealing adhesive (methanol, acetone, and MEK) and products released during curing of the sealing adhesive (hydrogen, methane, carbon dioxide, and water vapor). As a result, since some of these constituents are undesirable, it is recommended that, if packages are adhesive sealed, the lids contain a small vent hole and that, after sealing, the packages be baked-out to remove these constituents and then the vent holes be sealed using a very small amount of adhesive.

7. The adhesive-sealed FASCOS hybrids that were subjected to the ten-day moisture resistance test passed electrical functional testing with all parameters well within the specified tolerances even though subsequent mass spectrometric analysis showed that they contained the various constituents listed above and a substantial amount of water vapor (around 12 percent or 120,000 PPM_V).

8. Six of eight adhesive-sealed FASCOS hybrids subjected to the 1000 hour steady-state life test passed electrical functional testing and two failed. The two hybrids that failed were signal conditioners. Based on previous experience with seam-welded hybrids of this type, it is felt that these failures were not due to the fact

that these hybrids were adhesive sealed and contained larger amounts of water vapor than the seam-welded hybrids.

9. The FASCOS Signal Conditioner/Logic Control board which presently is an expensive eight-layer multilayer board with components mounted on both sides can be replaced by two inexpensive multiwire boards with components mounted on only one side. This apparently results in considerable cost savings. However, before this conclusion is accepted as fact, the compatibility of such a change with the size, weight, and performance (reliability) requirements of the FASCOS system should be determined.

In summary, from a cost reduction standpoint, this study showed the following for the FASCOS system:

1. Nickel-plated Kovar packages cost 35 percent less than gold-plated Kovar packages.
2. Adhesive sealing does not reduce either package sealing or delidding costs.
3. Design of the multiwire board cost only approximately 25 percent as much as that of the multilayer board.
4. In small quantity production, the 2 multiwire boards required to replace the multilayer board cost less than 20 percent as much as the multilayer board.
5. Allowing delidding would reduce the cost of the FASCOS hybrids by 20 to 25 percent.

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