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A THREE-AXES ANGULAR ACCELEROMETER SYSTEM

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A THREE-AXES ANGULAR ACCELEROMETER SYSTEM

FINAL REPORT

APRIL 1969

PREPARED UNDER CONTRACT NAS4-1238

By

TELEDYNE SYSTEMS COMPANY
19601 NORDHOFF STREET
NORTHRIDGE, CALIFORNIA 91324

FOR

00286

NASA FLIGHT RESEARCH CENTER • EDWARDS, CALIF.

FOREWORD

This report was prepared by Teledyne Systems Company, Northridge, California under National Aeronautics and Space Administration Contract NAS4-1238, "Three Axis Angular Accelerometer."

The program to deliver two, three-axes angular accelerometer systems began on 30 June 1967. Responsible personnel on the program were Mr. J. E. Lease, Program Manager; Mr. R. R. Kalthoff, Electronics Design and System Integration; Mr. P.J. Garvey, Project Engineer.

This is the final report and concludes the work on Contract NAS4-1238.

ABSTRACT

This report documents the results of the development and fabrication of two three Axes Angular Accelerometer Systems (3AS) for NASA Flight Research Center, Edwards, California. It includes a brief technical description, electrical schematics, outline and assembly drawings, input-output specifications, test procedures and results, and information rquired for installation, use and maintenance of the systems.

The Three Axes Angular Accelerometer System senses angular rate inputs about three orthogonal axes and provides an amplified analog dc voltage output which is proportional to the angular acceleration input.

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1. INTRODUCTION

The purpose of this report is to provide technical information concerning the design, development, fabrication and test of the NASA Three-Axes Angular Accelerometer System. In addition to the technical description, schematics and assembly drawings are provided in the Appendix of this report to facilitate use and field maintenance of the system.

The prime purpose of the contract, NAS4-1238, was to develop a three-axes angular accelerometer system which has greater accuracy, higher reliability, weighs less, and is smaller in volume than previously available systems. Teledyne fulfilled this goal by providing a 49 cubic inch, 2.5 pound, modular-designed system which meets or exceeds the specified performance parameters.

The two delivered systems were designed and built under the direction of The National Aeronautics and Space Administration, Flight Research Center (NASA FRC) of Edwards, California. The instruments are to be used for acquisition of flight test data in manned aircraft and other test vehicles. It is also possible to use the device as part of the stability augmentation on vehicles having a wide range of dynamic modes or widely changing system parameters.

2. DESIGN

2.1 Technical Description

The Three-Axes Angular Accelerometer System (3AS) consists of a three-axes angular acceleration sensor and all of the electronics required to convert input power and to process the sensor output signals. The input to the system is 115V, 400 Hz and +28 V dc power. The conversion of this input into voltages required within the system is shown schematically in Figure 1. The output is analog dc voltages proportional to the measured angular accelerations about three mutually perpendicular axes. Figure 2 is a system block diagram and Figure 3 is a photograph of the NASA Angular Accelerometer System. Figure 4 is an exploded view of the system.

The 3AS is comprised basically of three distinct, yet closely integrated and closely related, control loops. These control loops are distinguished in Figure 2 and are the following:

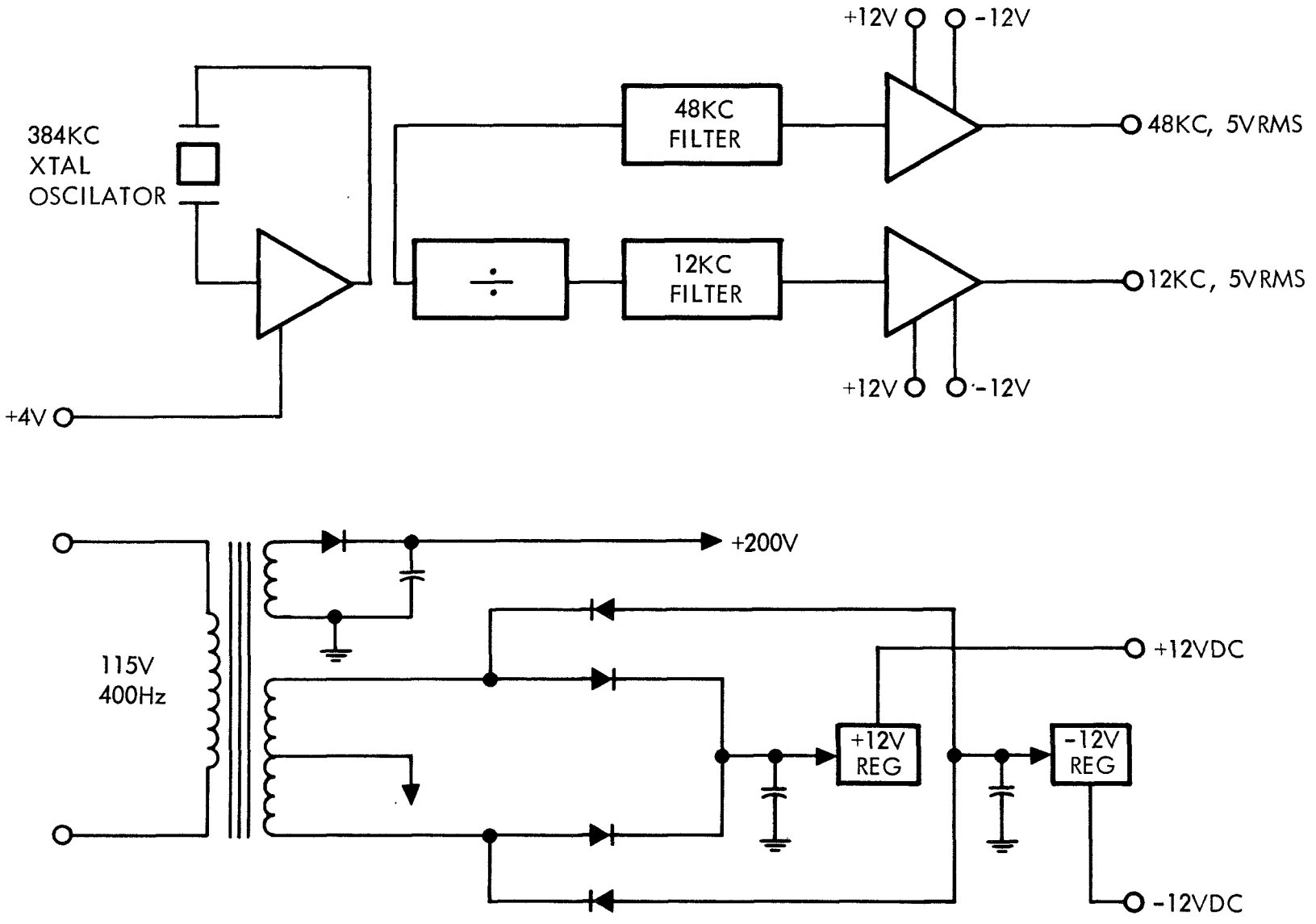
A. Float Centering (Translational Control)
B. Torque Rebalance (Angular Control)
C. Temperature Control (Environmental Sensitivity Control)

2.1.1 Angular Accelerometer

The angular accelerometer is a half-pound, electromechanical device which senses angular accelerations about three orthogonal axes. Figure 5 is an exploded view of the sensor. The sensor consists of a solid sphere with three pairs of voice coil precision torquers attached to the sphere such that current through a pair of torquer coils acts on a permanent magnet field to produce a force-couple about their respective axis. The sphere (float) is the seismic mass of the system and is suspended in a supporting spherical cavity (case) by means of a low viscosity flotation fluid whose density is equal to that of the seismic mass, at the sensor's operating temperature. In addition, the float is centered in the spherical fluid-cavity (formed by the upper and lower covers of the case assembly) by electrostatic forcers along three mutually perpendicular axes.

Rotational displacement of the float with respect to the instrument case is detected by capacitor pickoffs. Therefore, angular motion of the accelerometer case causes a voltage signal (pickoff signal) which is amplified and fed back as a restoring current to the appropriate torquer pair. Hence the sensitive element is continuously returned to null (zero displacement). This is the torque rebalance (angular control) loop. The current required to maintain a null pickoff signal is proportional to the input angular acceleration.

A capacitor pickoff scheme similar to that discussed above is also used to sense translational displacement of the seismic mass (float).



