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FABRICATION REPORT

SOLAR THERMOELECTRIC GENERATOR DESIGN AND PANEL DEVELOPMENT PROGRAM (U)

(TASK III)

By
L. H. GNAU

THERMOELECTRIC PRODUCTS ENGINEERING
SPECIAL COMPONENTS OPERATIONS
ELECTRONIC COMPONENTS
RCA
415 SOUTH FIFTH STREET
HARRISON, NEW JERSEY 07029

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-10600

RCA Electronic Components

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MARCH 20, 1968

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ABSTRACT

Three flat-plate sections of a developmental silicon-germanium solar thermoelectric generator, each with an area of 12.25 square inches, were fabricated in accordance with the Task II design for a 150-watt Solar Thermoelectric Generator. The development effort required to achieve fabrication of the feasibility sections is described. The fabrication and assembly process specifications for the test sections are also considered in detail, supplemented by engineering layout drawings of the generator and its components.

I. SUMMARY

Three (3) feasibility sections of developmental solar panel hardware, each with an area of 12.25 square inches were fabricated according to the design and specifications for a 150-watt flat-plate Solar Thermoelectric Generator described in the Task II panel design report.[1] The modules utilize the basic Air-Vac thermocouple construction in which the couple is cantilevered from the cold end and accepts heat through an absorber plate (hot shoe) joining the n- and p-legs at the hot end. The couples are electrically connected, using the RCA "Fleximod" approach, and mechanically fastened to a thin beryllium base plate. An advanced Min-K formulation (2002) is used for the thermal insulation.

The developmental effort resulted in the solution of a number of technical problems, including fabrication and bonding of the "hipped" silicon-molybdenum hot shoes. A technique for bonding beryllium to copper was developed for attachment of the mounting studs to the cold stack assembly. Methods were determined for machining Min-K 2002 thermal insulation to the precise dimensions required for the panel sections. Surface preparation techniques for bonding silicon-molybdenum n- and p-discs were improved, and detailed processing and fabrication specifications were written for the test panel sections.

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1. Task II Report (Design) NASA CR-72340

II. TEST SOLAR PANEL DESCRIPTION

A. TEST PANEL ASSEMBLY

Each test solar panel assembly consists of a flat-plate section having an area of 12.25 square inches. The panel assembly contains nine couples electrically connected in series with interconnecting straps which also serve as the assembly structure. The individual thermocouples are terminated at the cold end with a mounting stud which is used to bolt it to the supporting frame or radiator. The test panel section is described in Figure 1.

The basic unit of each panel is a thermocouple assembly made of silicon-germanium alloy, nominally 63.5 at. percent Si. The two active legs of the thermocouple are doped with phosphorus for the n-leg and with boron for the p-leg. These elements are joined at the hot end by a heat acceptor plate made of an 85 wt. percent silicon - 15 wt. percent molybdenum alloy. This plate or "hot shoe" has a higher thermal conductivity than that of the silicon-germanium alloy of which the element legs are made. The hot shoe surface will accept radiant thermal energy at a relatively low flux density and concentrate it for processing by the active element legs at a much higher flux density. The thermocouple assemblies are supported in cantilever fashion from the cold end and require no other mechanical structure. The hot shoe material, suitably doped for low resistivity, makes an electrical connection at the hot end of each thermocouple. A thin, ceramic disc is included in the stack assembly between each thermocouple cold junction and its base-plate mounting stud. The ceramic disc electrically isolates each couple from the base plate radiator and, at the same time, provides a good thermal path from each couple cold junction to the base plate.

The void between the couples in the panel is filled with the advanced Min-K 2002 thermal insulation (Johns-Manville) which is machined in bulk and fitted into large areas. Small, irregular areas are fitted with loose material of microquartz.

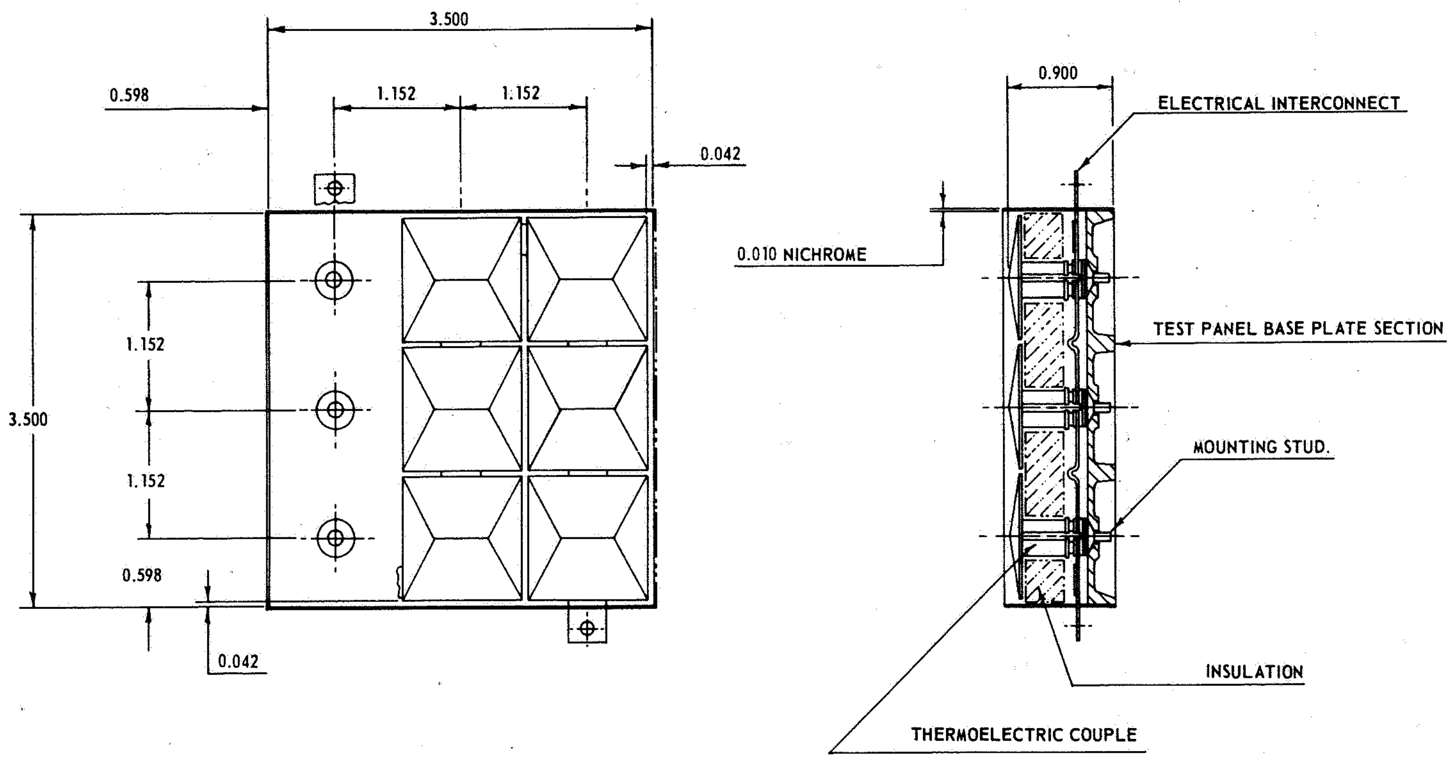

FIGURE 1. TEST PANEL SECTION

The couple assemblies are mechanically fastened to a thin, ribbed (waffled) beryllium base-plate structure which serves as a support structure as well as a radiator. Beryllium was chosen because of its excellent high temperature structural and thermal properties. The radiator surface includes an adherent emittance coating of calcium titanate.

The panel design report[1] contains a complete analysis of weight and electrical performance characteristics for the test panels section.

B. THERMOCOUPLES

The individual thermocouples consist of two elements or legs, one each of n-type (phosphorus-doped) and p-type (boron-doped) silicon-germanium alloys. These alloys exhibit good thermoelectric properties at high temperatures, and are not susceptible to "poisoning" in oxidizing atmospheres. Because this type of couple structure can operate in both atmospheric and vacuum environments, it has been named the "Air-Vac" couple. Modules using the Air-Vac couple have been operating successfully in both environments for many thousands of hours. Figures 2 and 3 illustrate the solar panel thermocouple and its components. A refractory metal contact is ionically bonded to the cold end of each element. These contacts or "cold shoes" provide means for both electrical and mechanical connections to the remainder of the module structure. This particular bond has operated efficiently at temperatures up to 500°C for many millions of couple hours.

C. STACK ASSEMBLY

Figures 4 and 5 show the stack assembly which consists of a number of elements and performs several functions. The assembly provides a mechanical support for the individual thermocouples. Stress compensation is provided in the stack assembly to enable the whole structure to maintain its integrity throughout the range of temperatures from room through processing through operating. To achieve stress compensation, it is necessary to go from the very low coefficient of thermal expansion of the

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1. Task II Report (Design) NASA CR-72340

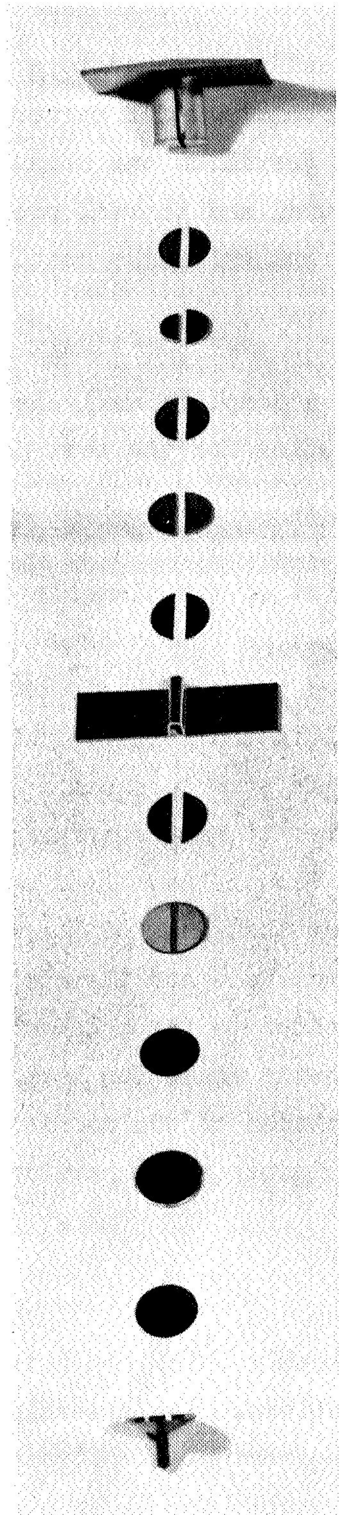


FIGURE 2. SOLAR PANEL THERMOCOUPLE COMPONENTS

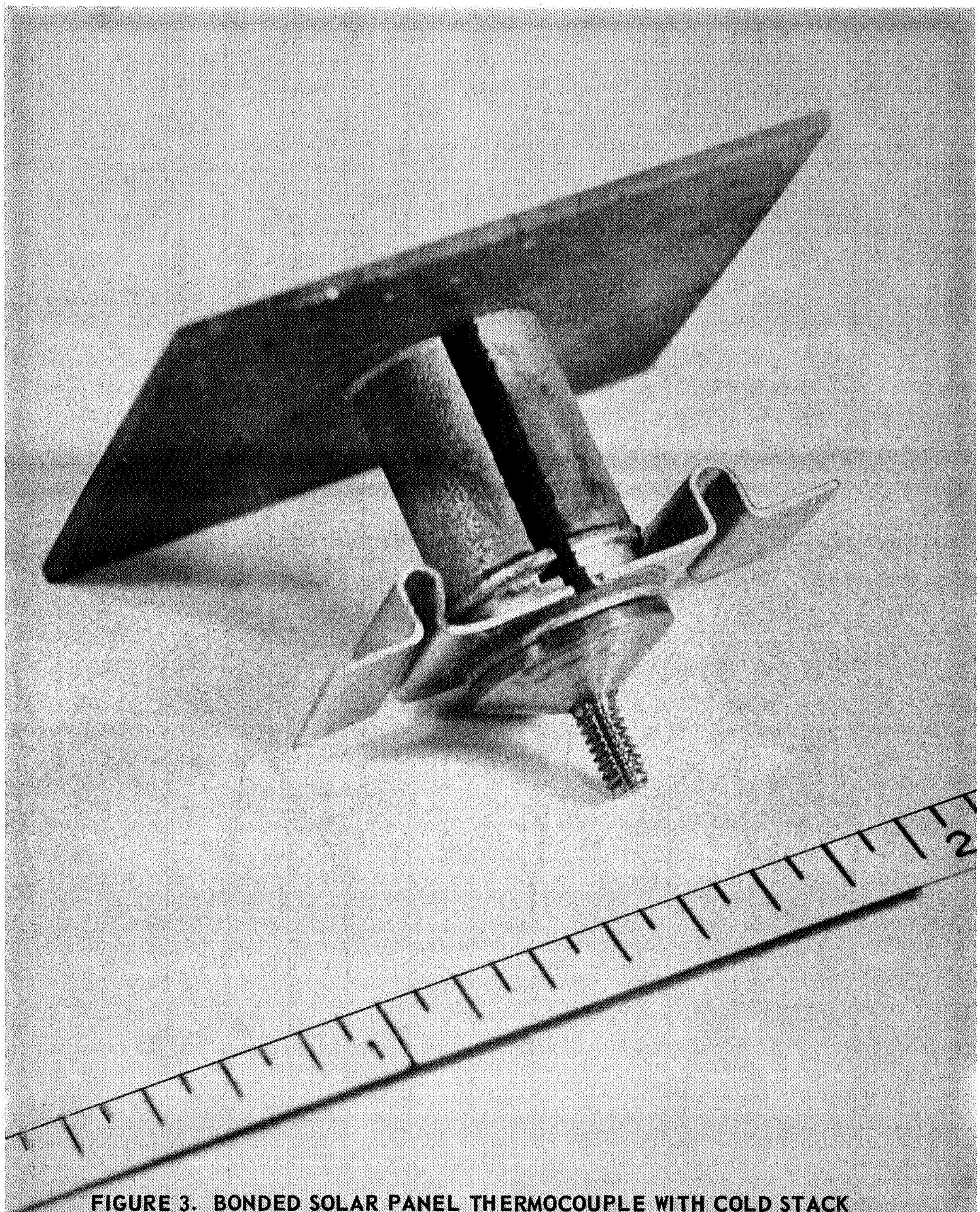


FIGURE 3. BONDED SOLAR PANEL THERMOCOUPLE WITH COLD STACK

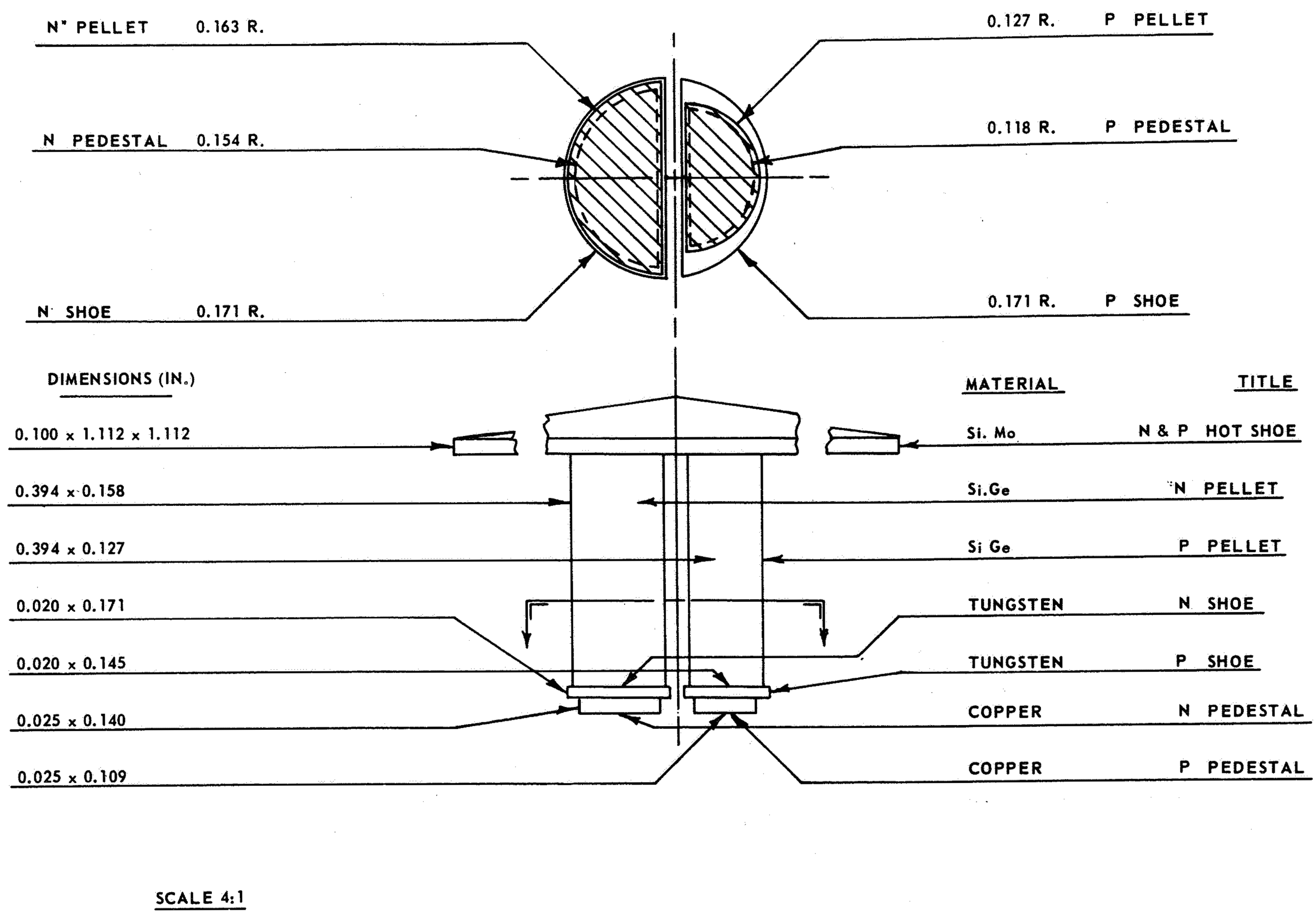


FIGURE 4. COUPLE ASSEMBLY

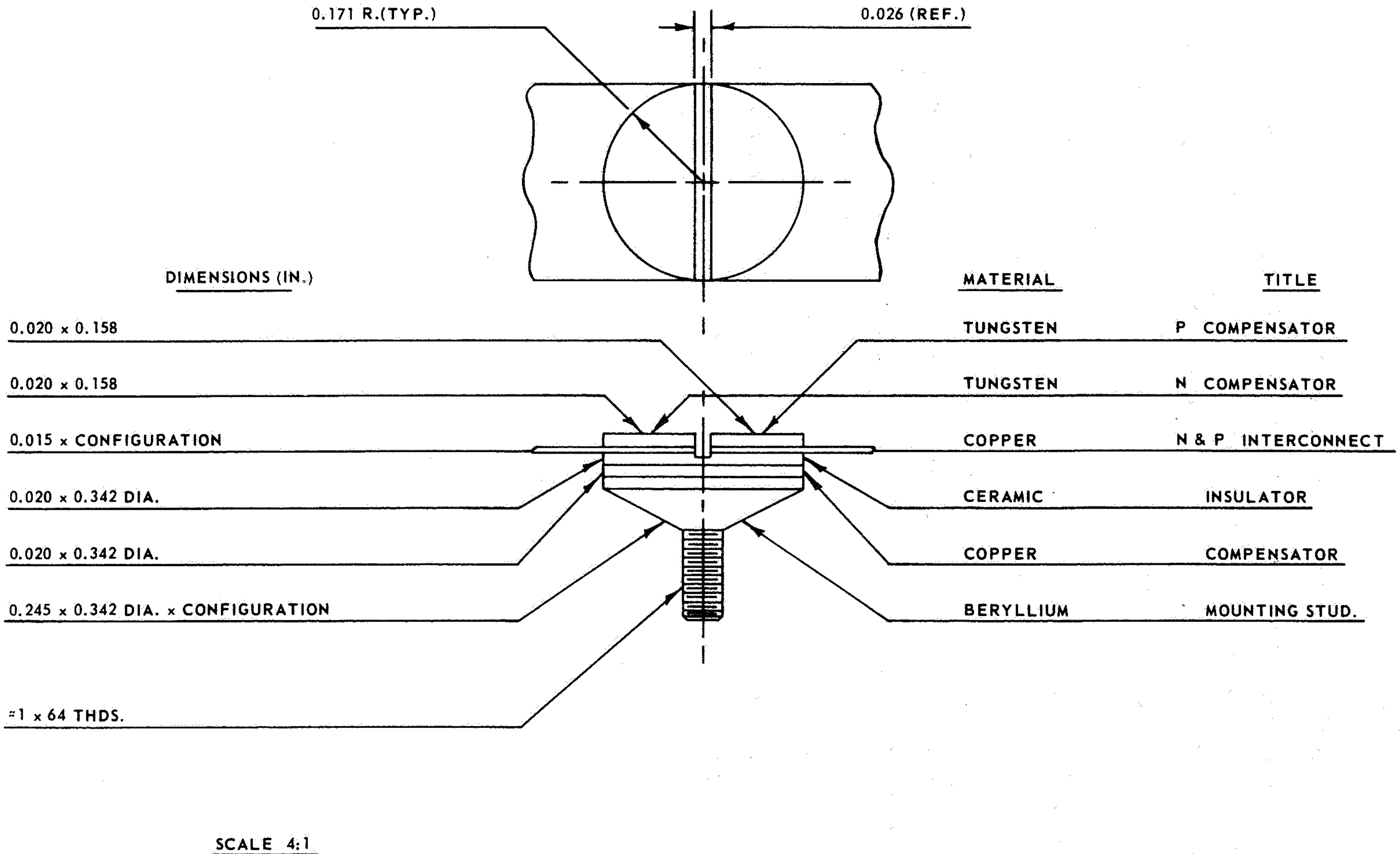


FIGURE 5. COLD END ASSEMBLY

silicon-germanium alloy and the cold shoes to the relatively high thermal expansion material, beryllium.

The stack assembly also serves as an electrical interconnection for the individual thermocouples. At the same time, the thermocouples are electrically isolated from the radiator by an aluminum oxide disc which presents a relatively low thermal impedance to the thermal energy being processed through the thermocouple.

D. FLEXIMOD PANEL STRUCTURE

The thermocouple array takes and maintains its form, prior to mounting on the base plate, from a network of flexible electrical interconnects. This configuration is the fleximod construction which simplifies the problems of fabricating the module in a planar arrangement.

After fabrication, the array is secured to the base plate by inserting the individual couple mount studs through the base plate holes and fastening with bolts.

III. COMPONENT DEVELOPMENT

The fabrication of the test solar panels was preceded by a development effort to resolve those problems unique to the solar panel and not previously encountered in Air-Vac-type construction.

A. "HIPPED" HOT SHOE

The unusual geometry of the silicon-molybdenum hot shoe presented some difficulties regarding the fabrication of the "hipped" configuration. Figure 6 depicts a special vacuum holding fixture designed to facilitate the grinding of the angular flats on one side of the hot shoe surface. This fixture proved successful in the fabrication of hot shoes with the "hipped" configuration, and the number of shoes rejected for reasons of geometry was negligible.

As work progressed with hot shoe fabrication, the machining of more than one shoe from a single silicon-molybdenum-bonded specimen was found practical. This procedure resulted in substantial savings in time and material.

B. THERMOCOUPLE BONDING

A thermocouple alignment fixture, shown in Figure 7, was designed and fabricated for accurate assembly of the couple components before bonding. The components, firmly held by tungsten clips to a ceramic base, were subjected to a bonding process previously developed for Air-Vac-type thermocouples. Special ceramic spacers were designed for use on the angular flats to avoid contact between the tungsten clips and the hot shoe where reaction might occur.

To ensure the integrity of all bonds in the couple, representative bonded specimens were analyzed metallographically in the "as-bonded" state and after isothermal life testing at elevated temperatures.

1. Hot Junction

Solar panel thermocouples were sectioned and examined in detail. The bonds of particular interest consisted of the SiGe-to-SiMo hot shoe bonds and the SiMo(n) - SiMo(p) junction bond.

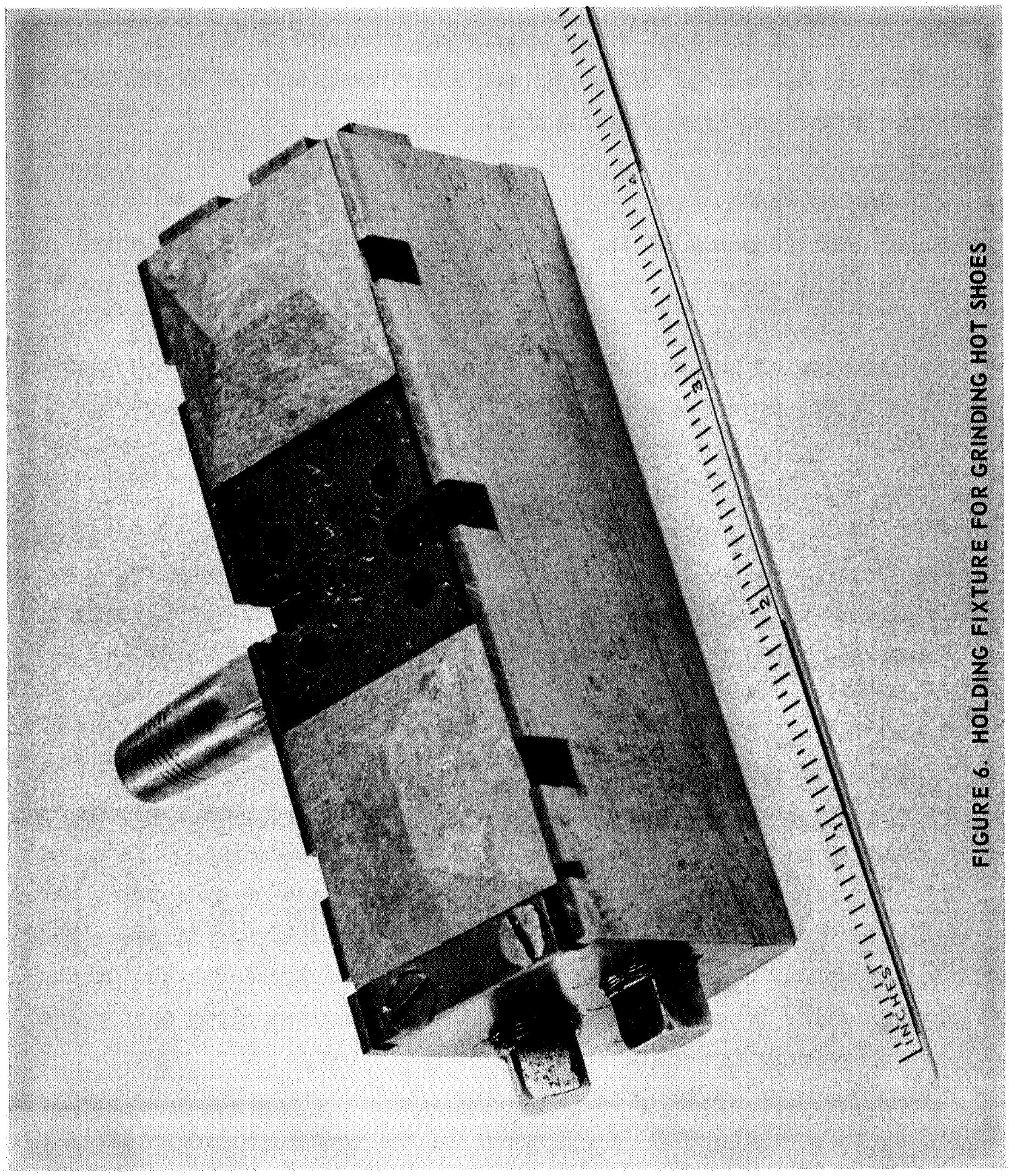


FIGURE 6. HOLDING FIXTURE FOR GRINDING HOT SHOES

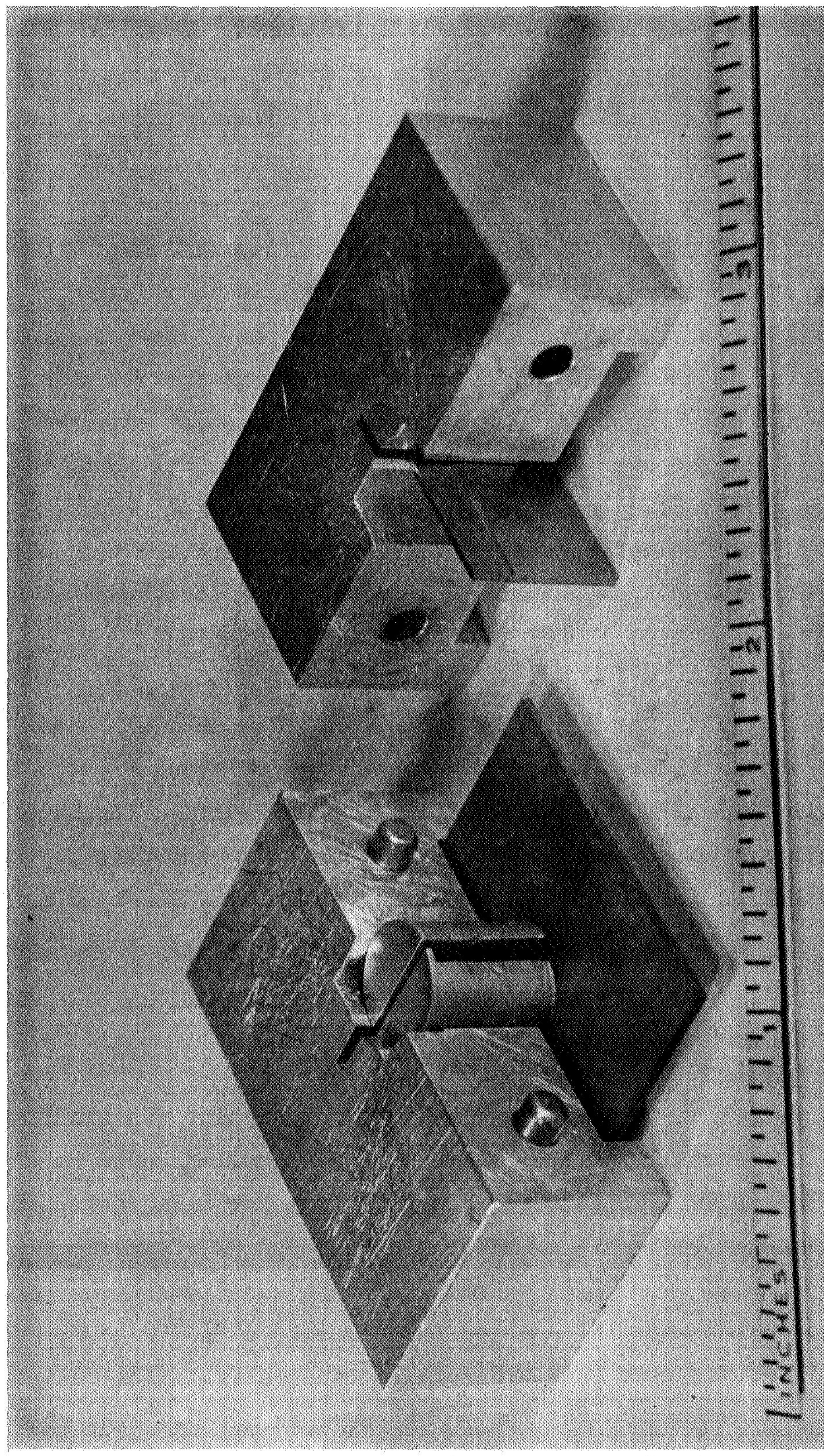


FIGURE 7. THERMOCOUPLE ASSEMBLY ALIGNMENT FIXTURE

The SiGe-SiMo hot junction bonds exhibited excellent sound joints in both the n-type and p-type configurations. A typical joint section, Figure 8, shows a minimum of cracks which can be quite prevalent in a sectioned SiMo structure. This condition indicates that the as-bonded stress in the bond is relatively low. Relative to uniformity, both bonds show areas with various amounts of low melting temperature material which solidifies differently from other parts of the bond, Figure 9. This capability is related to the Ge-rich concentration in the SiGe. Solar panel thermocouples were subjected to isothermal life testing in vacuum for 500 hours at 850°C and metallographically examined. Subsequent examination showed that the over-all integrity of the bonds was good, with no change in the SiGe and SiMo bonds from the initial condition, Figure 10. The solar panel hot junction temperature was 816°C; similar Air-Vac-type structures have been operated successfully at temperatures up to 1000°C for long periods of time.

Figure 11 shows the p SiMo- n SiMo bond. The over-all bond appears sound and uniform; however, the prevalence of cracks in the bond zone is typical of this type of bond and suggests a highly stressed condition. Fortunately, these cracks are perpendicular to the bond and parallel to the structure stress; therefore, the bond can serve to join the two structures. The majority of cracks do not extend into the SiMo.

2. <u>Cold Junction</u>

The SiGe pellet-to-tungsten, (W), cold shoe joint was examined metallographically in the as-bonded condition, as shown in Figure 12, and used as an initial reference condition for life tests. Both n- and p-leg bonds are sound and appear typical of previous production.

Thermocouples were life-tested isothermally at 500°C hours and the cold junctions were examined metallographically. (The design cold junction temperature for the solar panel is 425°C.) The cold junction SiGe-W bond was unchanged.following the isothermal life tests, Figure 13.

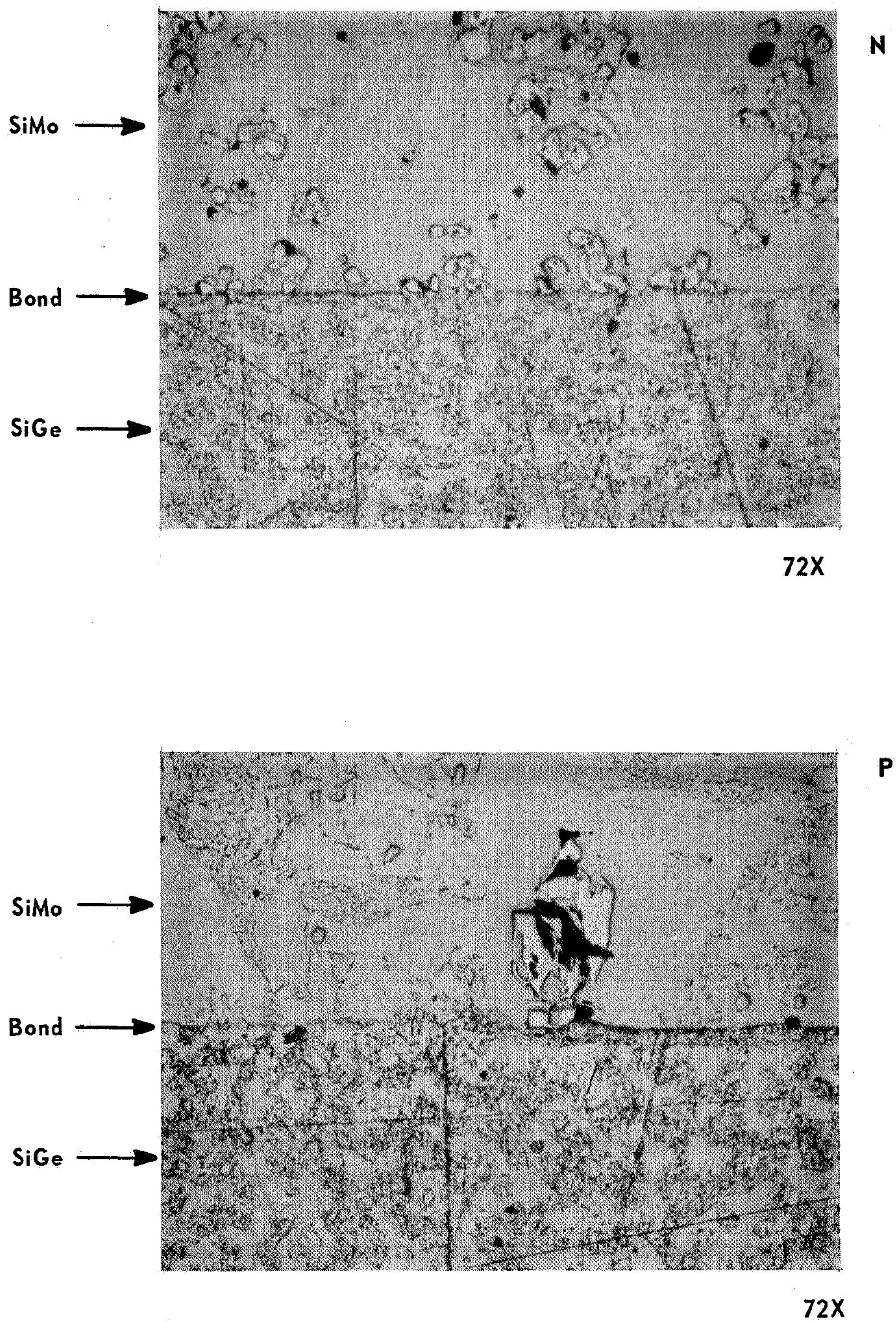
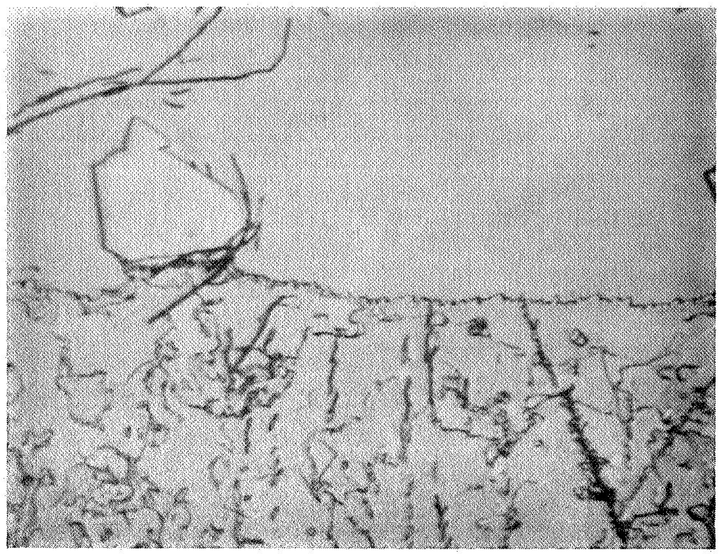


FIGURE 8. SOLAR PANEL HOT JUNCTION STRUCTURE AS-BONDED

Sound Bond (Selected Areas show 1/2 of each bond with obvious liquid phase and 1/2 with no obvious liquid phase).