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Figure 1. Power Supply

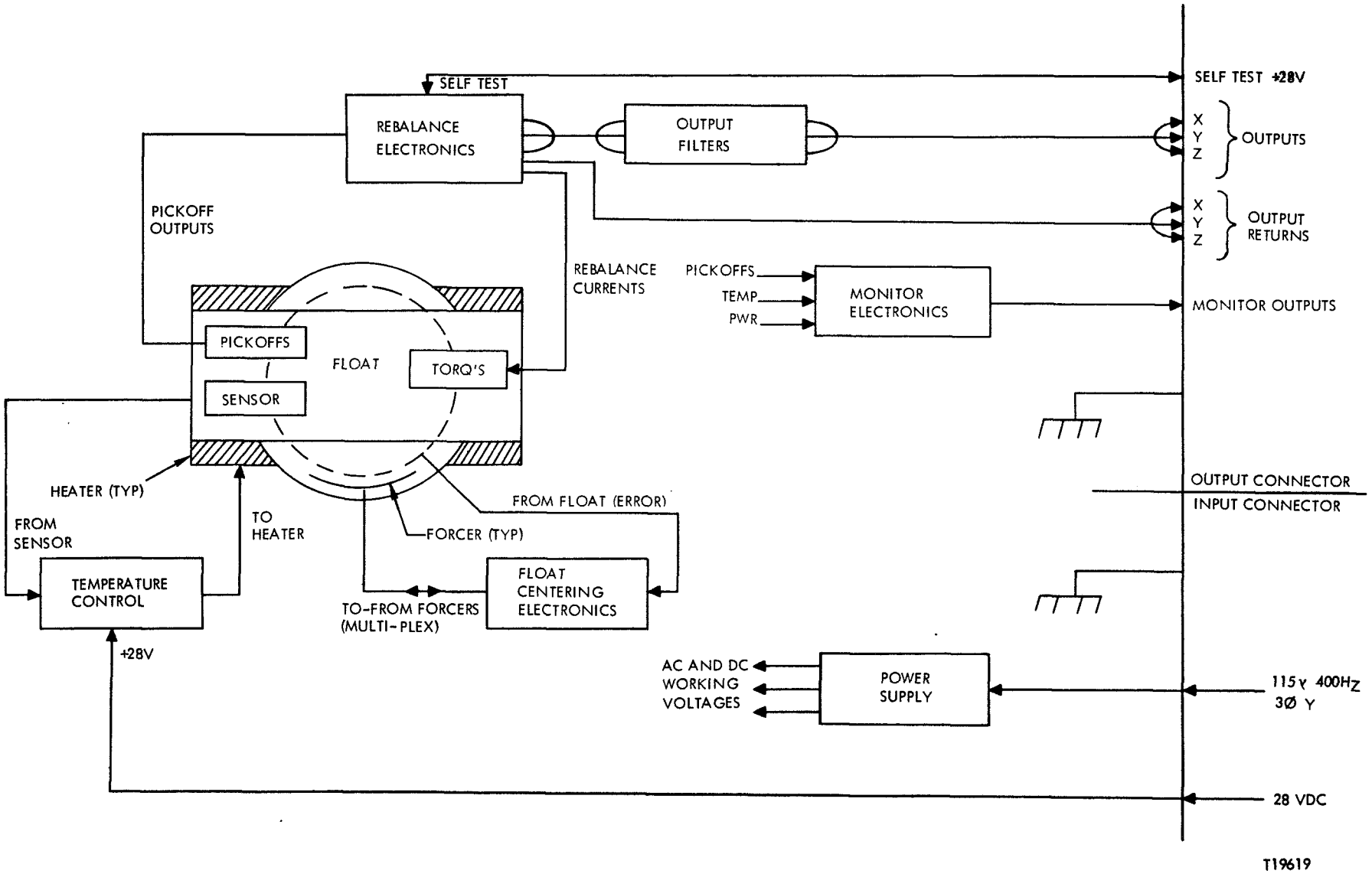


Figure 2. System Block Diagram

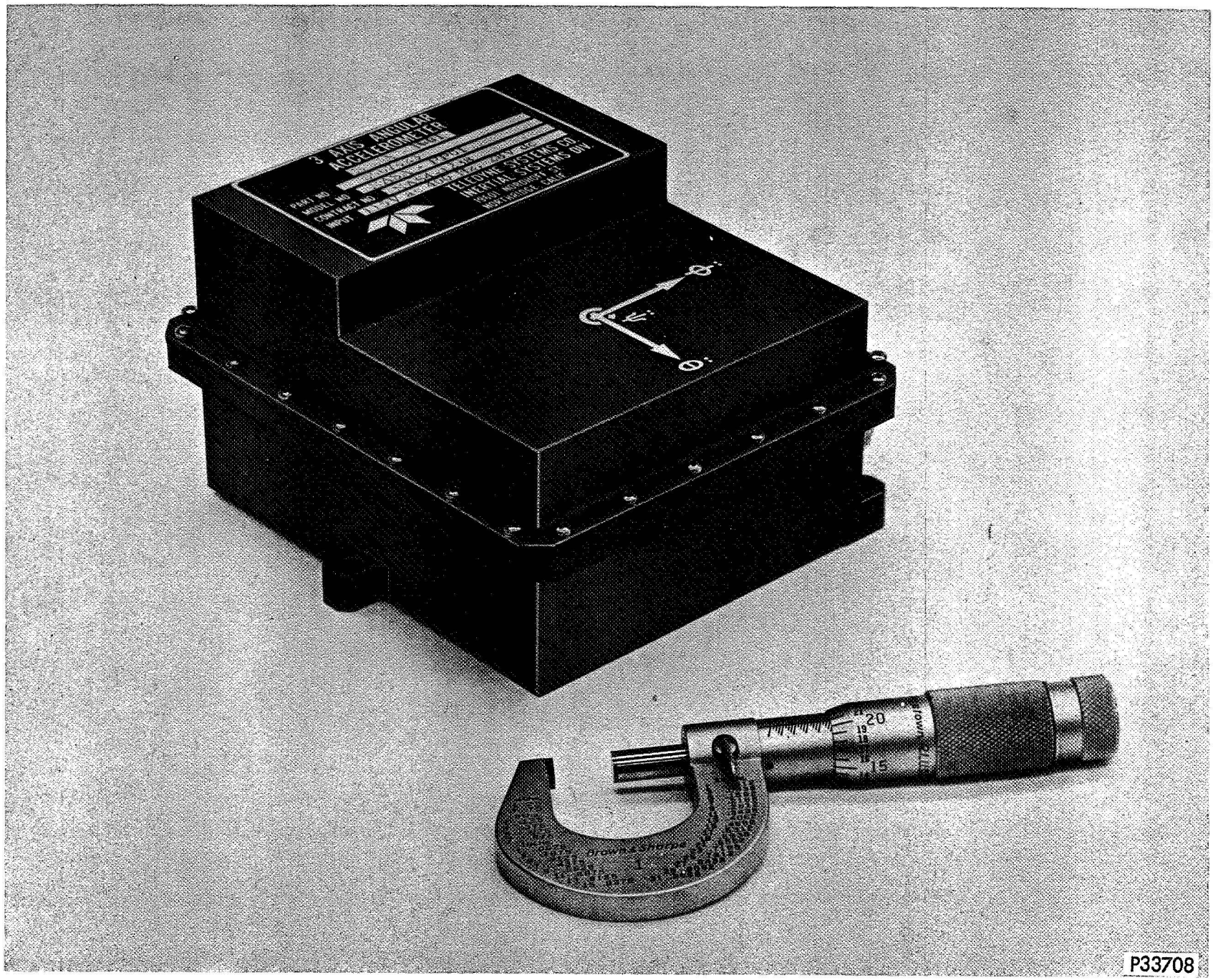


Figure 3. NASA System Photo

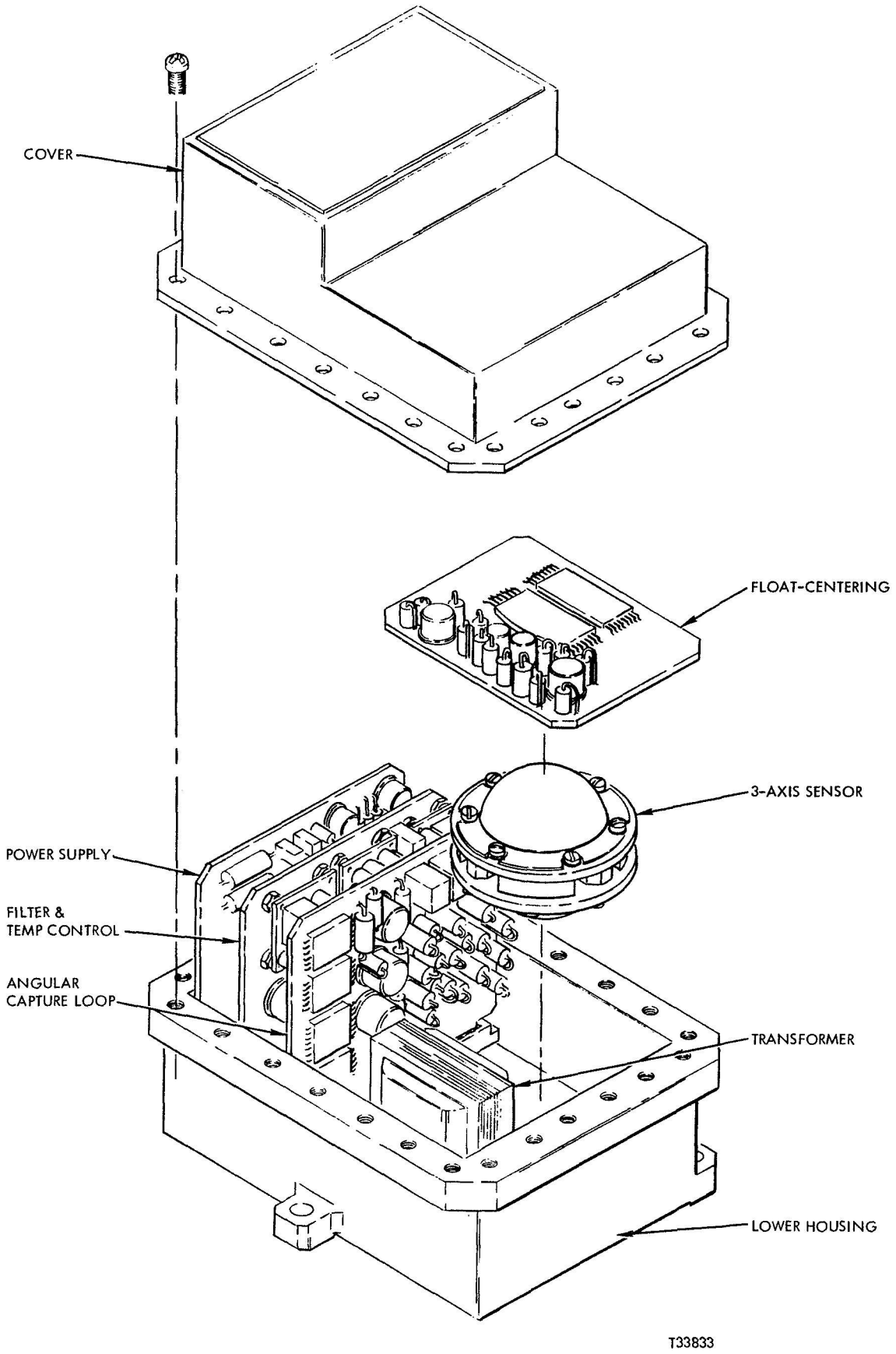


Figure 4. 3AS Exploded View

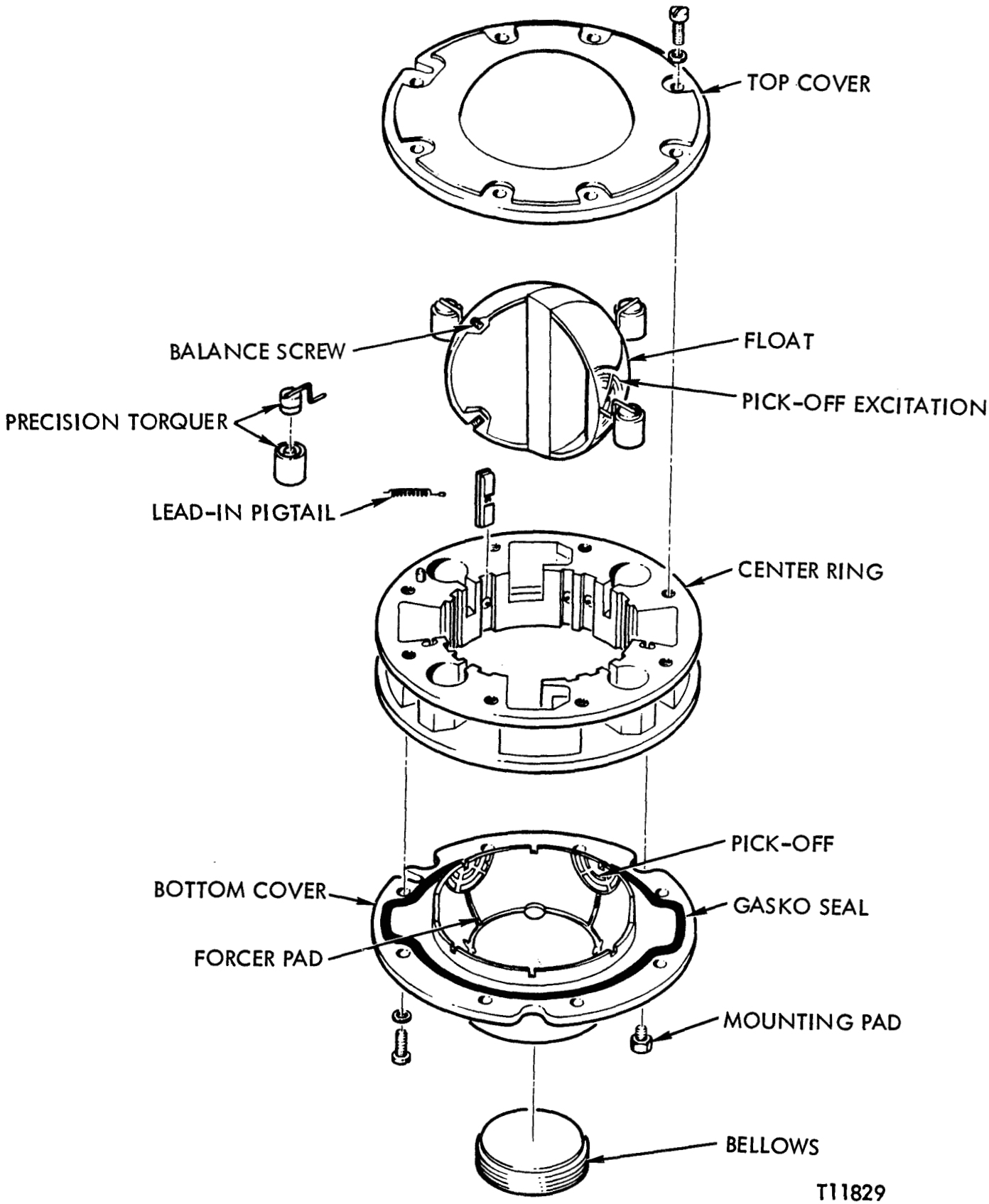


Figure 5. Sensor Unit Exploded View

Translational displacement generates a voltage in the forcer circuit which is then amplified and fed back as a dc voltage on the appropriate forcer plates which are located in the instrument covers. The float centering circuitry consists of a float pickoff isolation amplifier, mounted directly on the case of the sensor; an ac amplifier and a demodulator gated into three parallel channels. The three channels consist of high voltage switches and 200 V dc power amplifiers which apply the necessary voltages to the respective forcers. The gating circuit phases the translational pickoff excitation with the high voltage switches so that three sample data servo loops are established with the float used as a common capacitor plate in detecting translational motion of the float along any of the three orthogonal axes.

Since the seismic mass is supported by a flotation fluid, it is evident that the force required from the electrostatic forcers is zero regardless of translational accelerations whenever the temperature of the flotation fluid is maintained at the buoyant temperature of the float. Therefore a proportional-control temperature controller is provided to minimize the temperature excursions of the flotation fluid whose density is temperature dependent. The electrostatic forcer control loop maintains the float at translational null even if the instrument experiences accelerations at a non-buoyant temperature.

2.1.2 Electronics

The electronics consist of MEMAs and discrete components mounted on printed circuit boards or directly on the sensor.

MEMAs are Micro-Electronic Modular Assemblies in which multiple components, including monolithic integrated circuits and discrete resistors, capacitors, and semiconductors are mounted and interconnected within a single flat pack. Within the flat pack, a number of monolithic integrated or discrete component circuits are bonded to an alumina substrate and interconnected by printed circuitry bonded to the surface of the substrate. Figure 6 is an exploded view showing the elements of a typical MEMA.

A plan view photograph of a discrete-component MEMA with the cover removed is presented in Figure 7, and a typical integrated circuit MEMA without its cover is shown in Figure 8.

There are 18 MEMAs in the 3AS package. Four isolation amplifier MEMAs are mounted directly upon the center ring of the sensor and the rest of them are on the printed circuit boards.

Three of the printed circuit boards are plug-in modules as shown in Figures 9, 10 and 11. They are the Excitation Supply card, the Capture Loop Electronics card and the Filter and Temperature Control card. In addition, there is a p.c. board shown in Figure 12 which is not a plug-in type. This is the float centering circuit and it is mounted directly above the sensor on four standoffs.