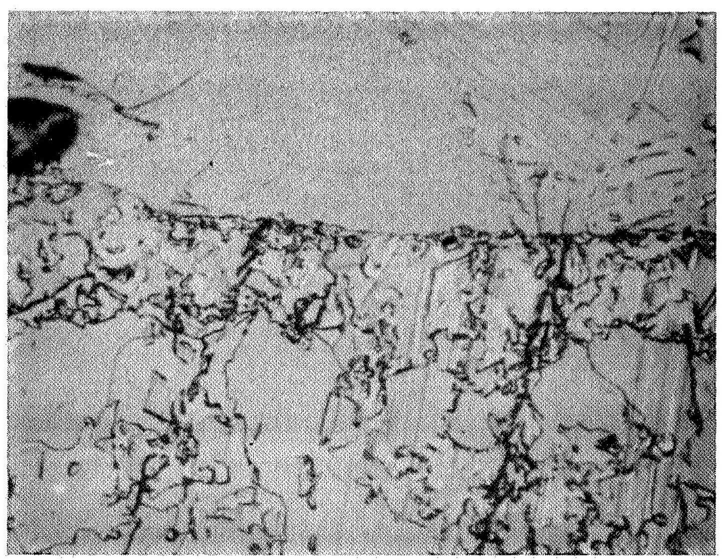
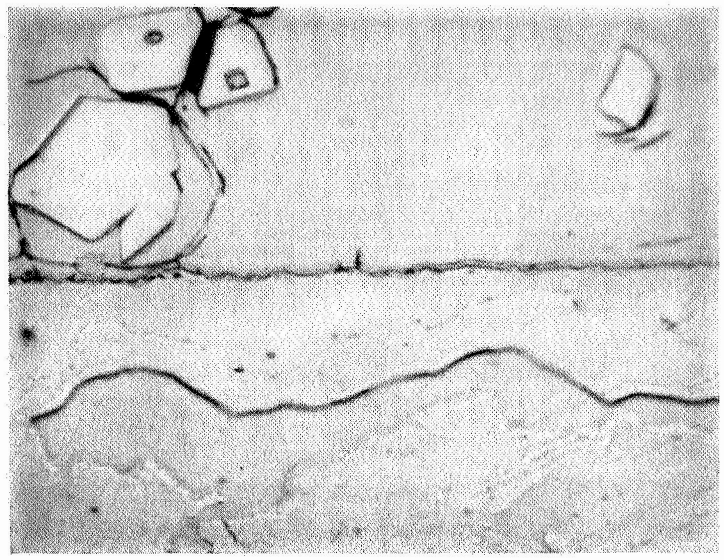


FIGURE 9. SOLAR PANEL HOT JUNCTION STRUCTURE AS-BONDED
Example of Two Types of Bond Structure - Liquid Phase Variation



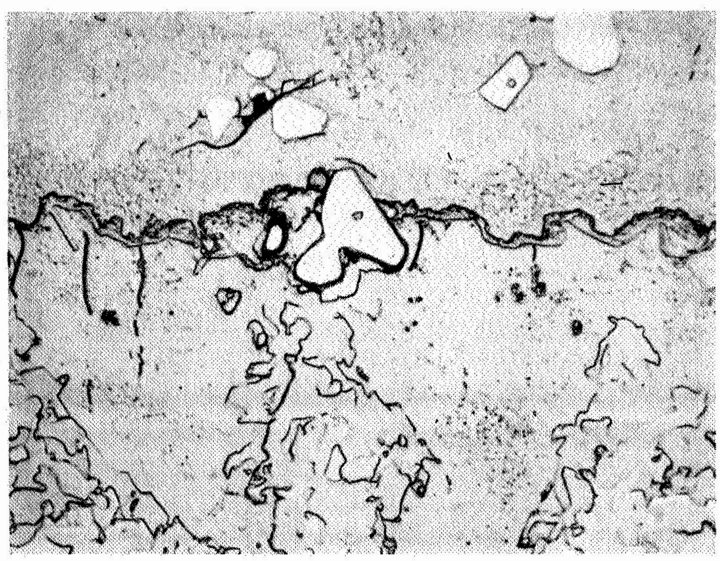
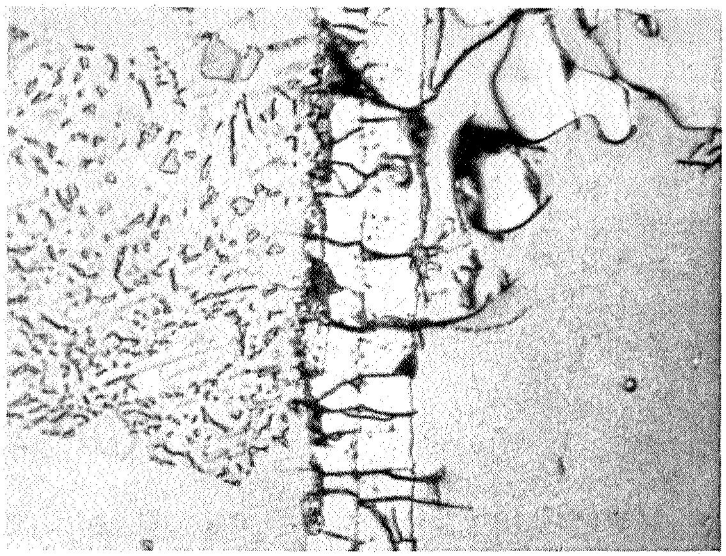


FIGURE 10. SOLAR PANEL HOT JUNCTION STRUCTURES ISOTHERMALLY TESTED
SiMo to SiGe Bonds—850°C - 500 Hrs. Vacuum

P-type
Si Mo



N-type
Si Mo

430X

FIGURE 11. SOLAR PANEL HOT SHOE N & P JUNCTION AS-BONDED

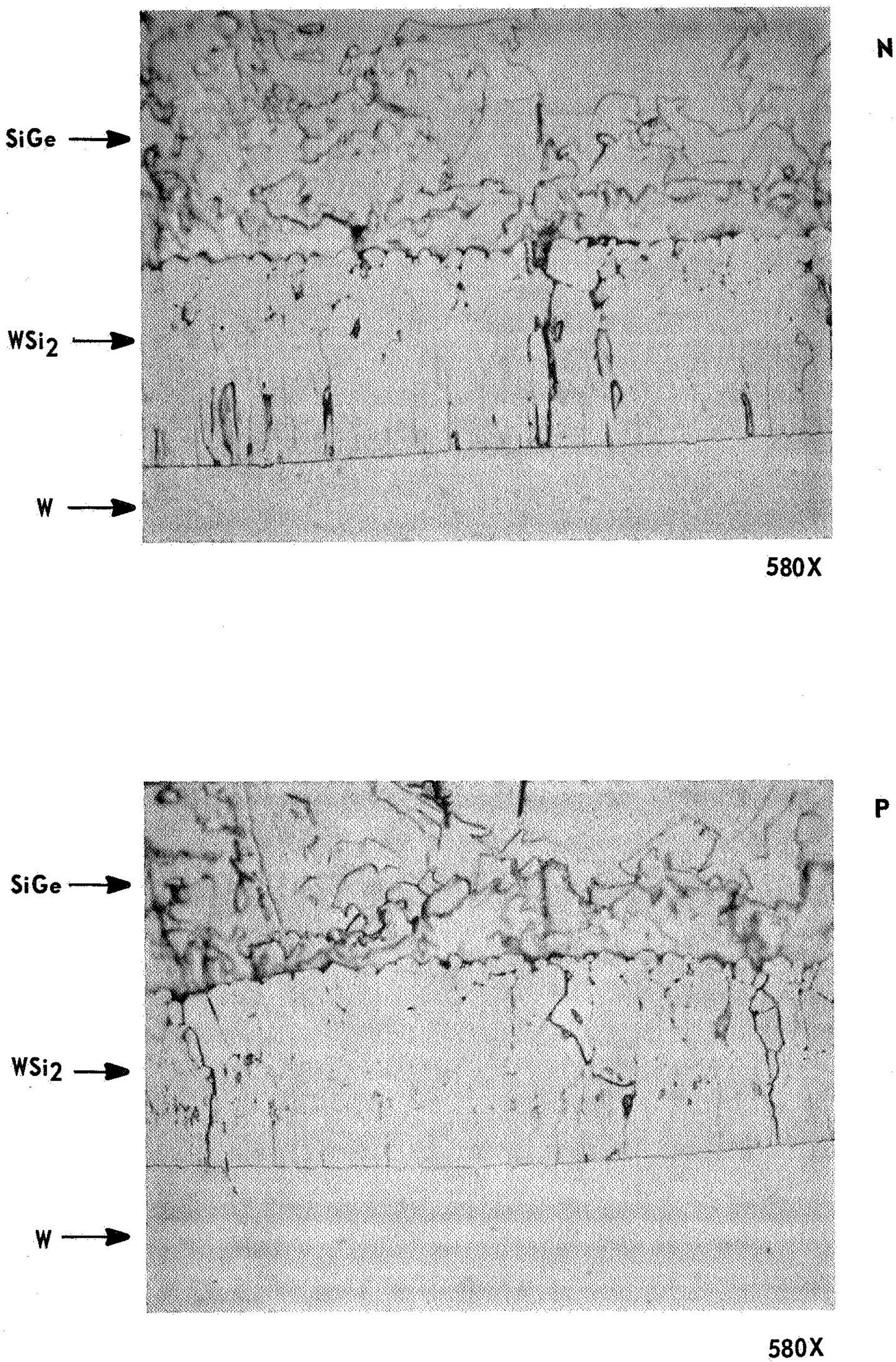


FIGURE 12. SOLAR PANEL COLD JUNCTION STRUCTURES AS-BONDED
Reference Cold Shoe Bonds

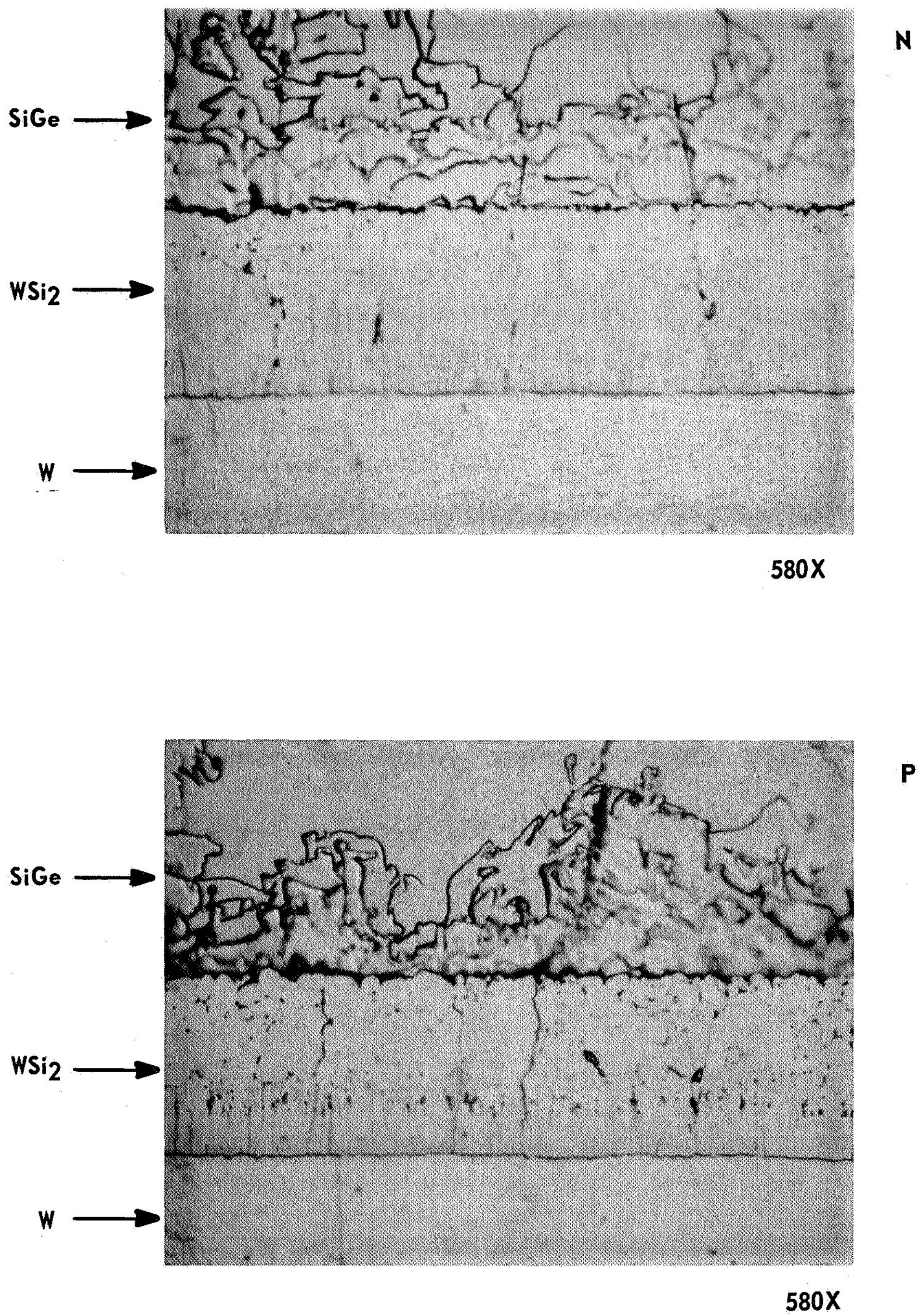


FIGURE 13. SOLAR PANEL COLD JUNCTION STRUCTURES ISOTHERMALLY TESTED

$SiGe$-To-W Bonds---500°C - 500 Hrs. Vacuum

C. MIN-K 2002 THERMAL INSULATION

Tests were completed to determine the machinability of Johns-Manville Min-K 2002 thermal insulation. A holding fixture was designed and fabricated to facilitate machining of the insulation into accurately-dimensioned parts. This fixture and machined parts are shown in Figure 14.

The Min-K 2002 insulation, which is white in the as-received condition, became discolored when fired at temperatures up to 800°C. A spectrographic analysis of the material showed a major constituent to be TiO_2 which, when heated in hydrogen, converts to Ti_2O_3 which is black in color. Johns-Manville has indicated that the thermal insulating property of the Min-K 2002 is unaffected by the color change.

D. SILICON-MOLYBDENUM DISC SURFACE PREPARATION

During the fabrication procedure for producing silicon-molybdenum hot shoes, n-type SiMo discs are bonded to p-type SiMo discs. The preparation of the bonding surface is an important factor in ensuring a high-integrity junction. Previously, this technique involved careful polishing of the disc-bonding surface, an operation that represented a substantial cost. In addition, polishing did not always guarantee an optimum surface condition. For these reasons, a study of methods for SiMo disc-surface preparation was completed. The results showed that as-cut disc surfaces were acceptable for bonding and that there were some indications of bond quality improvement.

During the study, SiMo discs were prepared with polished, sandblasted, and as-cut surfaces. The as-cut surfaces were those resulting from SiMo casting sliced on the Micromech slicing equipment with metal-bonded diamond wheels. Bonding parameters were those based on past experience for the fabrication of Air-Vac-type SiMo hot shoes using RCA-developed bonding conditions. Bonded specimens were compared by the use of tensile and metallographic techniques.

The tensile data were inconclusive because few specimens broke in the bond area. The metallographic data, however, showed definite improvements

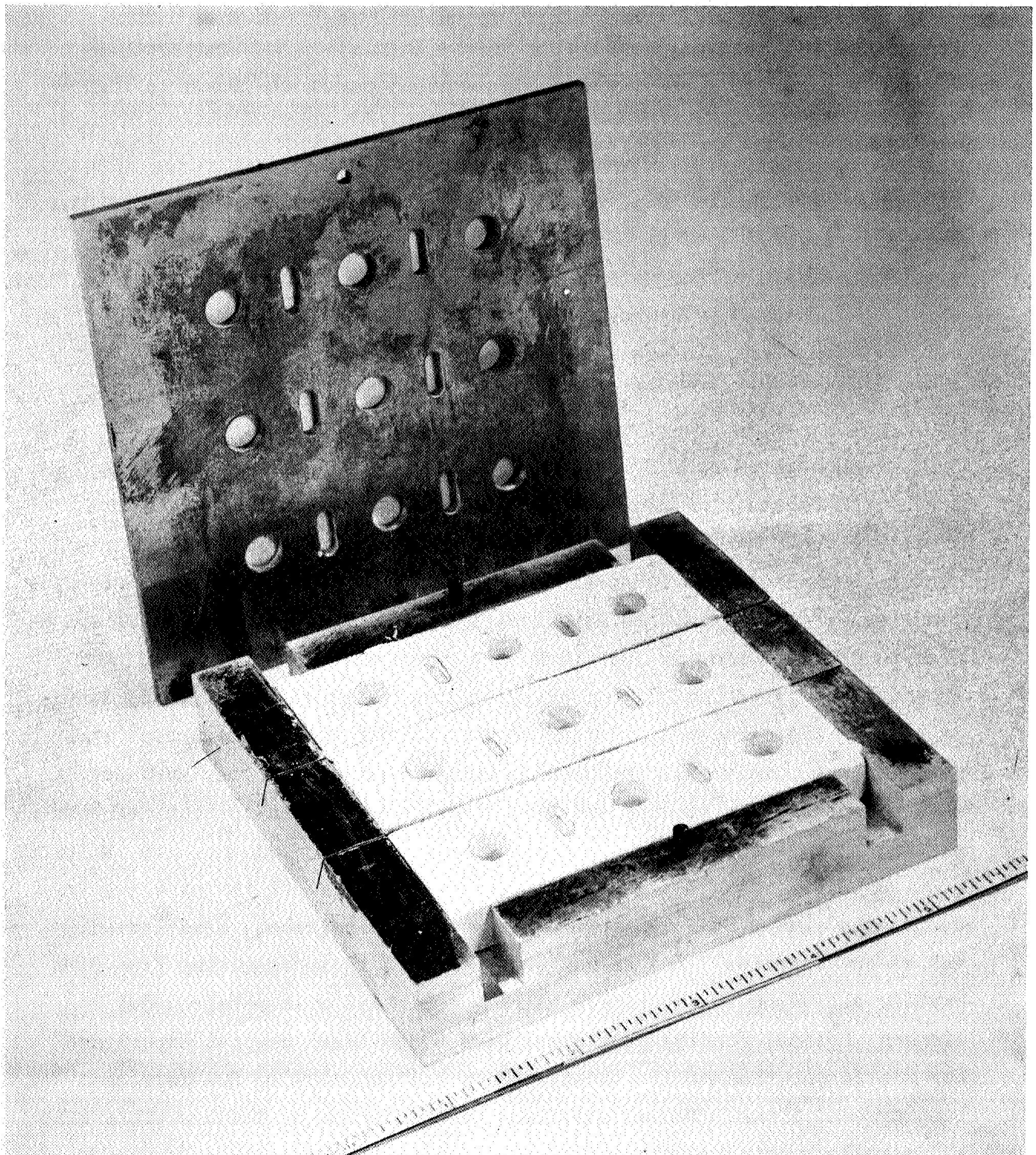


FIGURE 14. HOLDING FIXTURE FOR INSULATION MACHINING

in bonds with as-cut discs. Figures 15 and 16 are photomicrographs of bonds representing all the surface conditions studied. Figure 15a shows a bond with sandblasted SiMo surface preparation. This structure has large longitudinal cracks along the discs in the bond area. Figure 15b represents the polished surface bond, and Figure 16 shows the as-cut surface bond. The void counts in the respective bond areas, listed in Table I, confirm the as-cut condition to be superior in this series of tests.