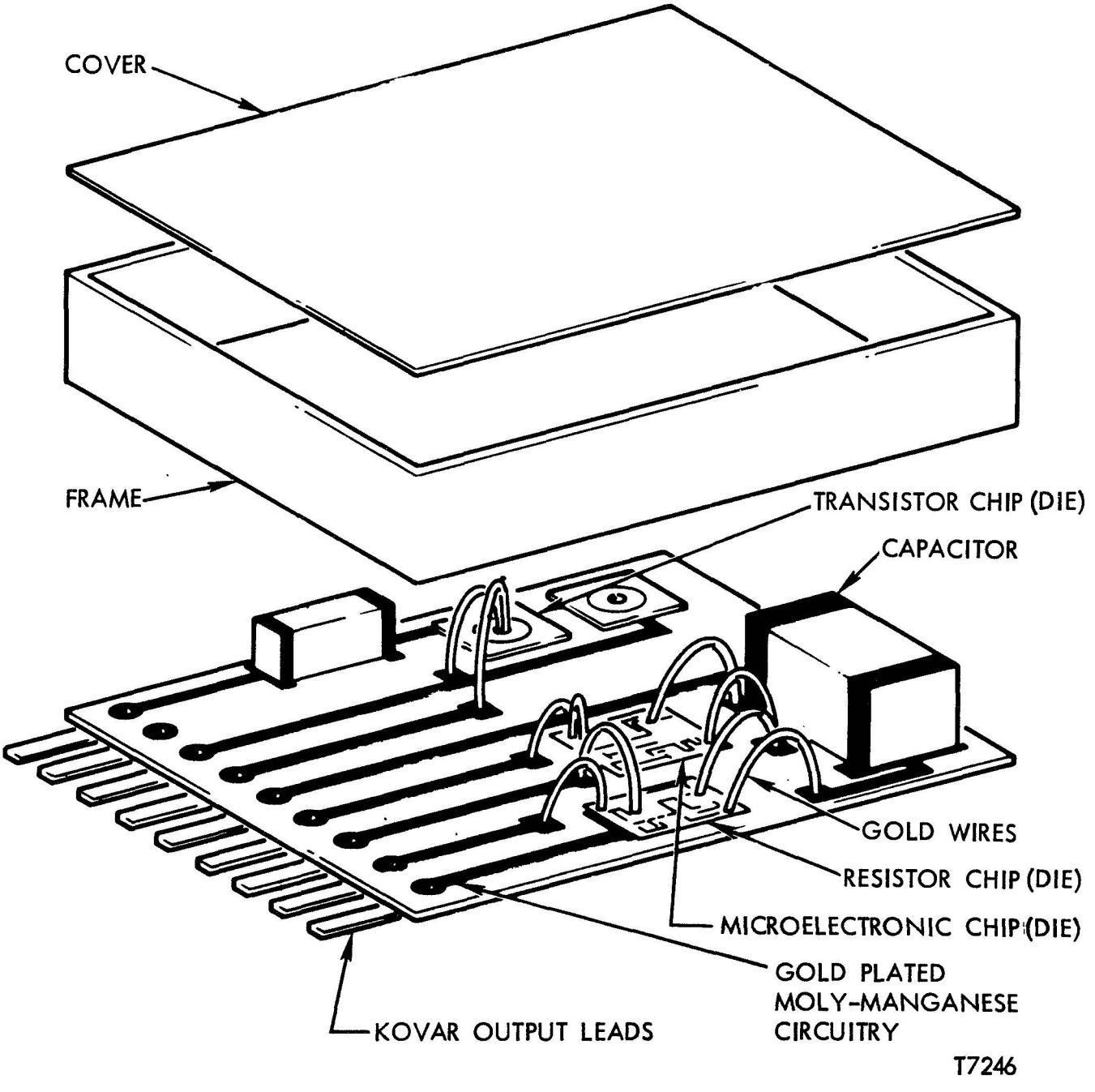


Figure 6. MEMA Elements

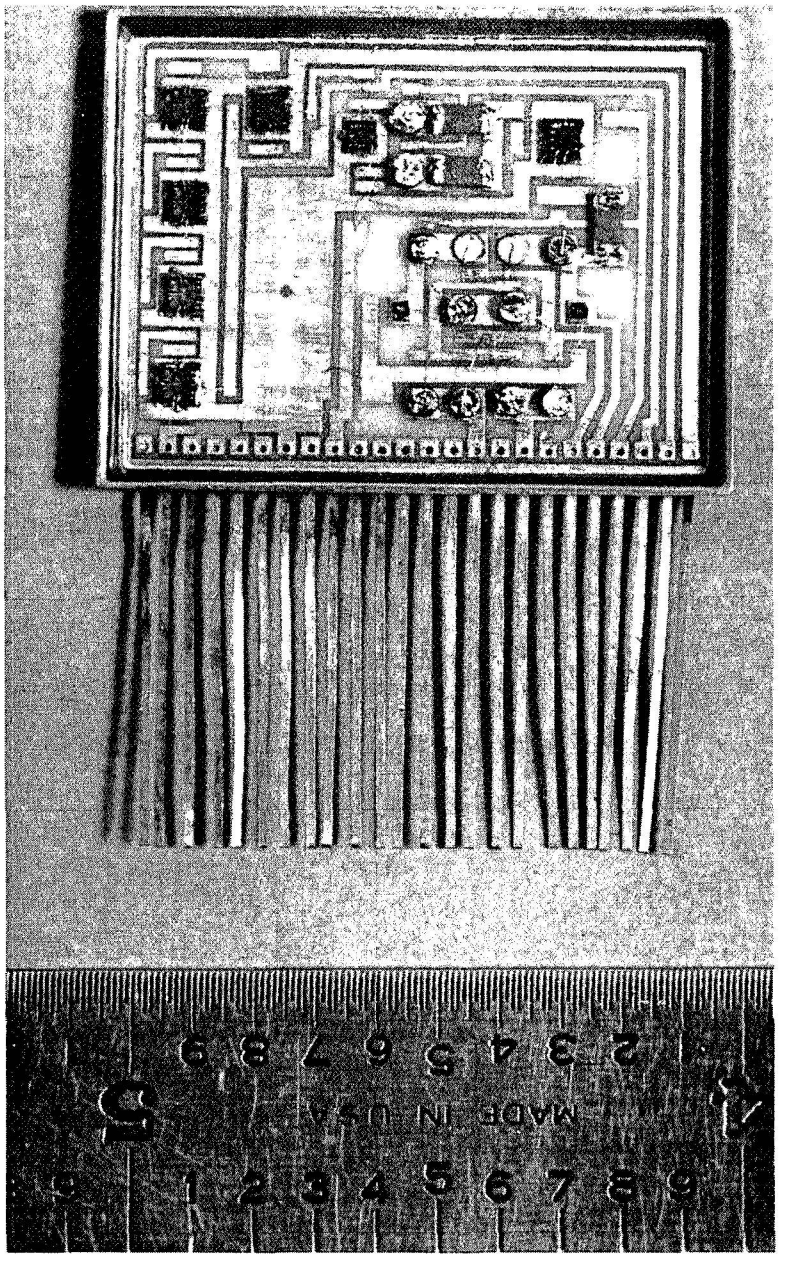
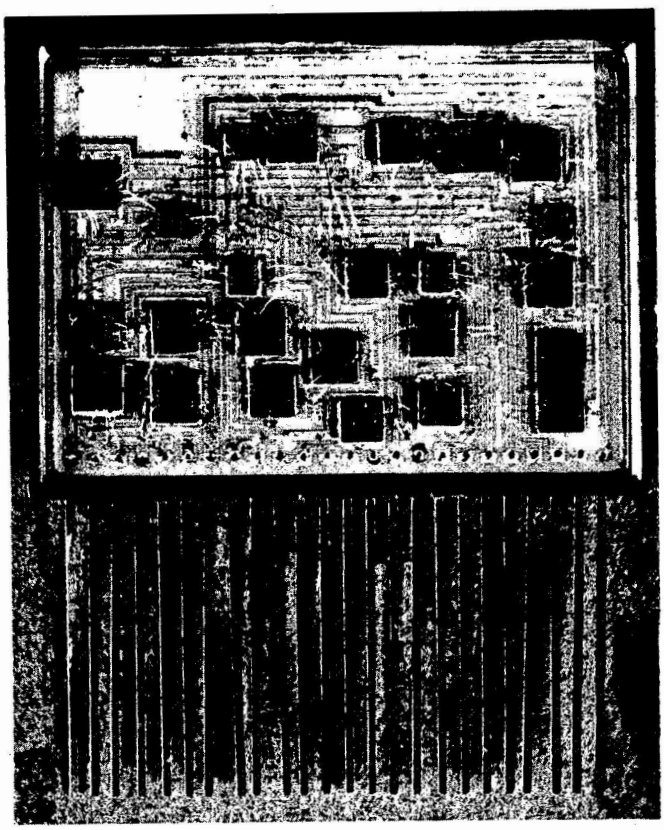
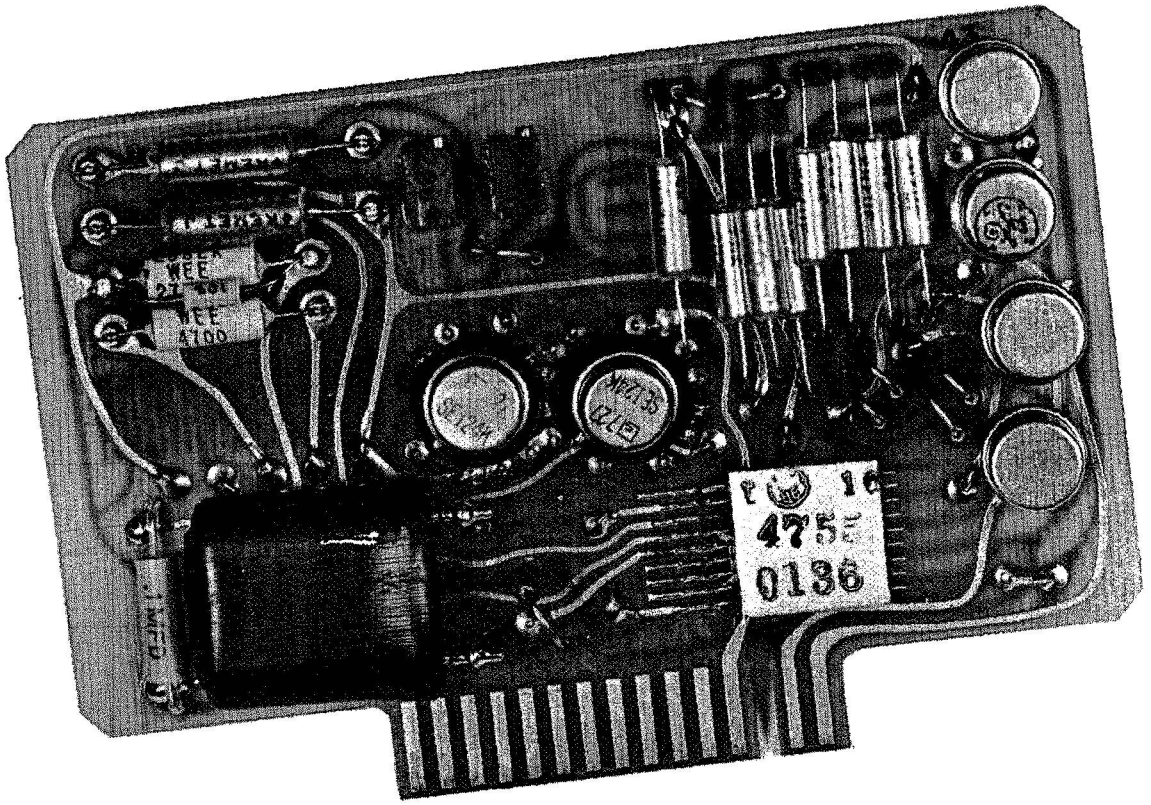