TABLE I

SiMo N-P BOND VOID COUNT

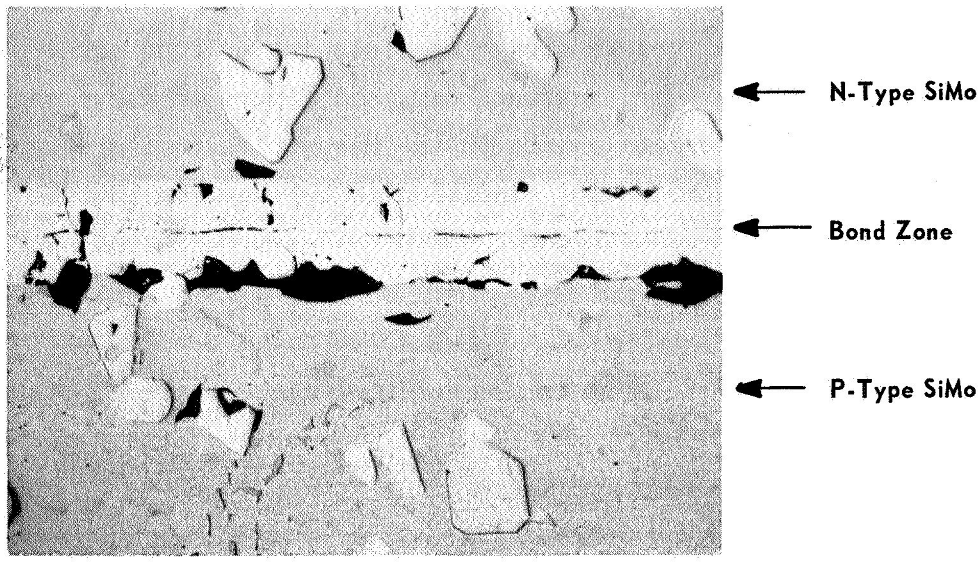
Surface Preparation	Void Count
Sandblasted	80 - 90%
Polished	8 - 10%
As-Cut	1 - 5%

Note: Void count expresses in percentage the length of uncontacted interfaces in a given bond system. The count is made under high magnification, usually 250X or 500X, linearly along the bonded area.

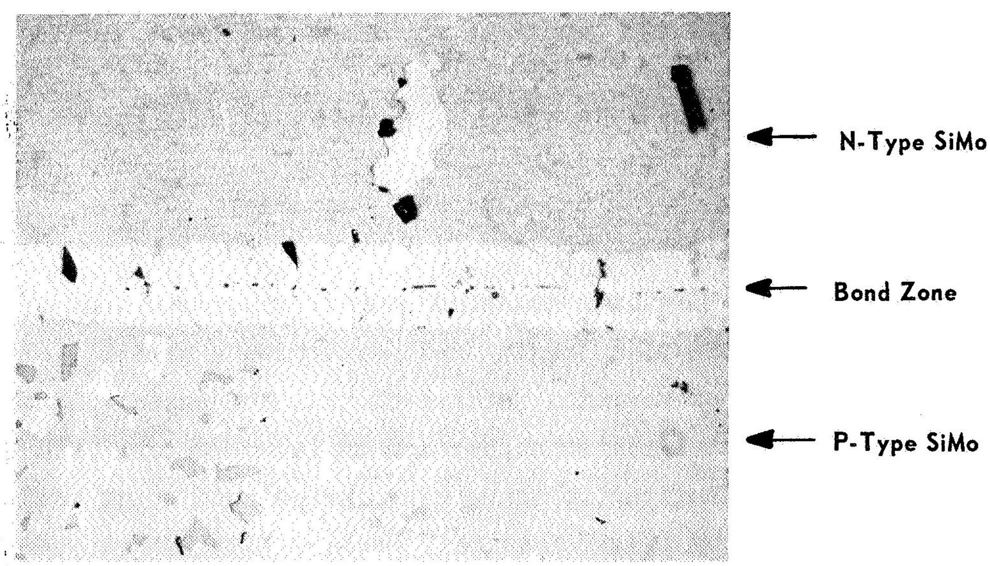
E. BERYLLIUM - COPPER BOND

Attachment of the beryllium mounting stud to the copper compensator required development of a bonding method to give a reliable, long-life joint. Specimens of unplated, nickel-plated, and copper-plated beryllium were brazed to nickel-plated copper and unplated copper. The brazing parameters were identical to those used during cold stack bonding, previously developed by RCA.

Representative specimens were tensile tested "as-bonded" or after isothermal life in sealed, evacuated quartz ampules. The tensile data are summarized in Table II. These data show the nickel-plated copper-to-unplated beryllium bond to be superior to the nickel-and/or copper-plated beryllium initially and after isothermal life.

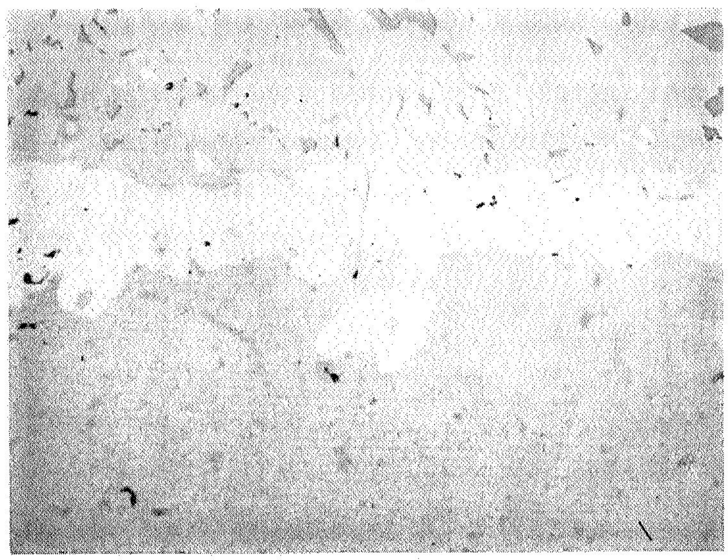


(A) Sandblasted Surfaces 297X



(B) Polished Surfaces 297X

FIGURE 15. SILICON-MOLYBDENUM DISC SURFACE PREPARATION



As-Cut Surfaces 297X

FIGURE 16. SILICON-MOLYBDENUM DISC SURFACE PREPARATION

The tensile data were supported by metallographic analyses of the bond areas which were examined after 168 hours at both 485°C and 600°C, Figure 17. Basically, the structure appears to have two general zones viz., a larger braze plus-Ni zone and a smaller Be-rich zone. Voids either from diffusion or "pull out" occur at the three interfaces; tensile separation occurs at the beryllium interface. The major developments from the 485°C test to the 600°C test were the expanded Be-rich zone and the increased voids at the Be interface.

The voids developed in the +60°C accelerated temperature tests of 485°C for 168 hours (cold junction design temperature is 425°C) did not impair the strength of the bond to any significant degree as shown by Table II. Additional tests with actual cold stack structures containing beryllium studs were satisfactory.

TABLE II

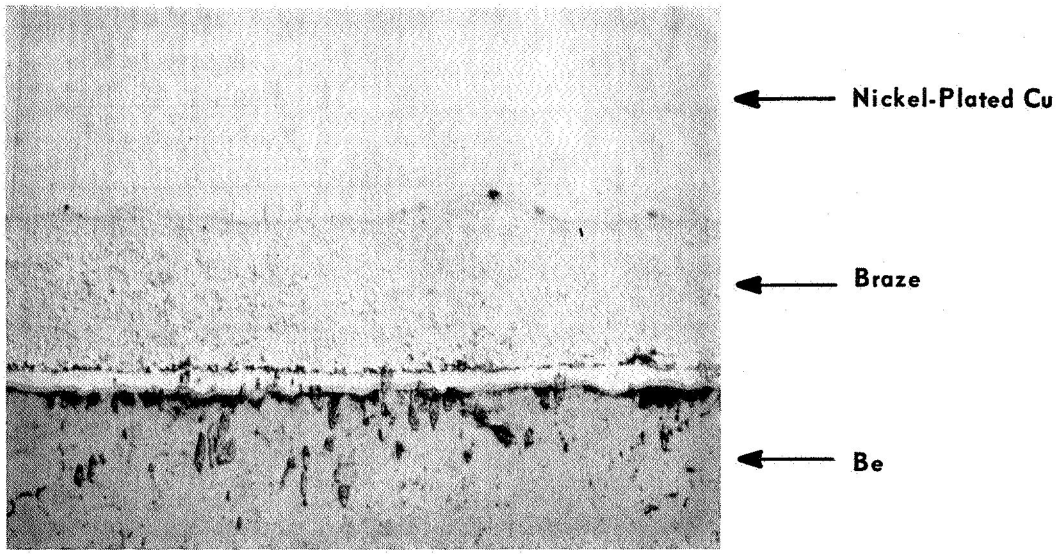
BERYLLIUM - COPPER BOND TENSILE DATA

Sandwich Configuration	Isothermal Time(hrs)	Temp(°C)	Breaking Load psi
*NiPl Cu - Bare Be-Bare Cu	As-Bonded		11,500
NiPl Cu - Bare Be-Bare Cu	168	485	10,455
NiPl Cu - Bare Be-Bare Cu	168	600	3,310
NiPl Cu - NiPlBe - Bare Cu	As-Bonded		30
NiPl Cu - NiPlBe - Bare Cu	168	485	306
NiPl Cu - NiPlBe - Bare Cu	168	600	35
NiPl Cu - CuPlBe - Bare Cu	As-Bonded		7,100
NiPl Cu - CuPlBe - Bare Cu	168	485	1,450
NiPl Cu - CuPlBe - Bare Cu	168	600	355

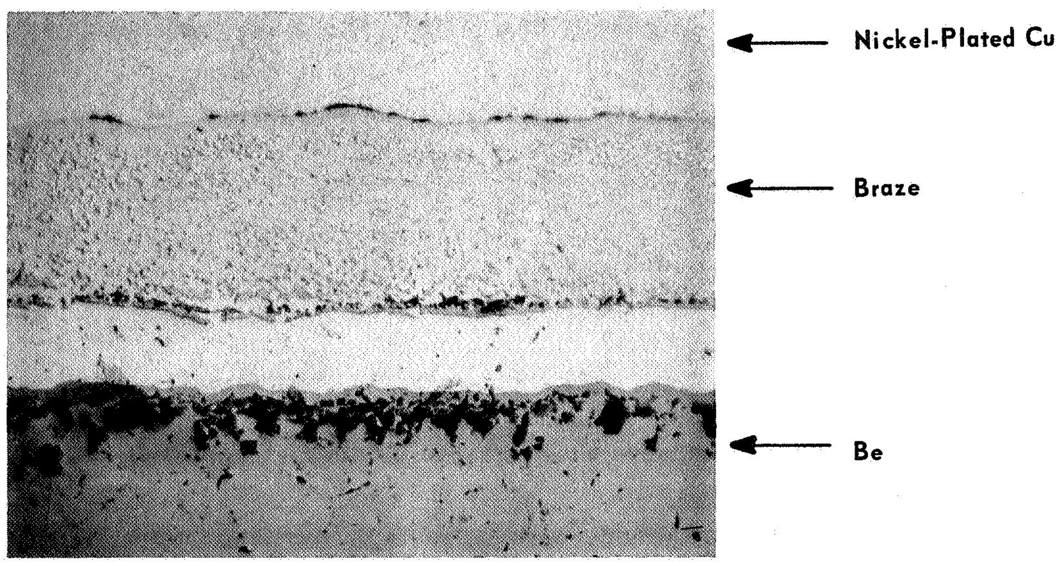
*NiPl - Nickel-Plated

F. SUMMARY OF DEVELOPMENT EFFORT TESTS

Table III lists the various tests performed during the development effort of the panel development program. These tests include metallographic sectioning, tensile, and isothermal life testing of both thermocouples and component parts. Included also are similar tests performed on Be-Cu braze coupons and SiMo-disc surface preparation specimens.



(A) 168 hours at 485°C 297X



(B) 168 hours at 600°C 297X

FIGURE 17. COPPER-BERYLLIUM BRAZE TESTS

TABLE III

SUMMARY OF DEVELOPMENT EFFORT TESTS

	Approximate Number of Tests			
	Sections (metallographic)	Photographs	Isothermal (life)	Tensile (Instron)
Thermocouple Bonding Hot Junction	10	11	6	5
Thermocouple Bonding Cold Junction	7	8	6	5
SiMo Disc Surface Preparation	11	10	-	20
Be-Cu Bond	15	14	10	12

IV. FABRICATION PROCEDURE

This section describes the procedures followed during the fabrication of the test panel sections. Supplementary information is contained in the Fabrication and Assembly Process Specifications, Appendix I.

A. THERMOCOUPLE ASSEMBLY

1. Silicon Molybdenum Hot Shoe

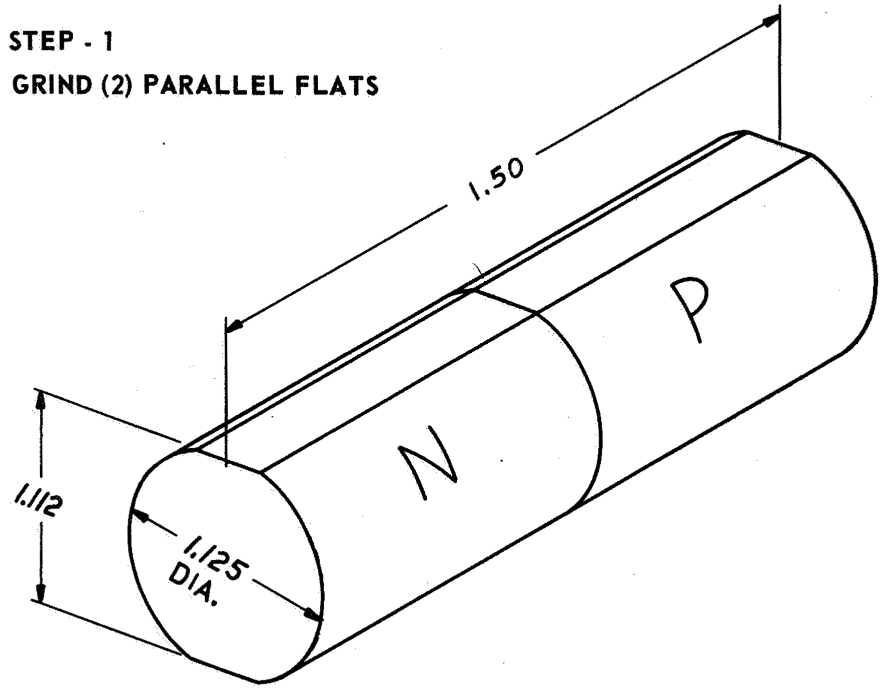
Silicon molybdenum is an experimental Si/$MoSi_2$ multi-phase alloy prepared by vacuum-casting the elemental constituents. Silicon and molybdenum were melted with the dopants (phosphorus or boron) in a quartz crucible by RF heating and poured into a carbonized quartz mold. On solidification, the castings were removed from the mold and sliced into discs 1-1/8 inch diameter x 3/4 inch long. Individual slice densities were measured by the water-immersion technique for subsequent matching of n- and p-slices. The bonding surface of each disc was polished and the n- and p-discs were metallurgically bonded. Figures 18 and 19 illustrate the machining sequence for the fabrication of the "hipped" configuration hot shoes. After washing in methanol-acetone to remove grease and grinding residue, the parts were inspected for visible structural faults and dimensions.

2. Thermocouple Legs

Silicon-germanium alloy is prepared by vacuum-casting the elemental constituents including the appropriate dopant to provide homogeneous feed material for subsequent zone-leveling. As shown in Figure 17A, the SiGe phase diagram consists of a complete series of solid solutions. To achieve zone-leveling of solid-solution alloys, a zone of liquidus composition (C_L) was moved through charge material of the corresponding solidus composition (C_S), as illustrated in Figures 20B and 20C. The result was a homogeneous, uniformly-doped polycrystalline SiGe alloy. The composition used for the test panels was 63.5 at. percent Si doped n-type (phosphorus) and p-type (boron).