Figure 7. Discrete Component MEMA



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Figure 8. Integrated Circuit MEMA



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Figure 9. 12 KH and 48 KH Reference Supplies

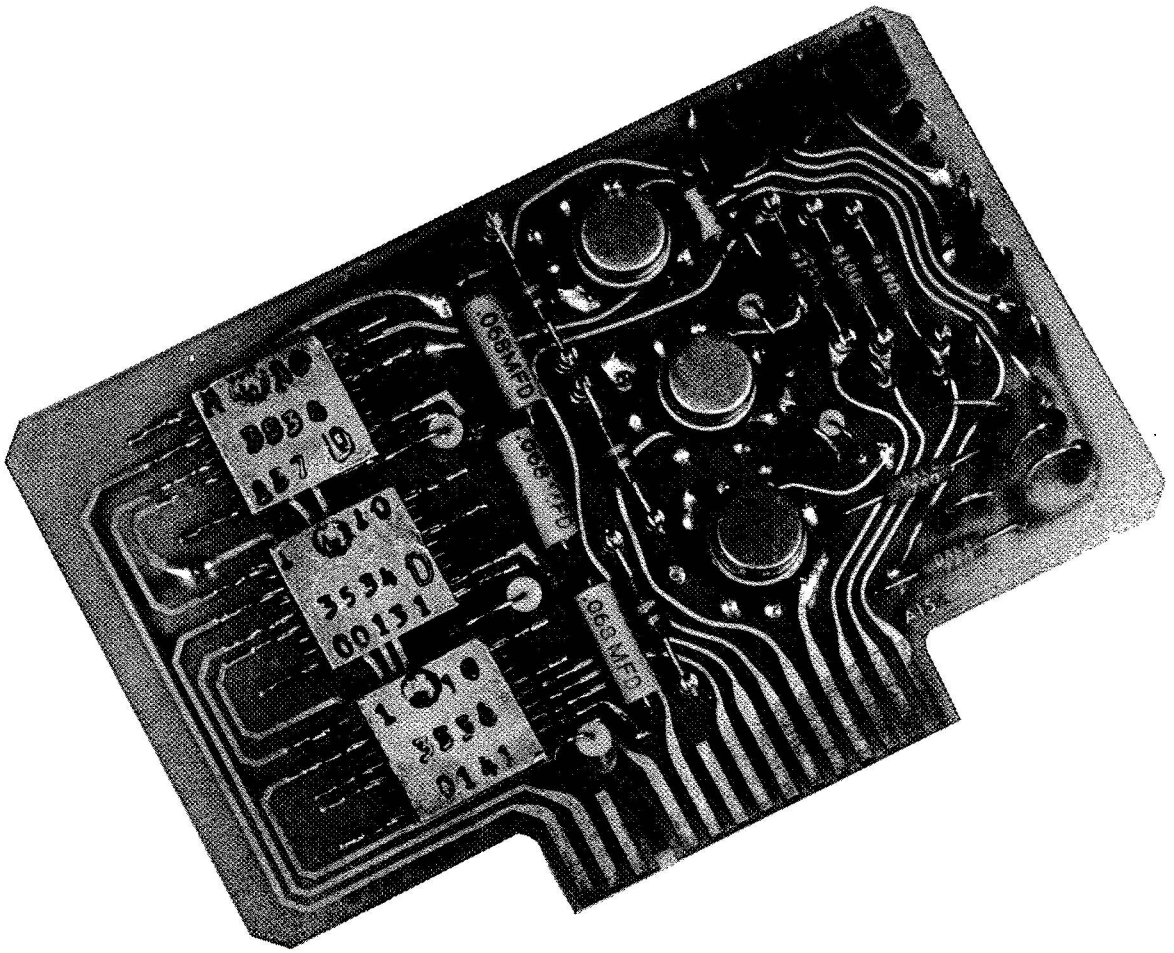


Figure 10. Capture Electronics

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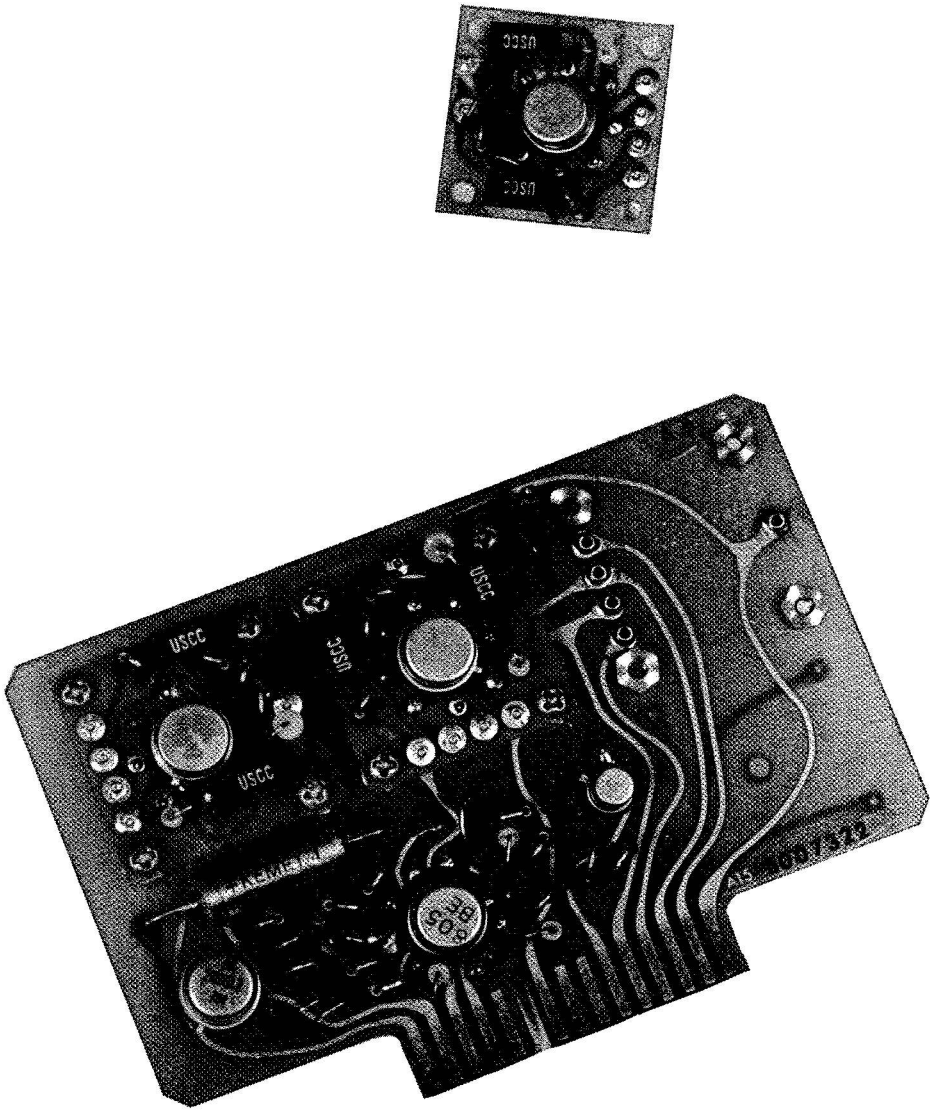
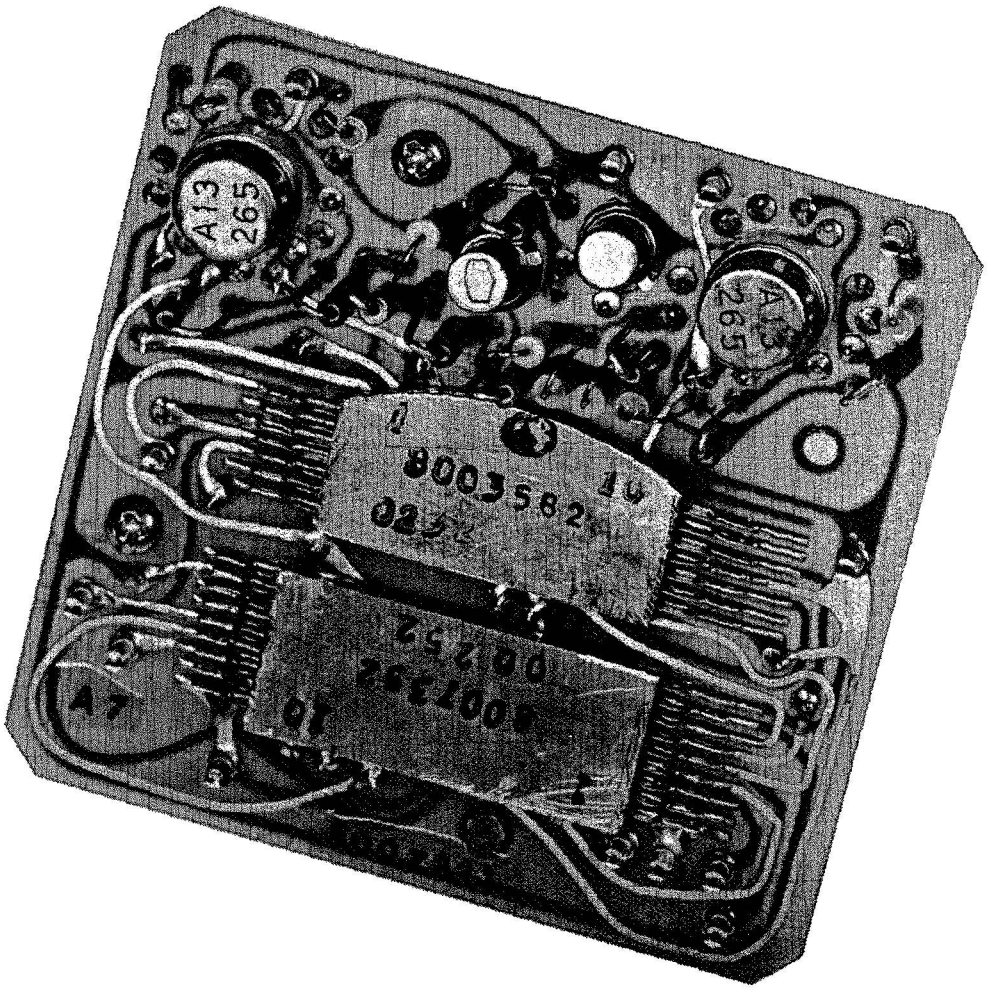