STEP - 1

GRIND (2) PARALLEL FLATS



STEP - 2

SLICE RECTANGLE

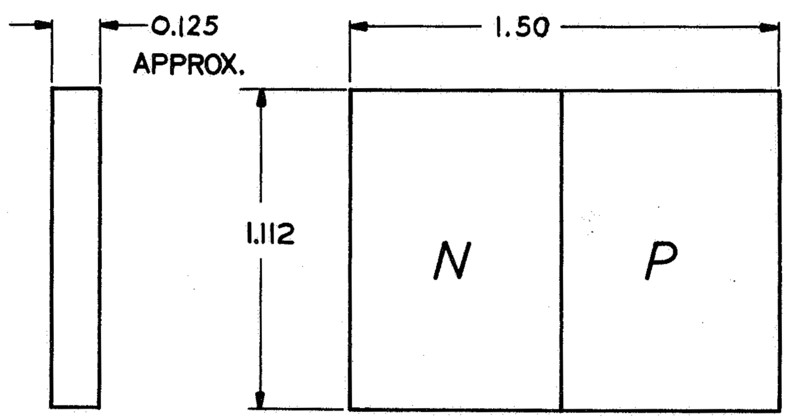
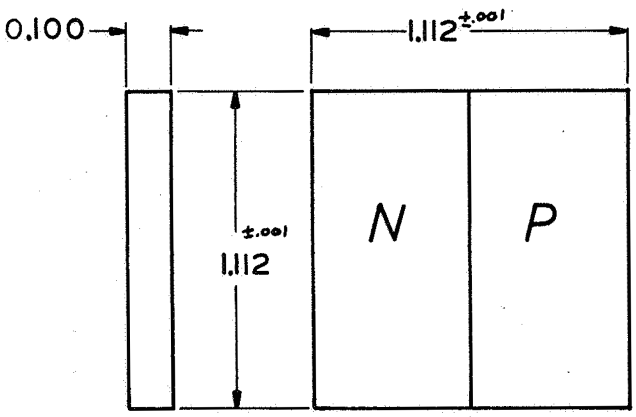


FIGURE 18. "HIPPED" HOT SHOE MACHINING SEQUENCE - STEPS 1 AND 2

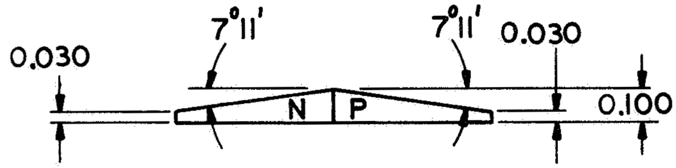
STEP - 3

SIZE RECTANGLE (GRIND)



STEP - 4

GRIND 1st PAIR OF ANGLES



STEP - 5

GRIND 2nd PAIR OF ANGLES

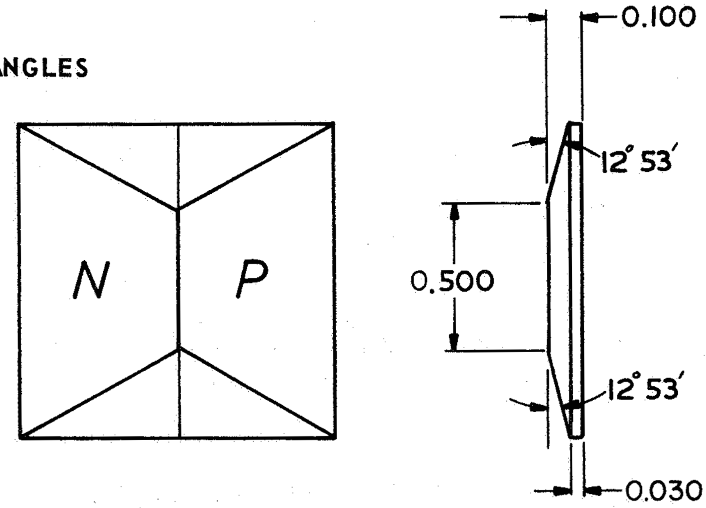


FIGURE 19. "HIPPED" HOT SHOE MACHINING SEQUENCE - STEPS 3, 4, AND 5

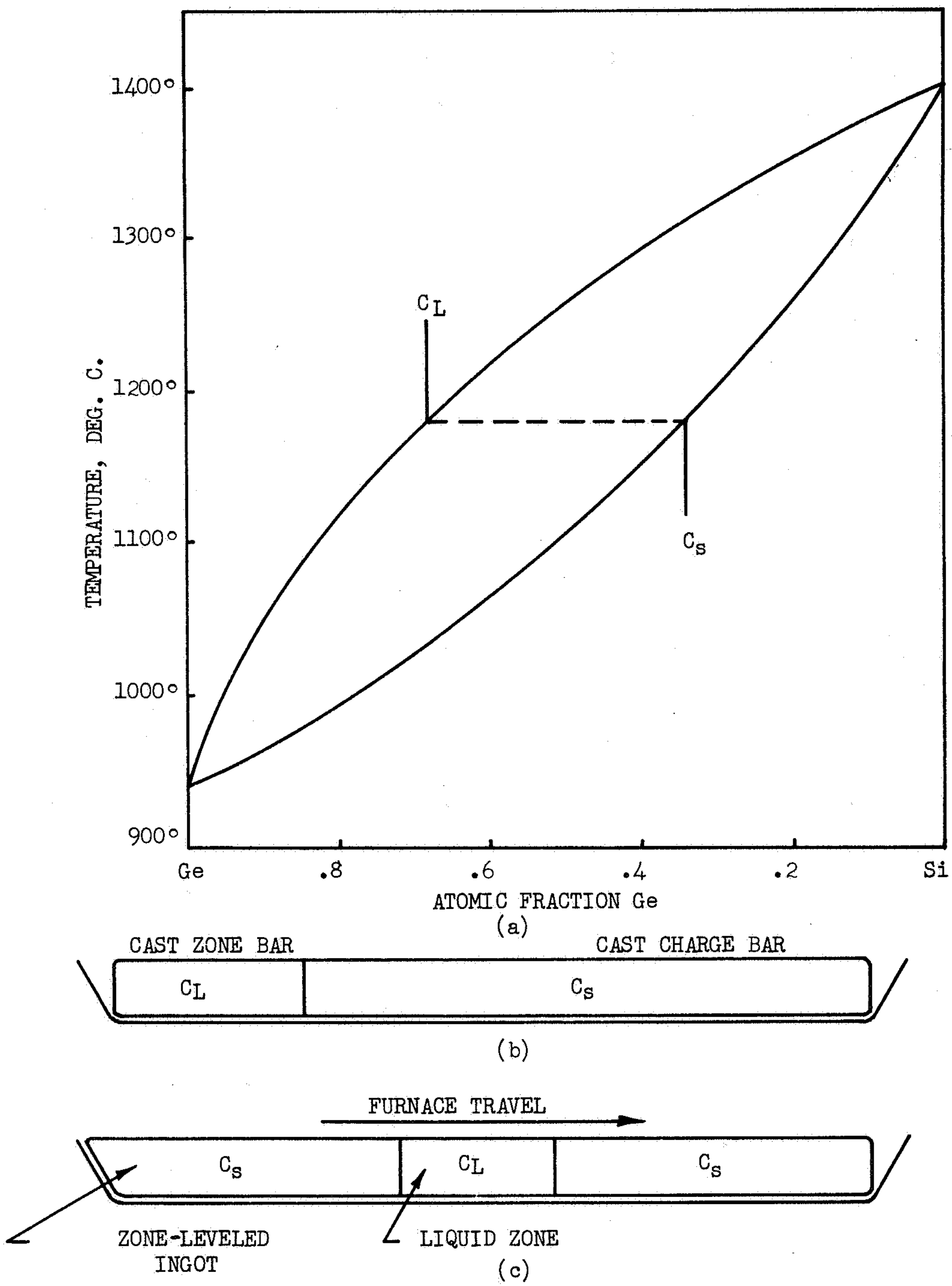


FIGURE 20. SiGe PHASE DIAGRAM AND ZONE-LEVELING SEQUENCE

The ingots were sliced into sections sufficiently long to permit end grinding of the legs to a finished dimension. Figure 21 depicts the machining sequence for the thermocouple legs. Each individual pellet was weighed to ensure correct composition, inspected for structural faults, and measured for dimension. N- and p-pellets were matched for length. The finished parts were washed in methanol-acetone to remove grinding residue and stains.

3. Cold Shoes

The tungsten cold shoes were fabricated from bar stock by the Cleveland Refractory Metals Company. The density of the bulk tungsten was specified to be 18.9 g/cm^3. Incoming shoes for the n-type and p-type SiGe legs were rigidly inspected for dimensions and flatness, then washed in hot Blacosolv, hot water, and methanol to ensure a clean surface for bonding. The tungsten cold shoes were stored in clean, properly identified envelopes.

B. THERMOCOUPLE FABRICATION

Thermocouple components consisting of a SiMo hot shoe, two SiGe legs, and two tungsten cold shoes were precisely aligned in an assembly jig. The components were rigidly held in position on a flat aluminum oxide plate by tungsten clips. Each assembly was identified by penciled numbers on the ceramic base.

The thermocouple assembly was transferred to a furnace and metallurgically bonded according to a schedule previously developed by RCA for Air-Vac-type couples. On removal from the furnace, each couple was identified by marking the couple number on the hot shoe and visually inspected under a low power microscope for structural faults and bond fillets. Thermocouples showing cracks or "cold" bonds were rejected. The couples were inspected electrically for total resistance, leg resistances, and all bond-contact resistances. (Figure 22 is a typical thermocouple resistance data sheet.)

The cold shoes were nickel-plated and sintered for subsequent bonding to the cold stack. (These* processes were developed previously by RCA for Air-Vac-type couples.)

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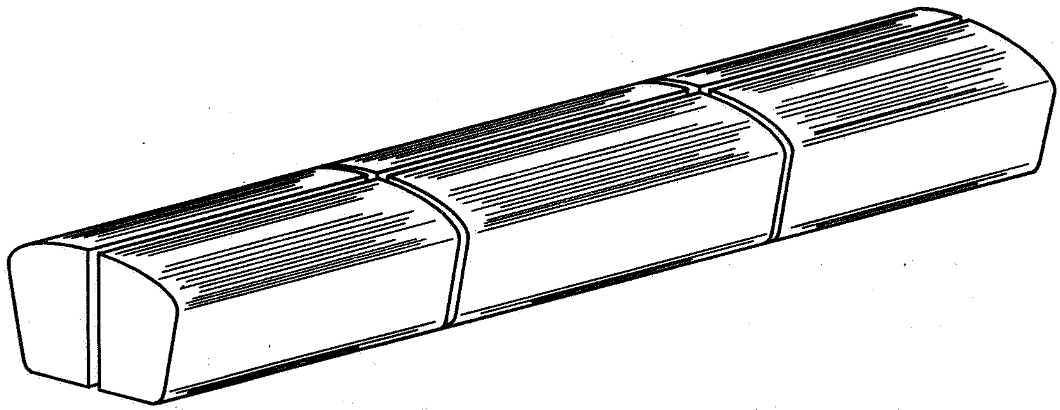
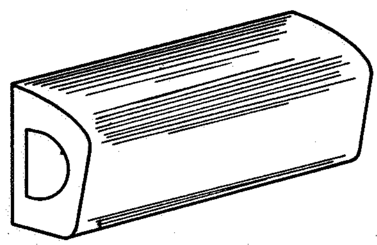
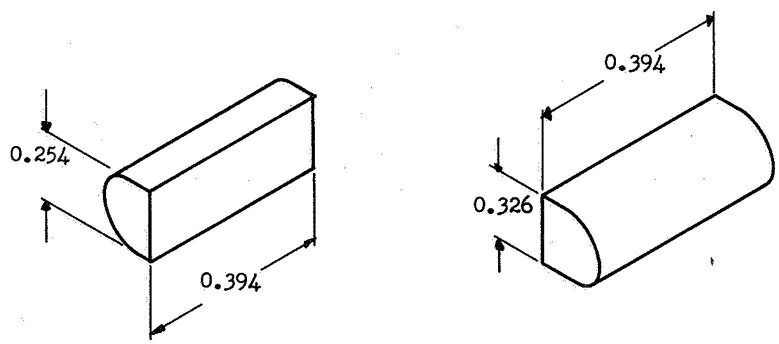
*RCA Proprietary



Sectioned Ingot



Section for Cylindrical Grinding

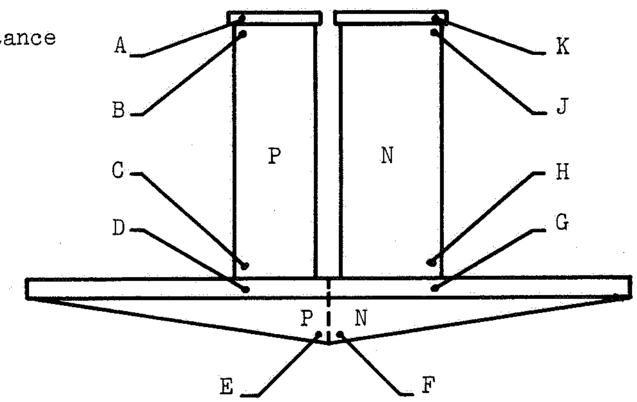


P - Pellet N - Pellet

FIGURE 21. SILICON - GERMANIUM PELLET MACHINING SEQUENCE

TEST SOLAR PANEL

Thermocouple Resistance Data



Material Information

			Seebeck V°C	Rho X 10^{-3}	Density g/cm^3
542 RN	N	Ingot	150	1.56	3.505
539 RP	P	Ingot	103	1.00	3.501

Comments: Bonded 11/8/67 - 11/9/67

#1 Brew

Couple No.	A–B	C–D	E–F	G–H	J–K	A–K	A–D	G–K
	Resistance							
37	.36	.20	.16	.51	.39	13.4	6.87	6.20
38	.42	.18	.14	.27	.56	13.6	7.07	6.12
39	.46	.19	.15	.23	.34	13.3	7.02	5.91
40	.38	.15	.18	.32	.21	13.6	7.08	6.02
41	.42	.17	.13	.22	.46	13.7	7.13	6.12
42	.40	.15	.12	.25	.46	13.4	6.9	6.27
43	.33	.16	.16	.24	.22	13.4	6.97	6.05
44	.30	.17	.12	.27	.28	13.2	6.97	5.85
45	.33	.15	.13	.29	.30	13.4	6.92	6.20
46	.26	.14	.17	.43	.44	13.4	6.82	6.18
47	.28	.17	.13	.29	.27	12.4	6.60	5.50

Date: 11-9-67

Data taken by: [signature]

FIGURE 22. SOLAR PANEL THERMOCOUPLE DATA SHEET

To accommodate the 5-mil W3Re/W26Re thermocouple wire for the hot junction temperature measurement, holes 0.035 inch in diameter and 0.100 inch deep were drilled in the hot shoe near the p-leg. The thermocouple bead was inserted in the hole. The bead and the ceramic sleeve housing the thermocouple wire were then cemented to the SiMo hot shoe with an aluminum oxide paste containing a hydrolyzed aluminum nitrate binder which does not react with the hot shoe or thermocouple materials. The binder converts to aluminum oxide during a baking sequence. The assembly is shown in Figure 23.

C. COLD STACK ASSEMBLY

1. Pedestal

The pedestals adjacent to the cold shoes were fabricated from 0.025 inch copper strip O.F.H.C. 1/2 hard. The parts were punched from the strip using a die and power press. To prepare the parts for plating, the pedestals were washed in hot Blacosolv, hot water, and methanol. If the surfaces of the copper pedestals showed evidence of oxidation, they were subjected to a wash in cyanide solution in addition to the previously described cleaning process. The parts were fired in dry hydrogen for 10 minutes at 800°C to ensure a bright, clean surface for nickel plating. The pedestals were *nickel-plated and *sintered by the previously described RCA processes. After a critical inspection for blisters under a low power microscope, the parts were stored in properly identified cardboard boxes.

2. Compensator

The tungsten compensators in the cold end assembly were fabricated by the Cleveland Refractory Metals Company, and had a specified density of 18.9 g/cm^3. The parts were inspected for dimension and flatness, then lightly sandblasted with an S.S. White sandblasting unit to roughen the surface for plating. After washing in 50 percent acetone and 50 percent methanol, the tungsten compensators were *nickel-plated and *sintered. The plated parts were inspected under a low power microscope and stored in labeled cardboard boxes.

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*Both processes are RCA Proprietary

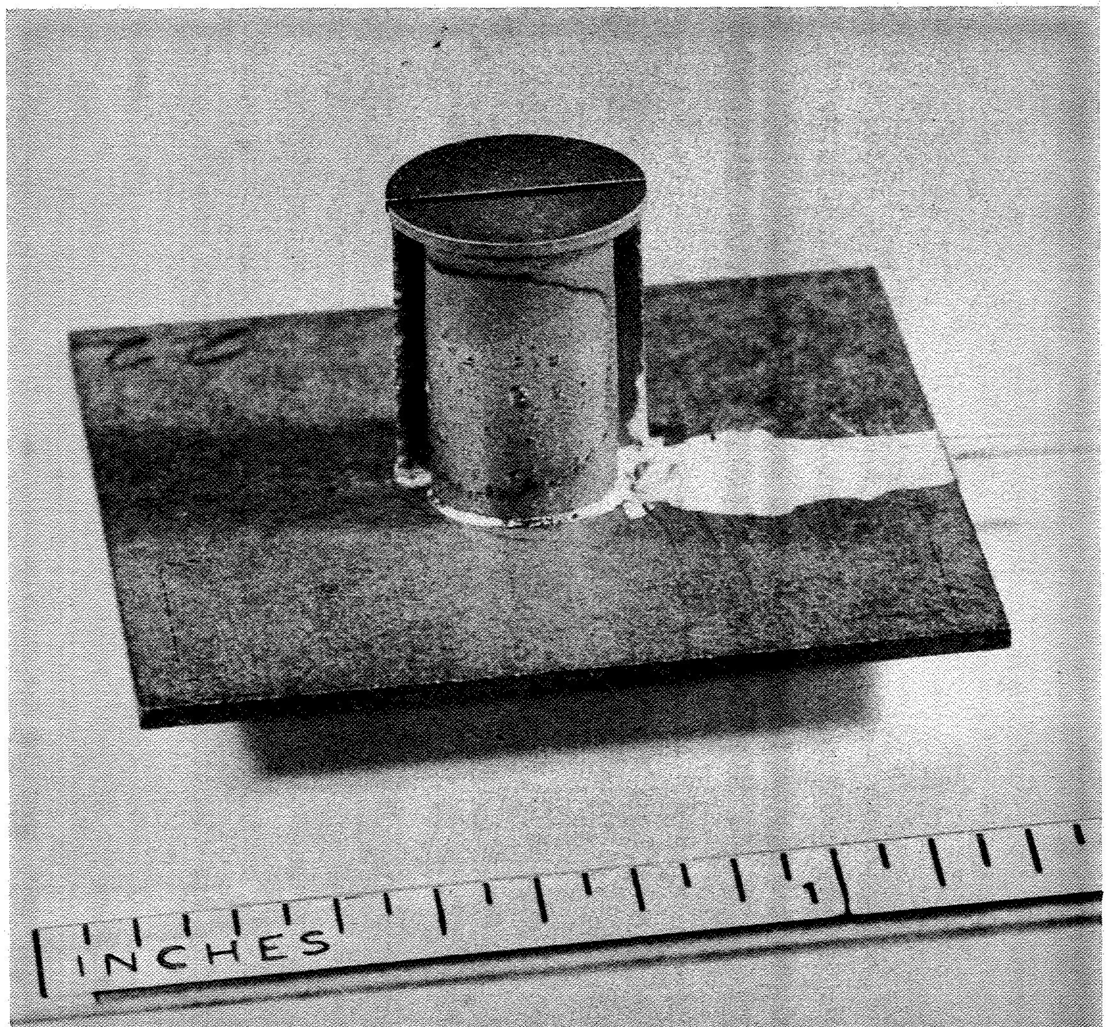

FIGURE 23. HOT SHOE TEMPERATURE MEASURING THERMOCOUPLE

3. Interconnect

The electrical interconnects were fabricated from 0.015 inch copper strip, O.F.H.C. 1/2 hard, using a power press and die. The parts were washed in hot Blacosolv, hot water, and methanol to remove oils and machining residues. If surface oxides were evident, the parts received an additional cleaning in cyanide solution. The copper interconnects were fired at 800°C for 10 minutes as a final step in ensuring a clean surface for plating. After *nickel plating and *sintering, the parts were inspected for dimensions, plating thickness, and blisters. Acceptable parts were stored in labeled cardboard boxes.