Figure 11. Output Filter and Temperature Control



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Figure 12. Float Centering Electronics

2.2 Development

The sensor and the three major control loops were designed and developed on previous contracts awarded by the Air Force; therefore, the prime development problems of this contract were to package the system into an extremely small configuration and redesign the control loops to meet the more stringent NASA performance requirements.

The original capture loops (angular control) were redesigned to meet the NASA specifications. One of the unique features of the design is the ability to change the input/output scale factor of each or all of the three independent axis by replacing resistors on one of the plug-in p.c. boards. Another convenient feature is that the filter networks for each axis are fabricated as self-contained submodules in the form of small p.c. boards which plug into the "mother" p.c. board. These features are discussed in detail in Section 4.2.

A modification was made to the 12KHz and 48 KHz Excitation supply circuit. This modification was made to ensure proper operation throughout the temperature range. The problem, discussed during temperature testing of the accelerometer, involved the incompatability (oven temperature) of an Amelco 901 amplifier driving a Signetics SE115 gate. The SE115 was being supplied with +5 VDC and ground with the -2 VDC terminal also being grounded. This is not unusual practice in digital systems when the true and false levels of the input signal are quite close to the plus supply and ground respectively. However, in this configuration, the input threshold level (for a false input to provide a true output) can experience wide variations with temperature. Signetics suggests the variation can be stabilized with the application of a negative voltage (not to exceed -8 VDC) at the terminal provided. This was accomplished in the modification by the addition of an IN937A voltage regulator diode connected between pin 8 of the 8004755 48 KHz source MEMA and -12 V line.

The output stage of the 901 amplifier consists of a transistor with resistance in both emitter and collector legs; the output being taken from the collector. Resistance in the emitter is necessary to provide enough negative feedback in concert with the crystal to oscillate. This resistance, however, prevents the output from ever reaching ground potential thereby providing an unreliable false signal to the SE115 gate input. The 901 false output level was optimized to fall below the gate threshold level at all temperatures. This was done by lowering the emitter resistance of the output stage but maintaining sufficient resistance to provide the negative feedback needed for oscillation. Lowering the emitter resistance was accomplished by adding a parallel resistor (510Ω) from pin 3 of the 8004755 MEMA to ground.

The modifications accomplished the end objective with a minimum of rework to the p.c. card and the addition of only two components.

One MEMA was redesigned especially for this application to help meet the physical packaging requirements. Two distinctly different system packages

were designed; one stressing modularity and maintainability and the other emphasized high density packaging to decrease the volume and weight. The final configuration which was delivered to NASA incorporated the best features of both designs to provide a small system which utilizes the modular concept.

By incorporating welded modules and designing additional MEMAs, a smaller and more modular system can be provided. An example of welded module packaging and the equivalent MEMA package is shown in Figure 13. Both of these concepts of electronics packaging are considerably smaller than discrete components on printed circuit cards. While all three techniques are used extensively by Teledyne on production systems, the development costs for new welded modules and MEMAs are much higher than discrete components on p.c. boards. Also the lead time is greater for new specific modules and MEMAs. Once the development work has been completed the production costs are very competitive between the three techniques.

3. TEST

3.1 Procedures and Equipment

After the individual modules (sensor, MEMAs and p.c. boards) were tested, the the components were assembled into the system housing. Upon completion of the system integration tests which consist of verification of signal phasing and condition, and adjusting the temperature control pot for proper floatation temperature; thesystem acceptance tests were initiated. The acceptance tests are of two basic types. The "static" tests consist of 1) null noise evaluation and 2) applying external forcing functions to the angular force-rebalance loop. The second type of evaluation is environmental testing. The tests subject the system to altitude, temperature and vibration environments which simulate the conditions described in the Statement of Work of the contract.

3.1.1 Static Test Procedures

The static tests were performed with the following general conditions. The 3AS was mounted, with $\ddot{\psi}$-axis vertical, on a seismic isolation pier which is located in the Teledyne inertial navigation test laboratory in Northridge, California. The piers in this facility were existing installations which had been specifically designed for gyroscope and inertial navigation systems testing. They are, therefore, not the optimum design for testing systems with a large frequency range such as the 3AS. Cultural noise, which lies in the range of 10 to 30 Hz, is not isolated by the piers. The piers do attenuate externally generated seismic inputs above 60 Hz and below 0.05 Hz.

Below is a list of the test equipment utilized in these tests:

1. 2-channel Hewlett-Packard Strip Chart Recorder
2. Tectronix Storage Oscilloscope

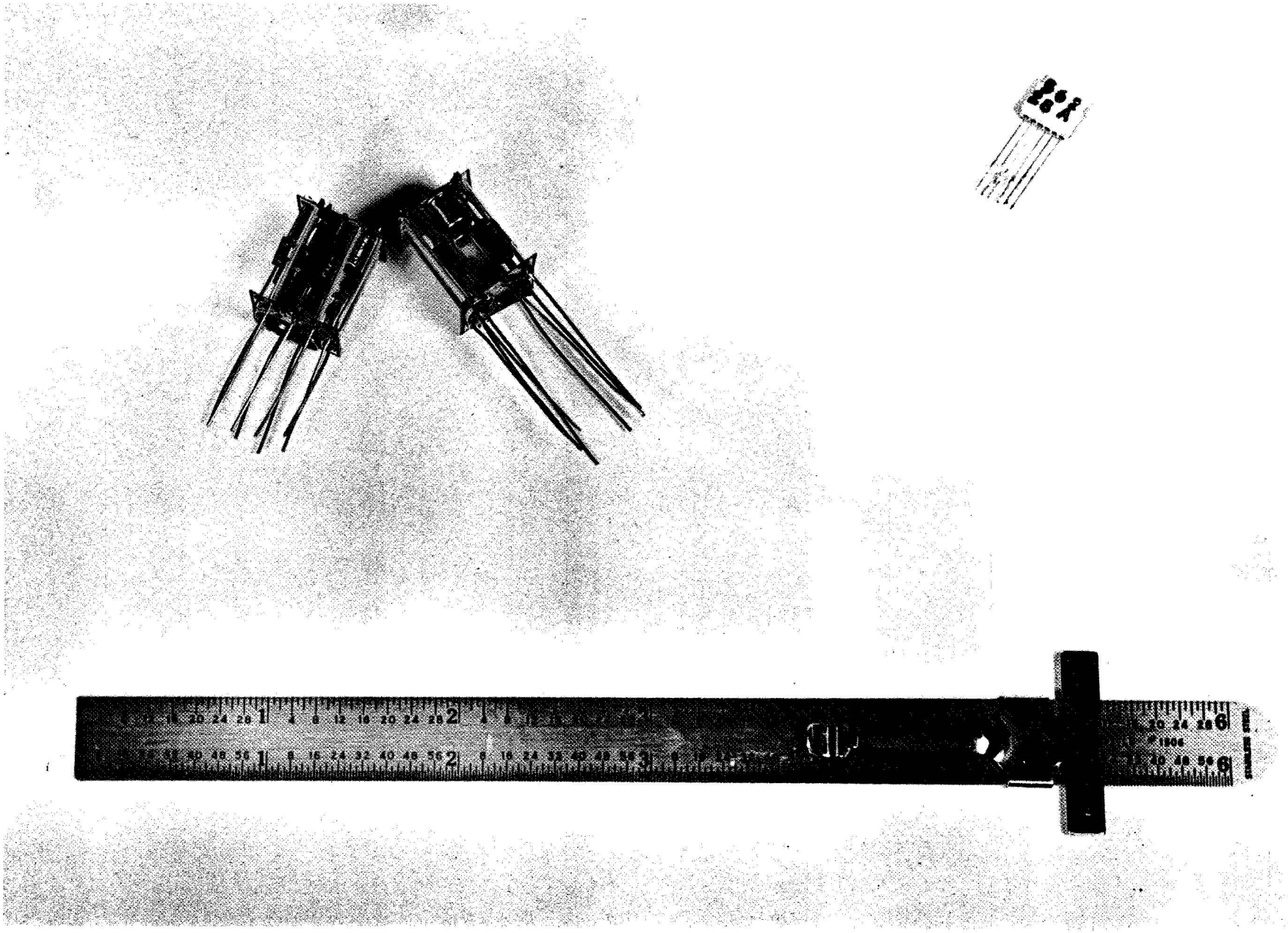


Figure 13. Welded Modules and Equivalent MEMA

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3. Hewlett-Packard Function Generator
4. Power Design +28 VDC Supply
5. The 115 V, 400 Hz, single-phase power was obtained from the laboratory power lines.

The first static test conducted was recording the null noise on each of the three axes. This consisted of recording the output of each axis with zero angular acceleration input. The test set-up for the null evaluation is shown schematically in Figure 14.

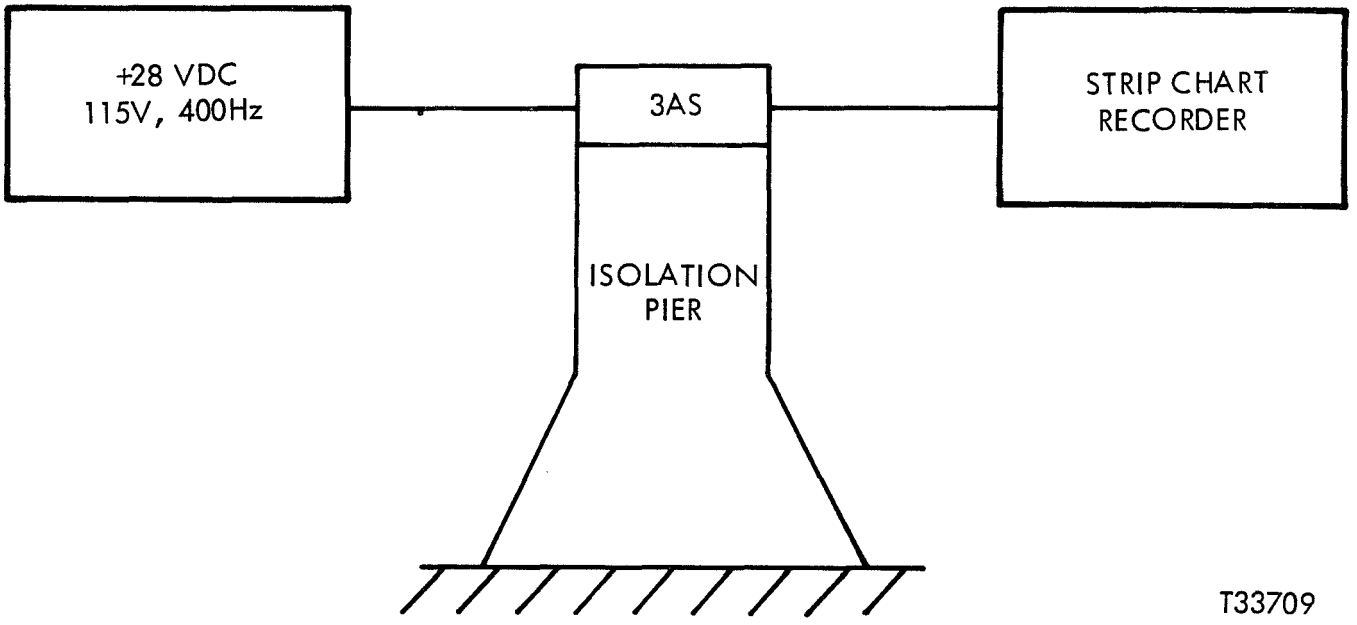


Figure 14. Static Test Configuration

Next, the forcing-function tests were conducted. Sinusoidal and square wave forcing functions were fed into the sensor's torquer coils from the HP Function Generator and the angular pickoff signals ($\ddot{\theta}$, $\ddot{\phi}$, $\ddot{\psi}$) were monitored one at a time on the strip chart recorder. To simulate an acceleration input, the forcing function is applied as shown in Figure 15. The input voltages and frequencies ranged from 6.5 to 10 volts at 0.5 to 20 Hz respectively.

Inputs to the torquer circuit up to 100 volts peak to peak and zero to 2000 hz will not cause malfunction or degradation of the sensor. However, the capture loop amplifiers will be saturated by inputs greater than 55 volts.

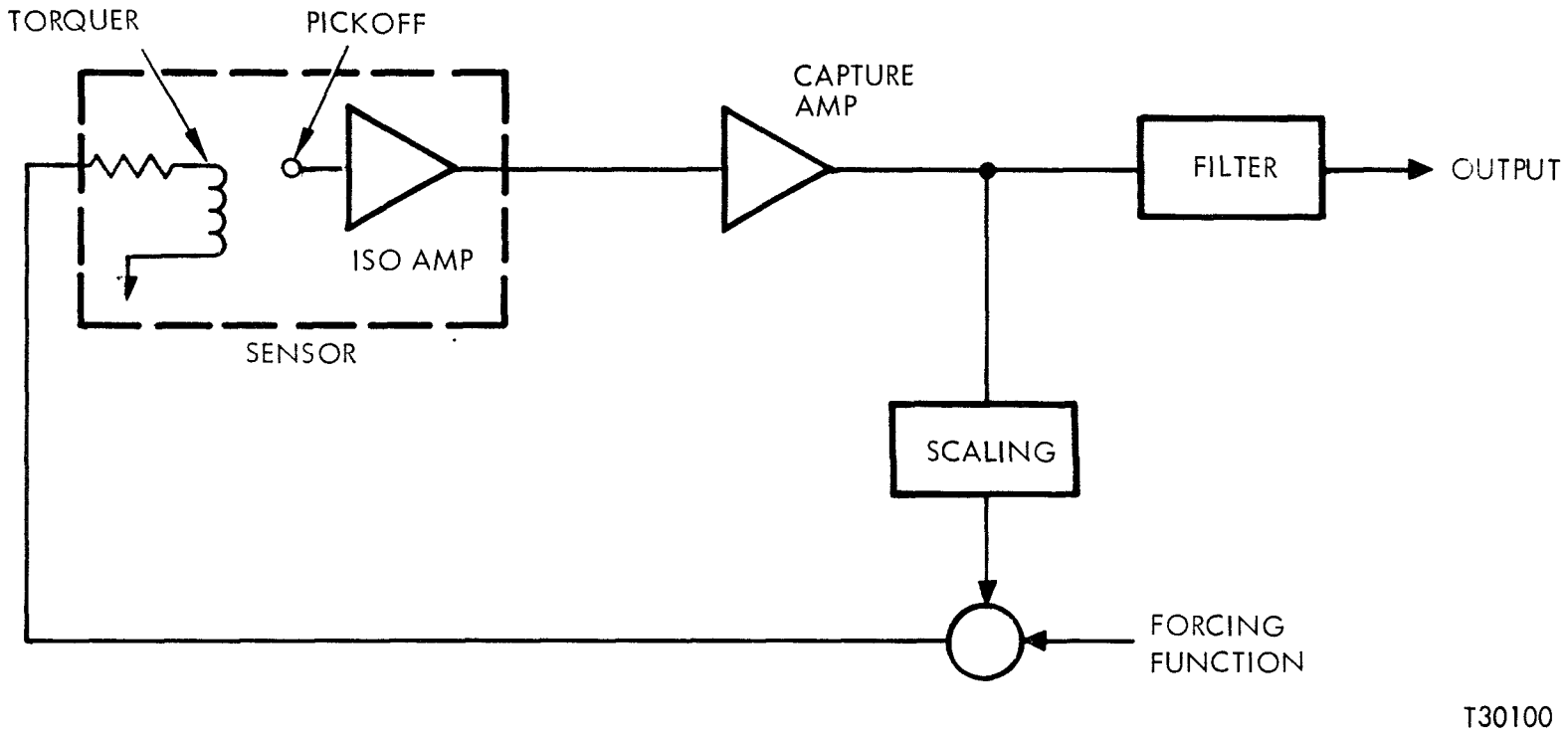


Figure 15. Accelerometer Mechanization

By comparing the input to the output as recorded on the strip chart recorder; the frequency response, damping ratio and general dynamic performance of the angular capture loop can be determined.