4. Insulator

The aluminum oxide insulators were metallized on two faces by an RCA proprietary technique. After bright firing at 1000°C in dry hydrogen to prepare the surfaces, the parts were *nickel-plated and *sintered. The insulators were carefully inspected for blisters in plating under a low power microscope. Following the inspection, the parts were slot-ground to the proper diameter. After washing in cold Blacosolv and methanol to remove grinding residue, the insulators were fired again in dry hydrogen for five minutes to ensure dryness. The parts were finally inspected for dimensions and stored in properly identified cardboard boxes.

5. Compensator

The compensator was fabricated from 0.020 inch copper strip, O.F.H.C. 1/2 hard, using a power press with a punch and die. Subsequent processing was identical to that given to the copper pedestal.

6. Mount Stud

The beryllium mount studs were fabricated by the Beryllium Manufacturing Corporation, using Ber Met 2.0 Grade supplied by the Beryllium Metals and Chemical Corporation. The specified density was 1.85 gm/cm^3 at 68°F. When received, the parts were inspected, washed in acetone, and stored in plastic boxes.

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*RCA Proprietary

7. Stud Nut

The mount stud nuts were fabricated by the Beryllium Manufacturing Corporation, using beryllium Mil B 21531 supplied by General Astro-Metals Corporation. The specified density was 1.84 gm/cm^3, or greater. The stud nuts were washed in acetone and stored in plastic boxes.

8. Base Plate

The beryllium base plate, Figure 24, was fabricated by Beryllium Manufacturing Corporation. The material used was beryllium Ber Met 2.0 with a specified density of 1.85 gm/cm^3 supplied by the Beryllium Metals and Chemical Corporation. The base plates were inspected for dimension and washed in acetone. The beryllium base plates were coated with calcium titanate.

9. Insulation

The thermal insulation, Min-K 2002, was supplied by Johns-Manville Corp. The density of this material was 10-20 lbs/ft^3 (nom.) and the composition was 84 percent SiO_2-16 percent TiO_2. The Min-K 2002 was fabricated into parts using a specially designed jig shown in Figure 14. During the machining process, no lubricants were used. No further processing was given the thermal insulation.

D. COLD STACK ASSEMBLY BONDING

The components, shown in Figure 2, were precisely aligned in the assembly and firing jig, Figure 25. One three-couple assembly, including the Min-K 2002 insulation, was processed each time. After metallurgical bonding, following procedures developed by RCA, the three-couple assemblies were examined visually and tested electrically. The copper electrical connectors were drilled with 0.018-inch holes to accommodate the thermocouple and voltage probes which were 0.005 inch diameter Chromel Alumel. The wires were inserted in the holes and the copper connector was peened to fix the wires in place. The locations of the thermocouple and voltage probes are shown in Figures 26 and 27.

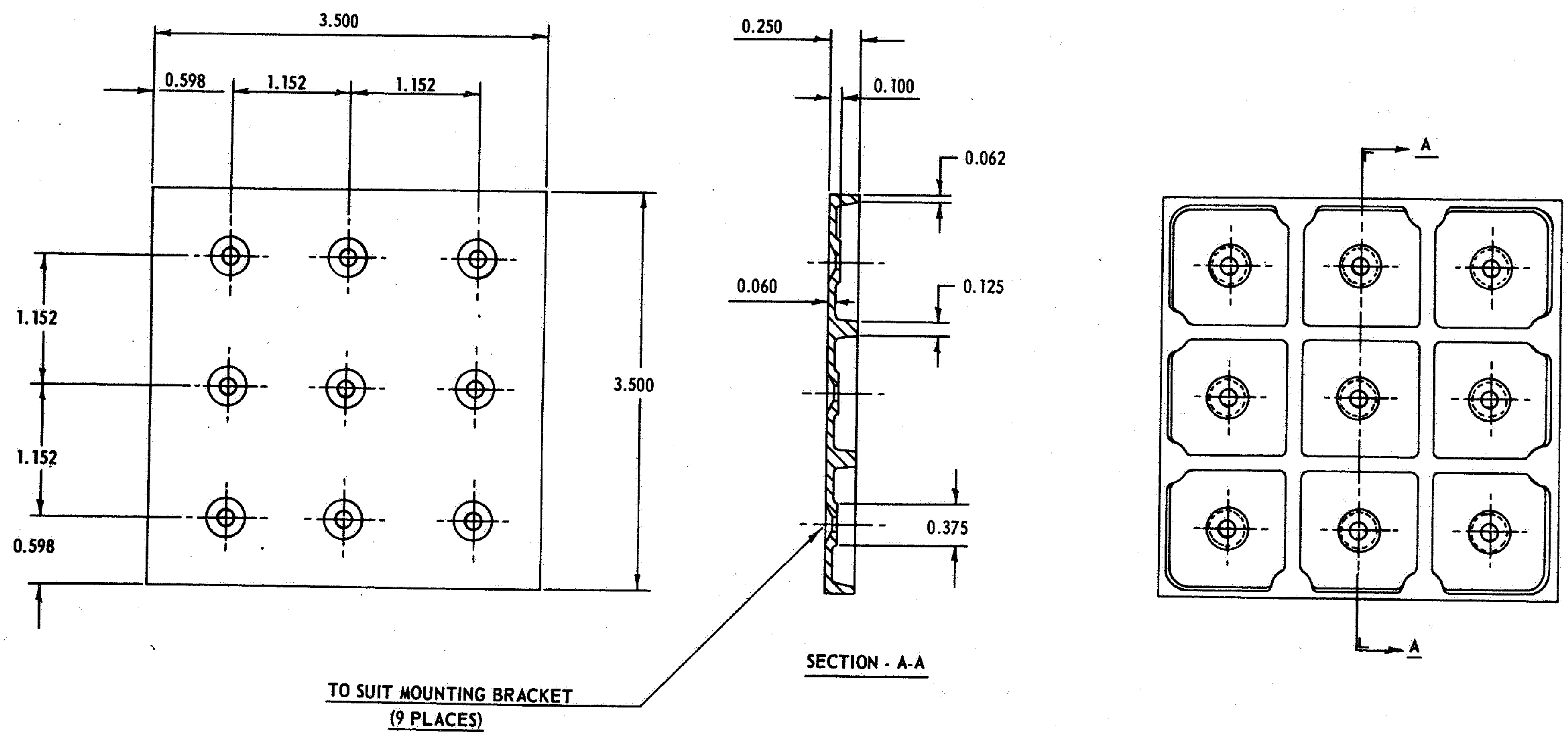


FIGURE 24. BERYLLIUM BASE PLATE

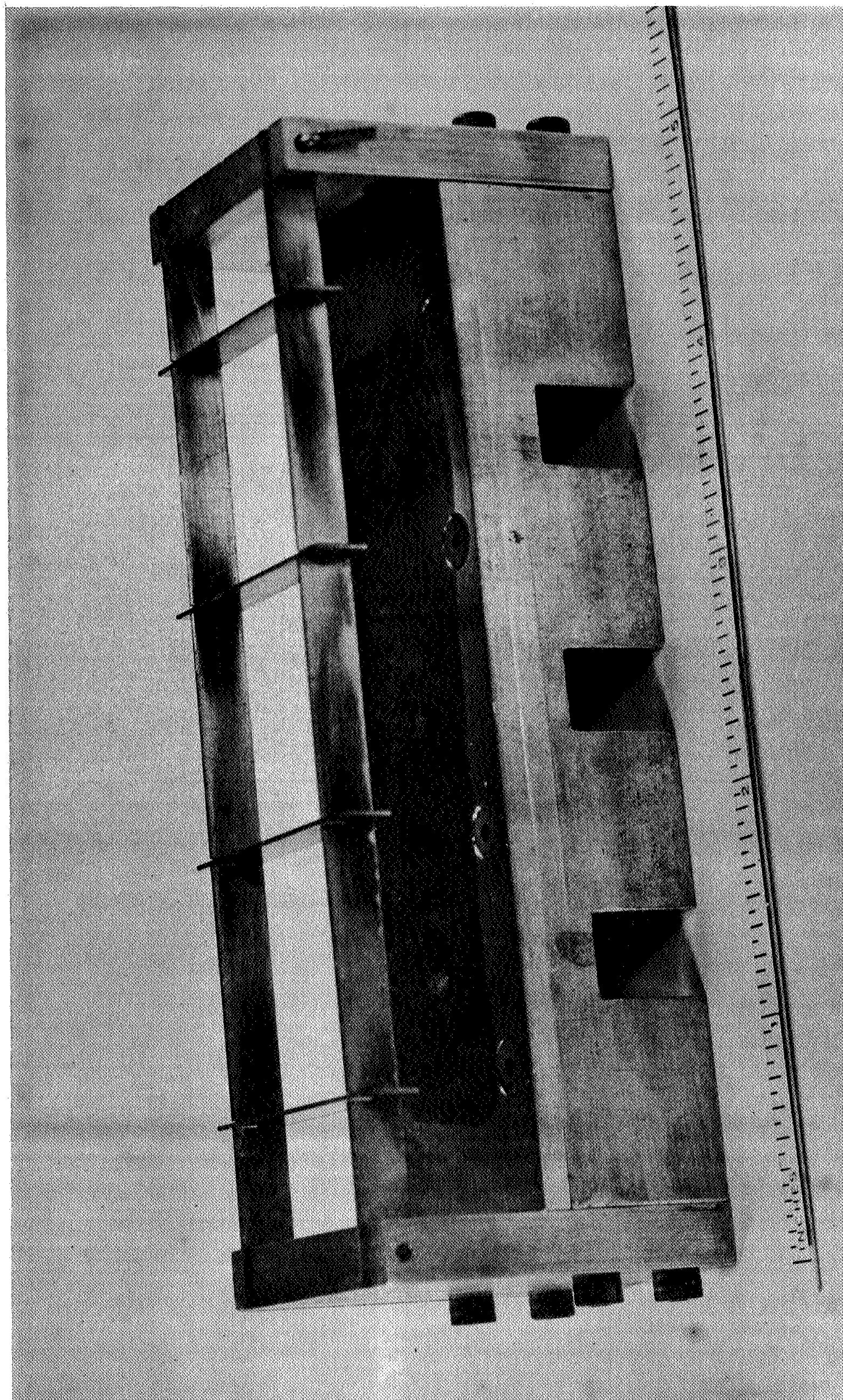


FIGURE 25. COLD STACK ASSEMBLY AND FIRING JIG

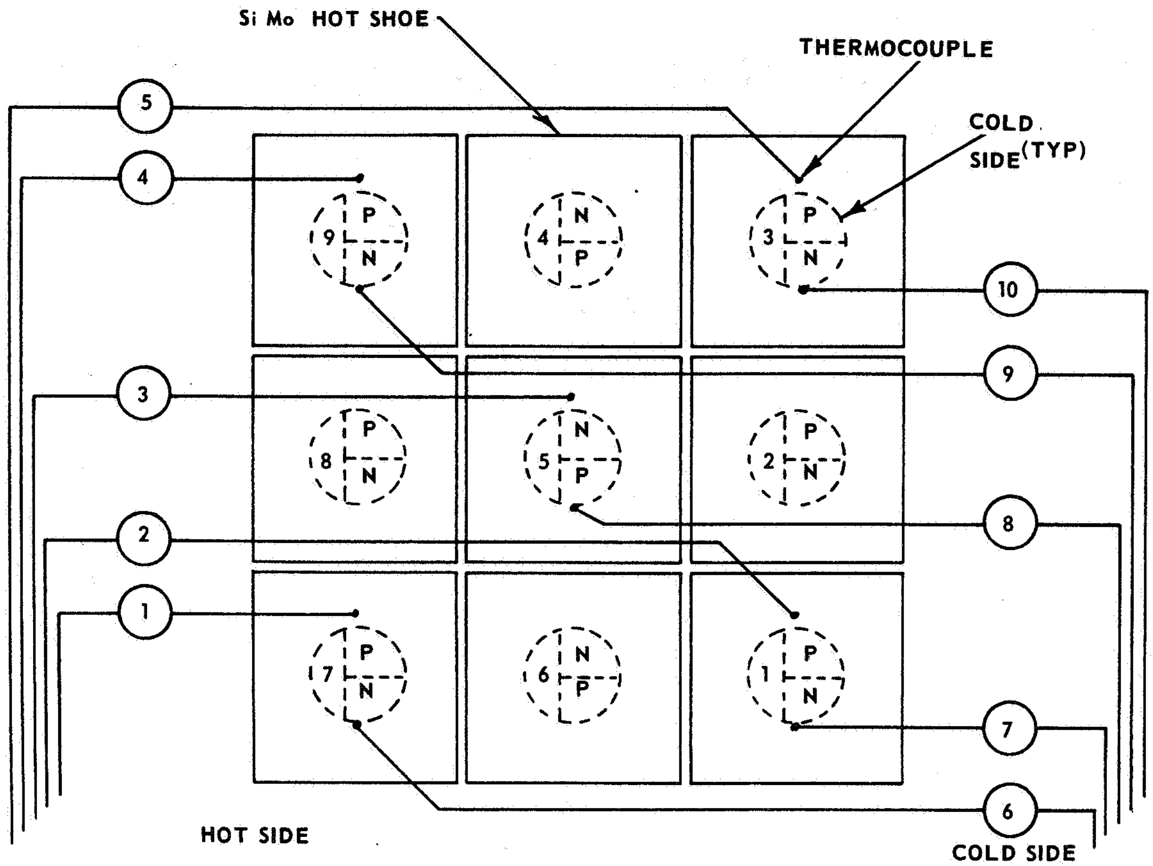


FIGURE 26. ADSORBER AND RADIATOR THERMOCOUPLES LOCATION

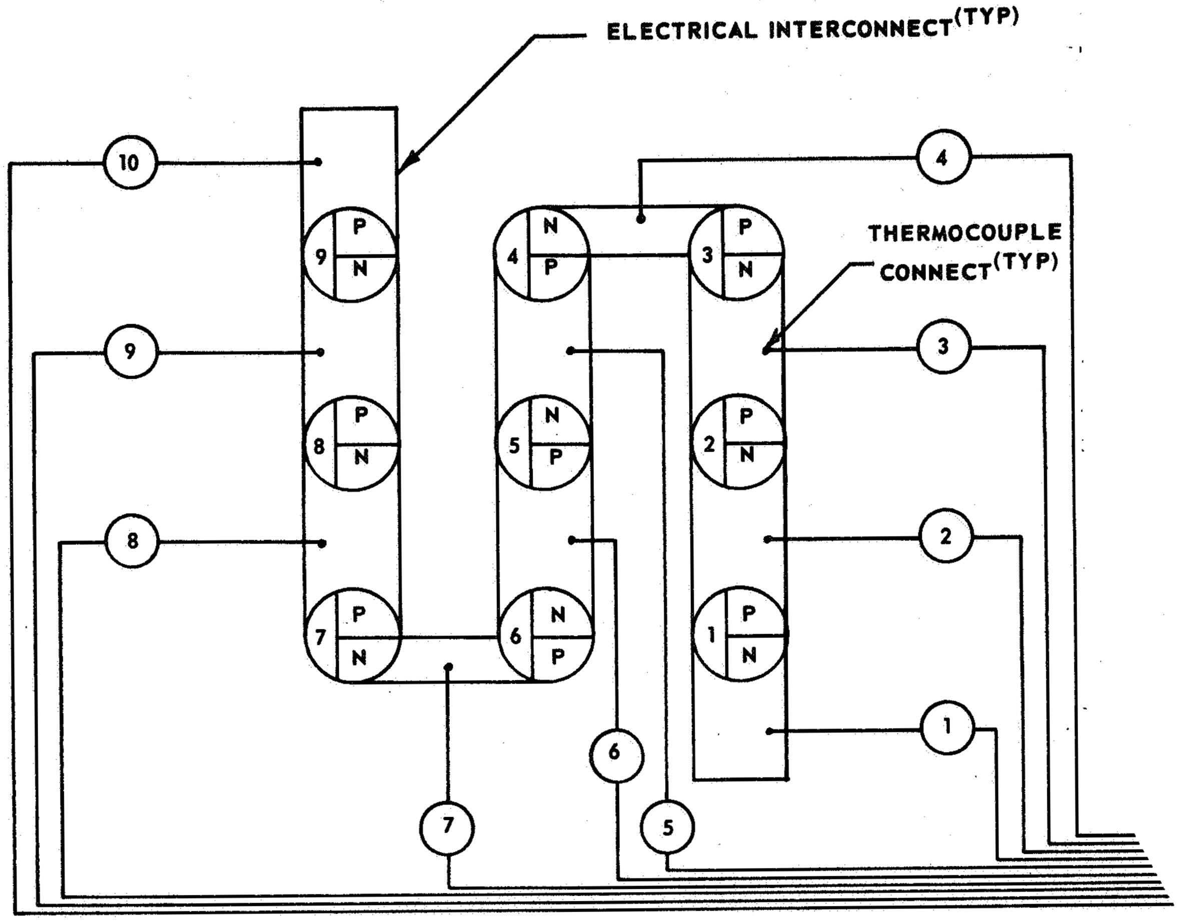


FIGURE 27. VOLTAGE TAPS AND CURRENT LEADS LOCATION

Three 3-couple assemblies were bolted together to form the nine-couple test panel section. Microquartz thermal insulation was placed between the thermocouple legs and under the connecting straps to insulate the small areas not filled with the bulk Min-K 2002. The test panel section is shown in Figure 28.

The test panel resistances were measured after instrumentation and before mounting on the beryllium plate. The locations and numbers of the thermocouples, individual couple resistances, and three-couple resistances are shown in Figure 29.

E. CALCIUM TITANATE EMITTANCE COATING

A calcium titanate emittance coating was applied to the radiator surface of the base plate.

F. BASE PLATE ASSEMBLY

Three 3-couple modules were assembled to the base plate, inserting the mount studs into the base plate holes. The mount studs were bolted to the base plate with the beryllium stud nuts. After the interconnects were bolted together, the test panel sections were given a final visual and electrical inspection.

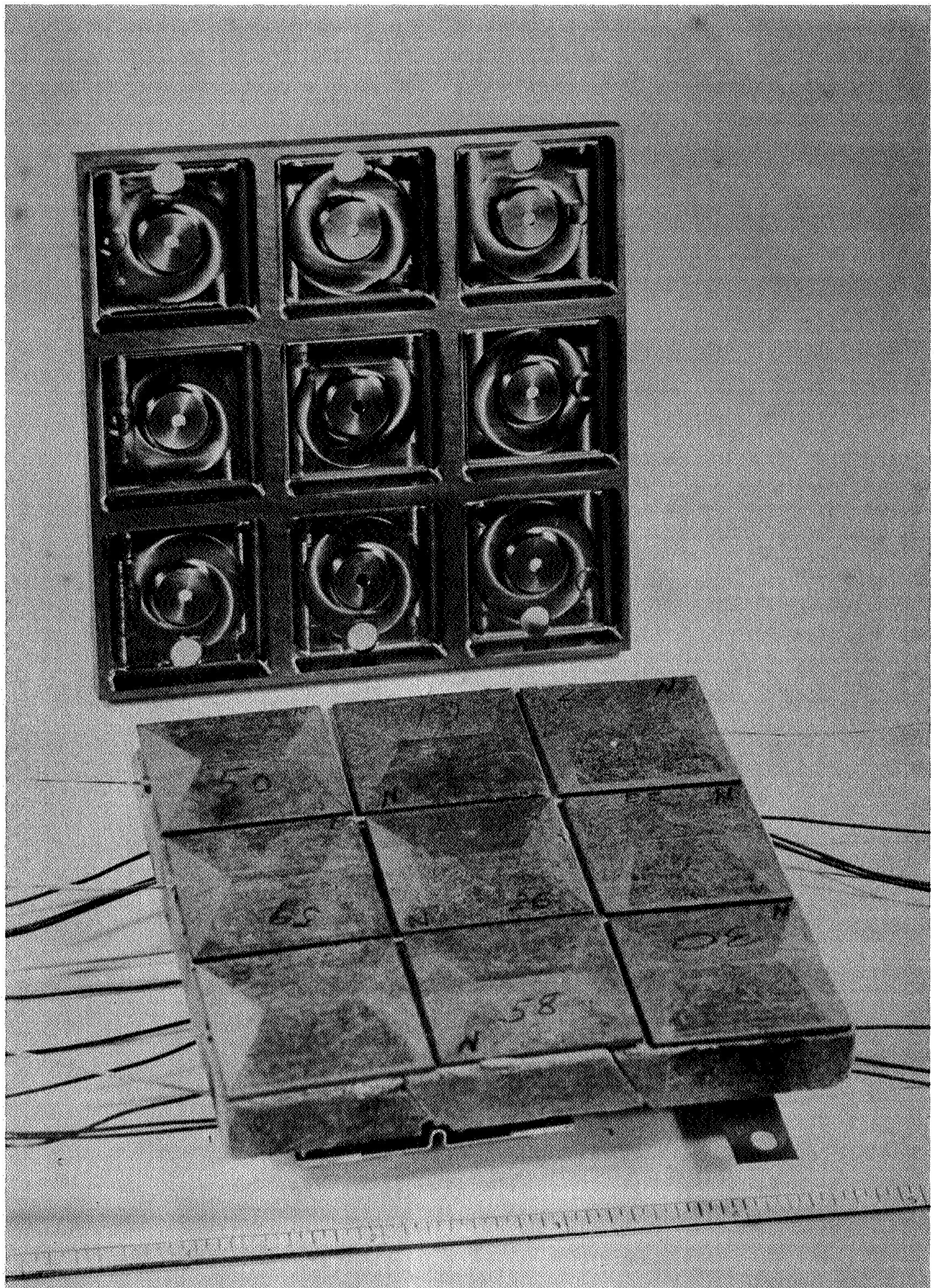


FIGURE 28A. TEST PANEL SECTION WITH BASE PLATE - ADSORBING SURFACE

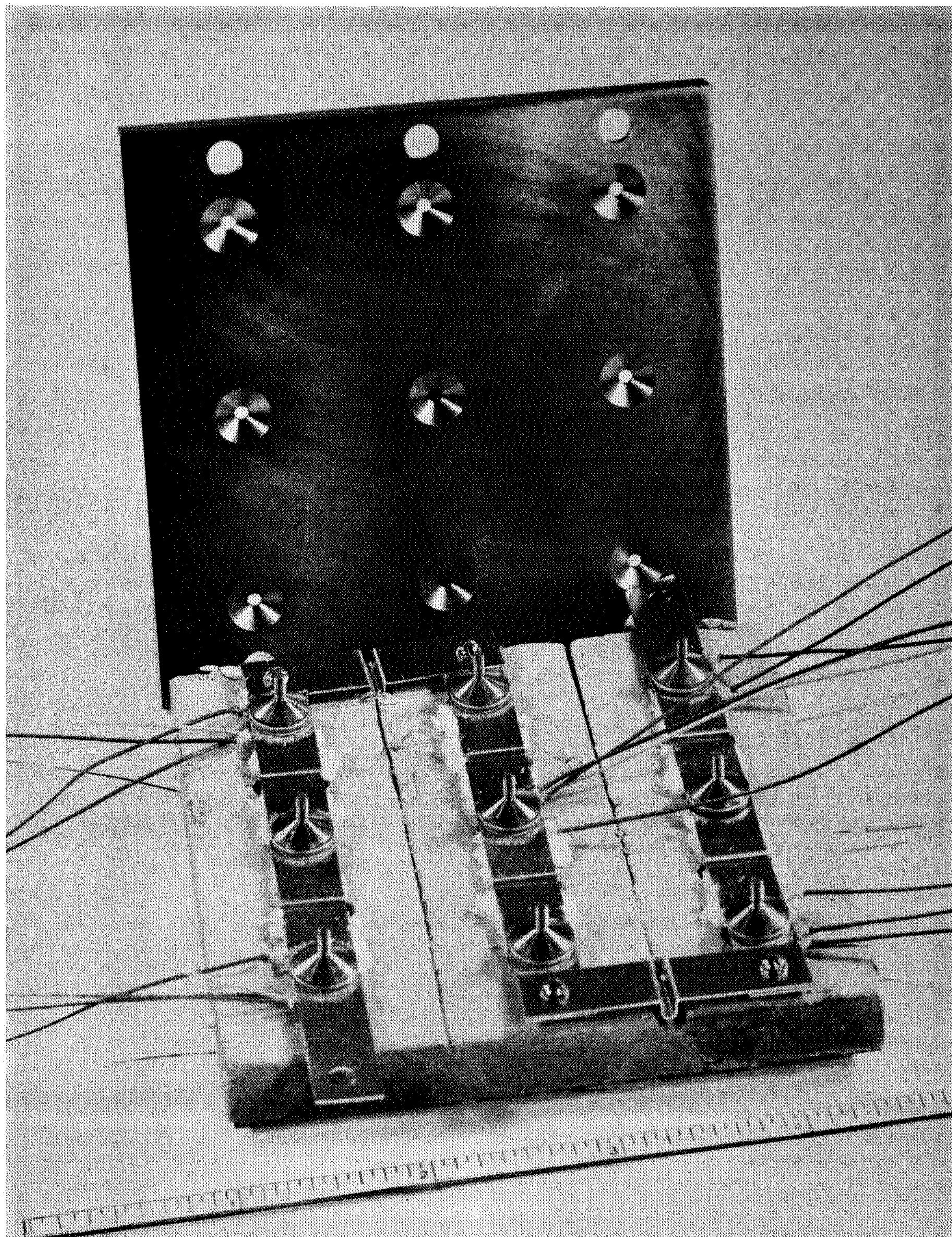
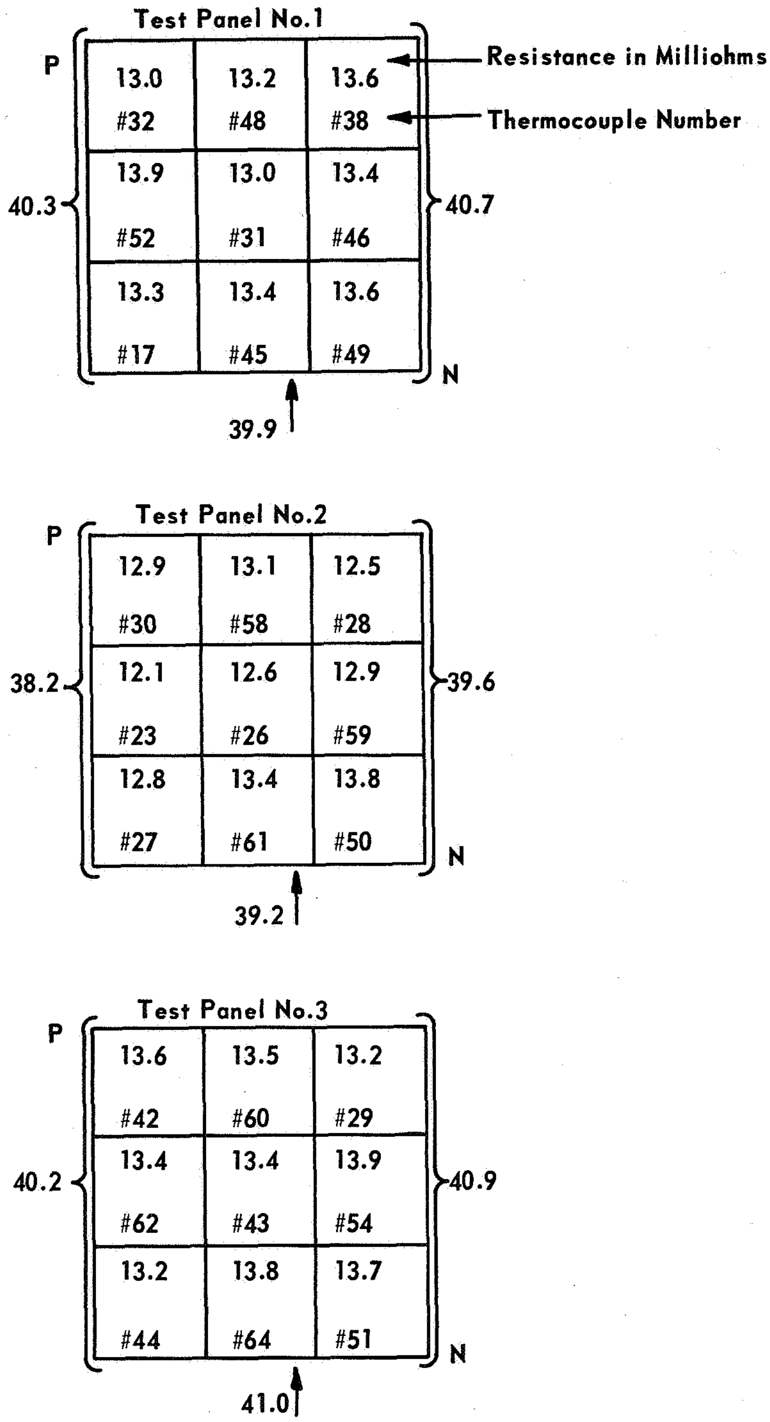


FIGURE 28B. TEST PANEL SECTION WITH BASE PLATE - COLD END



NOTE: Above resistances measured after instrumentation and before mounting on the beryllium plate.

FIGURE 29. COUPLE PANEL RESISTANCE DATA

APPENDIX I

I. FABRICATION AND ASSEMBLY PROCESS SPECIFICATIONS

A. THERMOCOUPLE ASSEMBLY

1. Hot Shoes

a. Material. Silicon - Molybdenum Alloy

Vacuum-Cast n-Type and p-Type Ingots

Composition(nom.)	Polarity Type	Dopant
85 Wt% Si-15 Wt% Mo	n	Phosphorus
85 Wt% Si-15 Wt% Mo	p	Boron

b. Process. Follow these steps:

1. Slice 1.125-inch diameter castings to 0.75± 0.025-inch length using Micromech slicing equipment and metal-bonded diamond wheels.
2. Measure and record the individual slice density using the water immersion technique. The material immersed in water is buoyed up with a force equal to the weight of the fluid displaced. Because the density of water at room temperature is one gram per cubic centimeter, the difference between the weight of the slice in air and in water represents its volume in cubic centimeters. Therefore,

$$\text{Density } (g/cm^3) = \frac{\text{Wt (gms) in air}}{\text{Wt (gms) in air} - \text{Wt (gms) in water}}$$

3. Match n-type and p-type slices according to density.
4. Polish one surface of each slice on a Brinkman metallurgical polishing table using silk cloth with Linde "A" abrasive followed by Rayvel synthetic velvet cloth with Linde "A" abrasive. Wash in methanol; dry with an air blower.
5. Metallurgically bond the polished surface of an n-type slice to the polished surface of a p-type slice. (RCA Proprietary)
6. Fabricate the "hipped" shoe configuration:
   (a) Slice on Micromech slicing equipment using a metal-bonded diamond wheel.

(b) Grind "hipped configuration on the Sanford surface grinding equipment using an 80-grit silicon carbide resin-bonded wheel and special vacuum holding fixture.

7. Wash in 50% Methanol - 50% Acetone.

8. Inspect and store in properly identified envelopes.

2. Thermocouple Legs

a. Material. Silicon-Germanium Alloy

Zone-Leveled n-type and p-type Ingots

Composition(At.% Si)	Density(g/cm^3)	Polarity	Dopant
61.8 - 65.0	3.482 - 3.588	n	Phosphorus
61.8 - 65.0	3.482 - 3.588	p	Boron

b. Process. The following steps are the order of procedure:

1. Slice the ingots on the Micromech slicing equipment, using a metal-bonded diamond wheel.
2. Cylindrically grind to the proper radius on the Myford grinder, using an 80-grit silicon carbide resin-bonded wheel.
3. End-grind to 0.394-inch length on the Sanford surface grinder, using an 80-grit silicon carbide resin-bonded wheel. Microfinish is not critical to subsequent processing.
4. Weigh and inspect.
5. Wash in 50% methanol - 50% acetone.
6. Package and identify individual pellets as to ingot number and position.
7. Store.

3. Cold Shoes

a. Material. Tungsten Bar Stock - Density: 18.9 g/cm^3.

Supplier: Cleveland Refractory Metals Company

b. Process. These are the procedural steps:

1. Fabricate into n-type and p-type cold shoes: p-type shoe 0.020" x 0.145"; n-type shoe 0.020" x 0.171" (shoes fabricated by vendor).
2. Inspect for dimensions and flatness.
3. Wash in hot Blacosolv, hot water, and methanol.
4. Identify and store in labeled envelopes.

B. THERMOCOUPLE FABRICATION

1. <u>Assembly</u>

   The following steps are the order of assembly:

   a. Assemble thermocouple components in alignment fixture:

      SiMo Hot Shoe

      SiGe n-Pellet

      SiGe p-Pellet

      W n-Cold Shoe

      W p-Cold Shoe

   b. Place ceramic flats on the hot shoes and cold shoes. Clip with tungsten springs to keep components in position during bonding.

   c. Identify thermocouple by penciling the number on the bottom ceramic base. Store in a clean area.

2. <u>Bonding</u>

   This procedure is accomplished by the following steps:

   a. Transfer the thermocouple assembly to the bonding furnace.
   b. Insert the thermocouple leads.
   c. Metallurgically bond. (RCA Proprietary)
   d. Identify by penciling the thermocouple number on the hot shoe.
   e. Inspect microscopically.
   f. Inspect electrically for total thermocouple resistance and all bond-contact resistances.
   g. Nickel-plate cold shoes. (RCA Proprietary)
   h. Sinter. (RCA Proprietary)
   i. Store in Compartmented Cardboard Boxes.

C. COLD STACK ASSEMBLY

1. <u>Materials and Processes</u>

   a. Pedestal. Use copper, O.F.H.C. 1/2 Hard - One each, n-Leg & p-Leg. Processing is accomplished by these steps:

      1. Fabricate from 0.025" strip using a die and power press.
      2. Wash in hot Blacosolv, hot water, and methanol. If required, wash in cyanide solution to remove surface oxides.
      3. Fire in dry hydrogen for 10 minutes at 800 °C.
      4. Nickel-plate. (RCA Proprietary)
      5. Sinter. (RCA Proprietary)

6. Inspect for blisters; store in labeled cardboard boxes.

b. Compensator. Use tungsten bar stock 18.9 g/cm^3 density.

Supplier: Cleveland Refractory Metals

The following steps are the processing procedure:

1. Fabricate from bar stock. (fabrication completed by vendor).
2. Sandblast with S.S. White Co. sandblasting unit.
3. Wash in 50% acetone 50% Methanol; dry.
4. Nickel-plate. (RCA Proprietary)
5. Sinter. (RCA Proprietary)
6. Inspect for blisters; store in labeled cardboard boxes.

c. Interconnect. Use copper, O.F.H.C. 1/2 Hard.

Process as follows:

1. Fabricate from 0.015" strip, using a power press.
2. Wash in hot Blacosolv, hot water, and methanol. Blow dry. If required, wash in cyanide solution to remove surface oxides.
3. Fire in dry hydrogen for 10 minutes at 800°C.
4. Nickel-plate. (RCA Proprietary)
5. Sinter. (RCA Proprietary)
6. Inspect for blisters, dimensions, and plating thickness.
7. Store in labeled cardboard boxes.

d. Insulator. Use Aluminum Oxide.

Process as follows:

1. Metallize two faces. (RCA Proprietary)
2. Bright-fire 1000°C in dry hydrogen.
3. Nickel-plate. (RCA Proprietary)
4. Sinter. (RCA Proprietary)
5. Inspect for blisters in plating.
6. Grind slot and o.d. to size.
7. Wash in cold Blacosolv and Methanol. Blow dry.
8. Fire in dry hydrogen at 800°C for 5 minutes.
9. Inspect and store in labeled boxes.

e. Compensator. Use copper, O.F.H.C. 1/2 Hard.

Process as follows:

1. Fabricate from 0.020" strip, using a power press with punch and die.

2. Wash in hot Blacosolv, hot water, and methanol. Blow dry.

3. Hydrogen-fire at 800°C for 10 minutes.

4. Nickel-plate. (RCA Proprietary)

5. Sinter. (RCA Proprietary)

f. Mount Stud. Use beryllium, Ber Met 2.0 Grade or S-200D Type I.

Supplier: Beryllium Metals and Chemical Corporation

Density: at 68°F - 1.85 gm/cm^3

Process as follows:

1. Fabricate (Fabrication completed by the Beryllium Manufacturing Corporation).
2. Wash in acetone.
3. Inspect and store.

g. Mount Stud Nut. Use beryllium Mil B21531 or S-200.

Supplier: General Astrometals Corporation

Density: 1.84 gm/cm^3 or greater

Process as follows:

1. Fabricate (Fabrication completed by the Beryllium Manufacturing Corporation).
2. Wash in acetone.
3. Inspect and store.

h. Base Plate. Beryllium Ber Met 2.0 or S-200D Type I

Supplier: Beryllium Metals and Chemical Corporation

Density: at 68°F - 1.85 gm/cm^3

Process as follows:

1. Fabricate (Fabrication completed by the Beryllium Manufacturing Corporation).
2. Wash in acetone.
3. Inspect and store.

i. Insulation. Min-K 2002 - Supplier, Johns-Manville Corporation

Density: 19-20 lbs/ft^3 (nom.)

Composition: 84% SiO_2 - 16% $Ti\ O_2$

Porosity: 88% (nom.)

Process as follows:

1. Using the special tooling provided, machine parts to dimension.
2. Inspect for dimension.
3. Store in labeled cardboard boxes.

2. Cold Stack Assembly Bonding

a. Assembly. Follow these steps:

1. Carefully assemble insulation to thermocouple.
2. Assemble cold stack components to the thermocouple cold shoe in the assembly bonding jig.
3. Inspect for alignment.

b. Cold Stack Bonding. Follow this procedure:

1. Place three-couple assembly in the bonding furnace.
2. Metallurgically bond. (RCA Proprietary)
3. Inspect: Visually (microscope)
   Electrically (resistance)

D. CALCIUM TITANATE COATING APPLICATION

1. Coating Procedure

Process as follows:

a. Clean the base plates by vapor-degreasing or by washing thoroughly in petroleum solvent and drying.

b. Condition the surface to be coated by grit-blasting with 60-mesh silicon carbide or 60-mesh aluminum oxide. A surface roughness of 80 to 100 microinches, AA, is recommended. Clean surfaces shall be handled only with gloves.

c. Coat with calcium titanate powder; 99 percent minimum purity. Use Plasmadyne plasma-spraying equipment with the following approximate settings:

Current	- 500 amperes
Arc Gas Flow	- 55 CFH
Powder Carrier-Gas (Argon)	- 30 CFH

d. Clean, as required, to remove all masking and adhesive residue.

E. BASE PLATE ASSEMBLY

1. Procedure

Assemble as follows:

a. Assemble three 3-couple modules to the base plate, inserting the mount studs into the base plate holes.

b. Bolt the mount studs to the base plate.

c. Bolt the interconnects.

d. Inspect: Visually and Electrically.

e. Package and store.

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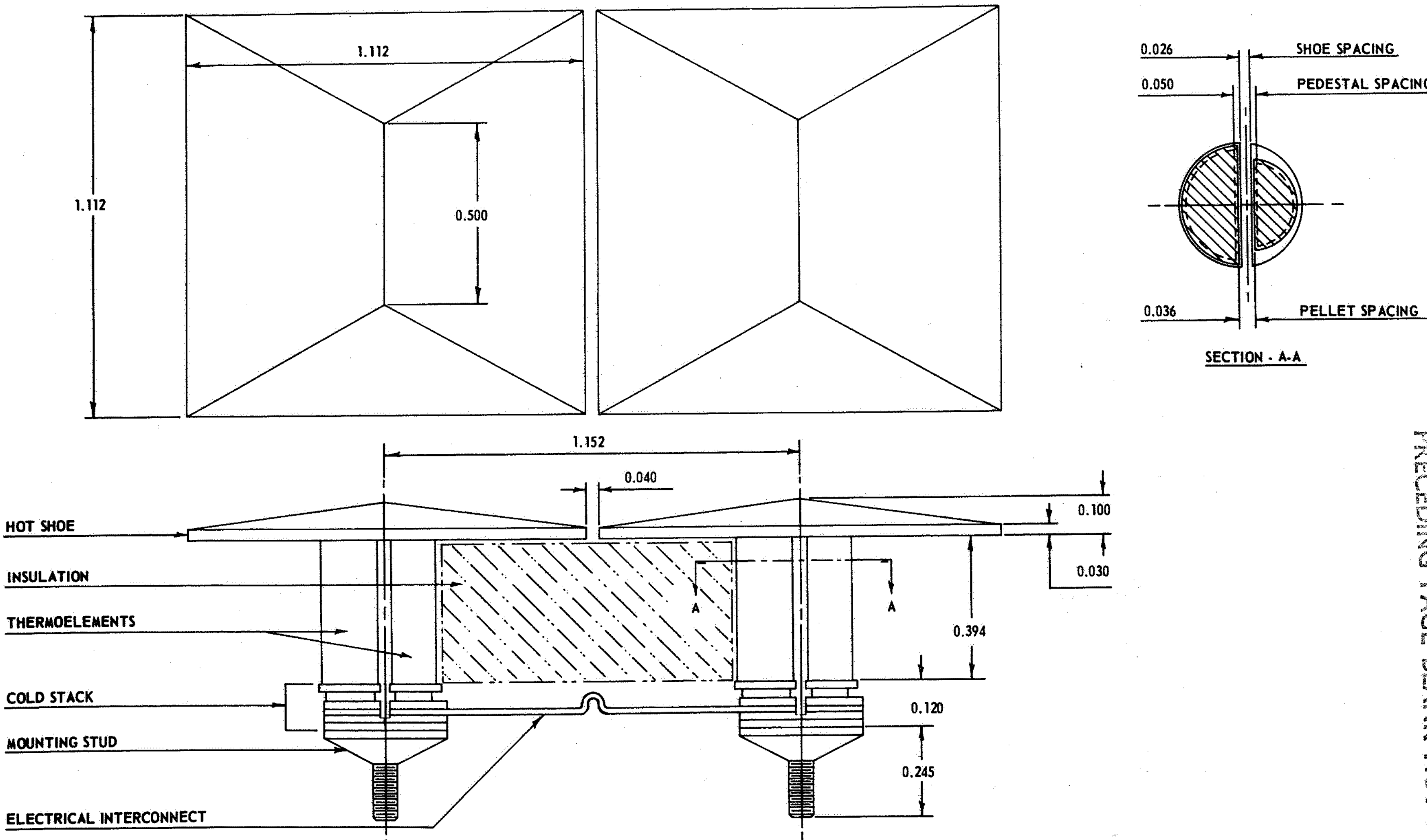

FIGURE A-1. REFERENCE DESIGN—THERMOCOUPLE ASSEMBLY

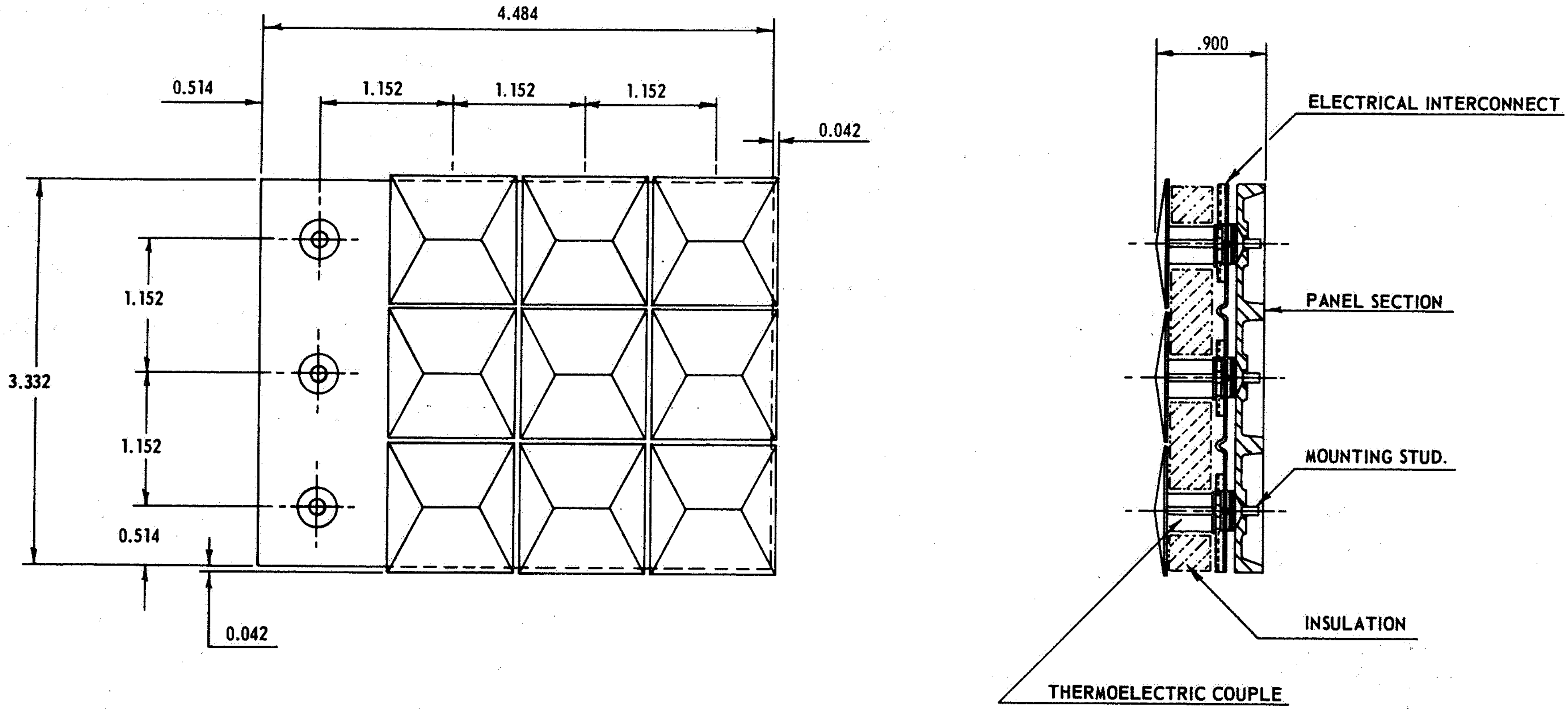

FIGURE A-2. REFERENCE DESIGN—GENERATOR PANEL SECTION ASSEMBLY

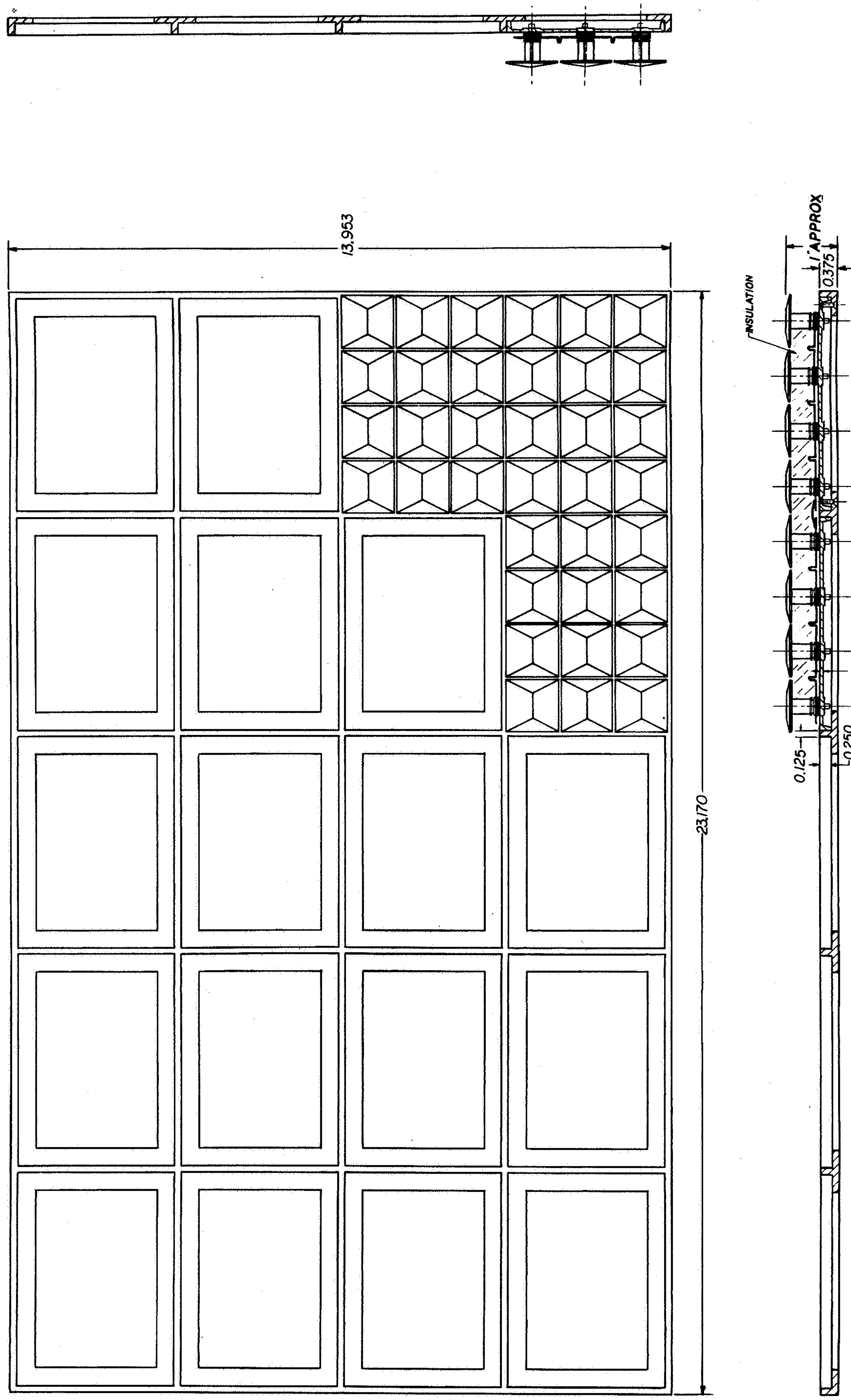

FIGURE A-3. REFERENCE DESIGN—GENERATOR PANEL ASSEMBLY

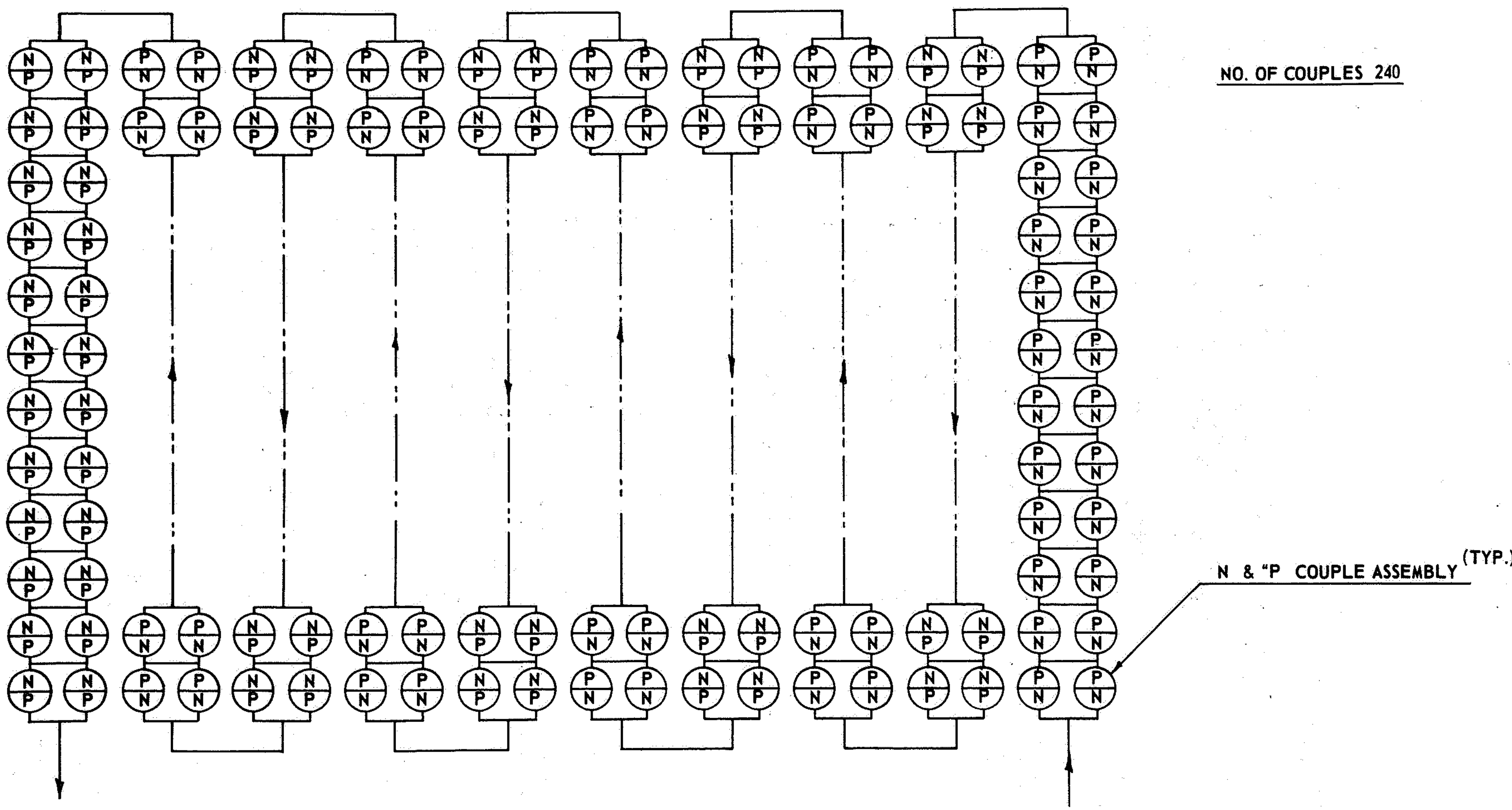

FIGURE A-4. REFERENCE DESIGN—GENERATOR PANEL ELECTRICAL ASSEMBLY

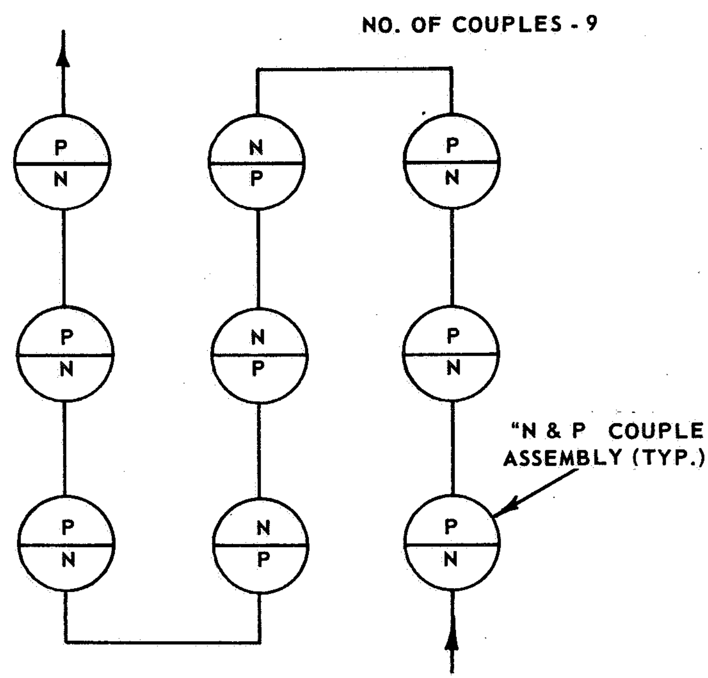

FIGURE A-5. ELECTRICAL SCHEMATIC—TEST PANEL SERIES CIRCUIT