3.1.2 Environmental Test Procedures

The environmental tests consisted of exposing the systems to pressure and temperature conditions which can be found at sea level up to 180,000 feet and to a vibration input along each of the system axes of 0.036 inches double amplitude from 5 to 55 Hz, then $\pm$ 5 g's from 55 to 500 Hz.

The first series of tests were conducted with the following general conditions. The 3AS was mounted in an altitude chamber with the $\ddot{\psi}$ axis vertical. The system was energized and forcing functions were supplied from an HP Function Generator to the torquer coils of one sensing axis. The output of the angular control loop was monitored on a HP recorder with the input monitored simultaneously while the system was exposed to the various environmental conditions listed below.

3.1.2.1 Altitude and Temperature Tests

With the above general conditions, the temperature of the altitude chamber was lowered to -65° F and maintained for one hour, then the pressure in the chamber was reduced until it was 1×10^{-2} inches Hg (equivalent to 180,000 feet altitude). This condition of low temperature and low pressure was maintained for one hour. Although it is not required by the specifications, the NASA-1001 system was turned off for five minutes at -60° F and the equivalent of 160,000 feet and was re-energized without any trouble.

The chamber temperature was then raised until the mounting surface of the system was +200° F and the pressure was one atmosphere. This condition was maintained for one hour.

3.1.2.2 Vibration Tests

The vibration input of 0.036 inches double amplitude from 6 to 55 Hz followed by $\pm$ 5 g from 55 to 500 Hz was generated by an Unholtz-Dickie 83-CD Vibration Machine. This shaker can be operated in the horizontal as well as vertical orientation. The $\ddot{\theta}$ and $\ddot{\phi}$ axis were vibrated with the shaker axis in the horizontal attitude and the $\ddot{\psi}$ received its input with the shaker vertical. The frequency range was swept without dwelling at any particular frequencies.

The 3AS was operational during the tests. Forcing functions were imposed on the $\ddot{\theta}$-axis and the $\ddot{\theta}$-axis was monitored during the vibration inputs along each of the three orthogonal axes. The output of the $\ddot{\theta}$-axis and the vibration axis was monitored on two separate HP 413AR DC Null Voltmeters.

3.2 Test Results

The actual data taken during tests performed prior to shipment to NASA FRC are in the Appendix Envelope. There are two distinct sets of data. The package dated May 1968 contains the tests conducted on the system before it was repackaged in the final, hermetically sealed housing. The original housing was similar but not hermetically sealed. The sensors, p.c. boards and other components were exactly the same items except for and isolation amplifier MEMA which was on sensor S/N-004 in system NASA-1002. This MEMA failed during component test and was replaced before the second data package was obtained. The second data package is dated February 1969 and is the final data taken prior to delivery of the two hermetically-sealed systems to NASA FRC.

3.2.1 Null Noise

The May 1968 data reveals that the null noise for each of the horizontal positioned axes ($\ddot{\phi}$ and $\ddot{\theta}$) is less than 95 urad/sec^2 peak to peak. The null noise for the $\ddot{\psi}$-axis which is in the vertical position was as high as 320 urad/sec^2 on the NASA-1002 system and was 130 urad/sec^2 on the NASA-1001 system. Analyzing the data it is obvious certain frequencies are predominate. The predominant noise lies in the frequency range of 30 to 40 Hz. It is believed that much of this output is caused by seismic inputs whose source is within the industrial park adjacent to the test facility. The spikes at 10 to 15 Hz are almost certainly due to cultural noise from the usual urban sources.

3.2.2 Forcing Function Response

Figures 16 & 17 show the frequency response of the systems for sinusoidal forcing with the system firmly mounted on the isolation pier. The February 1969 data was obtained with the system sitting standard work bench or inside the altitude chamber. Hence, there is more noise riding on the output data obtained in February.

The response to the square wave inputs confirms that the damping ratio on each axis of both systems is 0.8 ± 0.05.

3.2.3 Altitude and Temperature

It was found from the tests conducted in the altitude chamber that the systems perform to specifications when exposed to altitudes up to 180,000 feet. Simultaneously, if the temperature of the system mounting surfaces does not exceed the range of -65° F to +200° F, the system performs as specified. Data taken during these tests are presented in the Appendix Envelope.

It was also noted that the systems can be turned off and restarted without degradation of performance with the temperature at -60° F and the external pressure at 5×10^{-2} inches Hg.

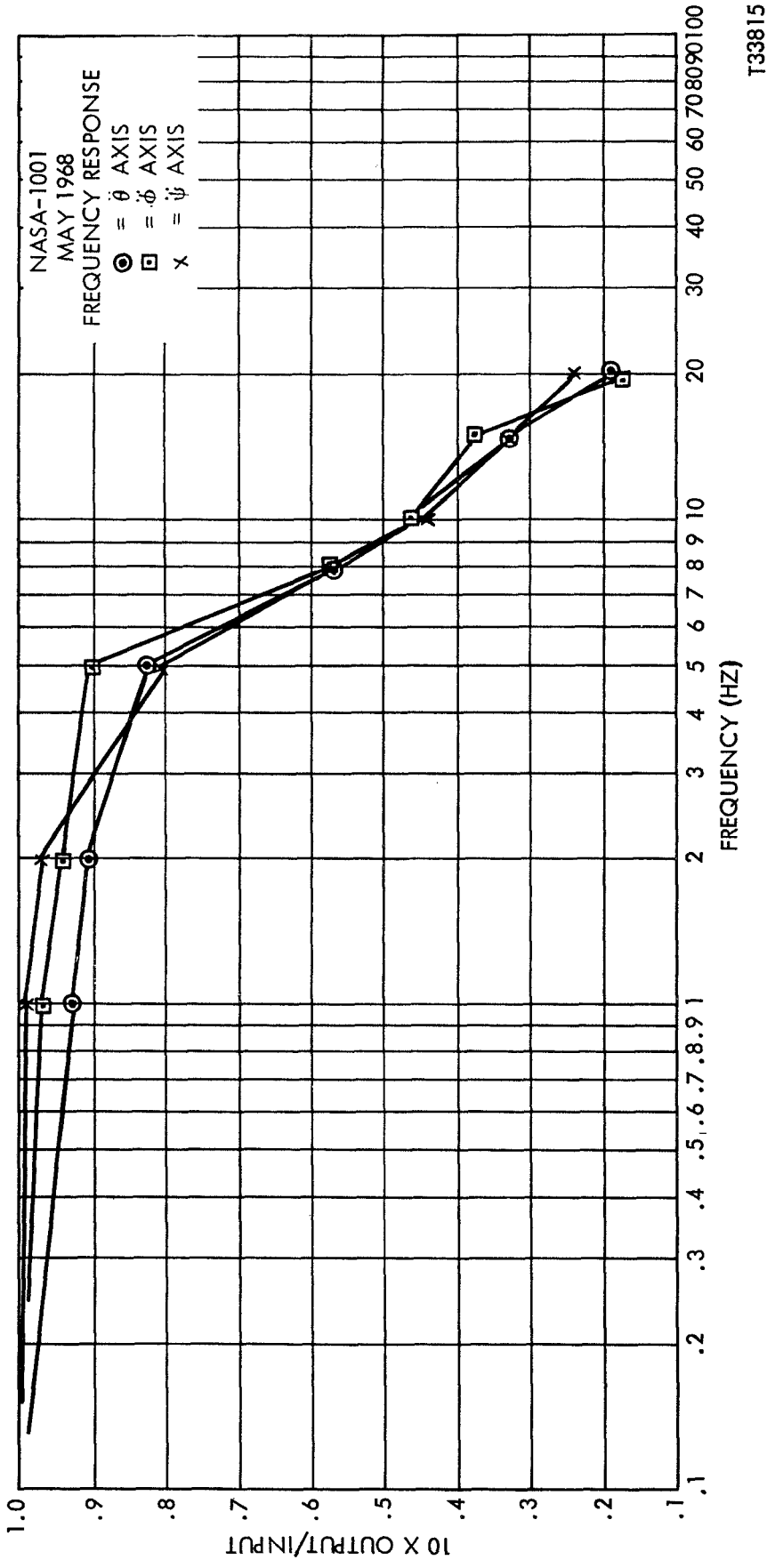


Figure 16. NASA-1001 Frequency Response

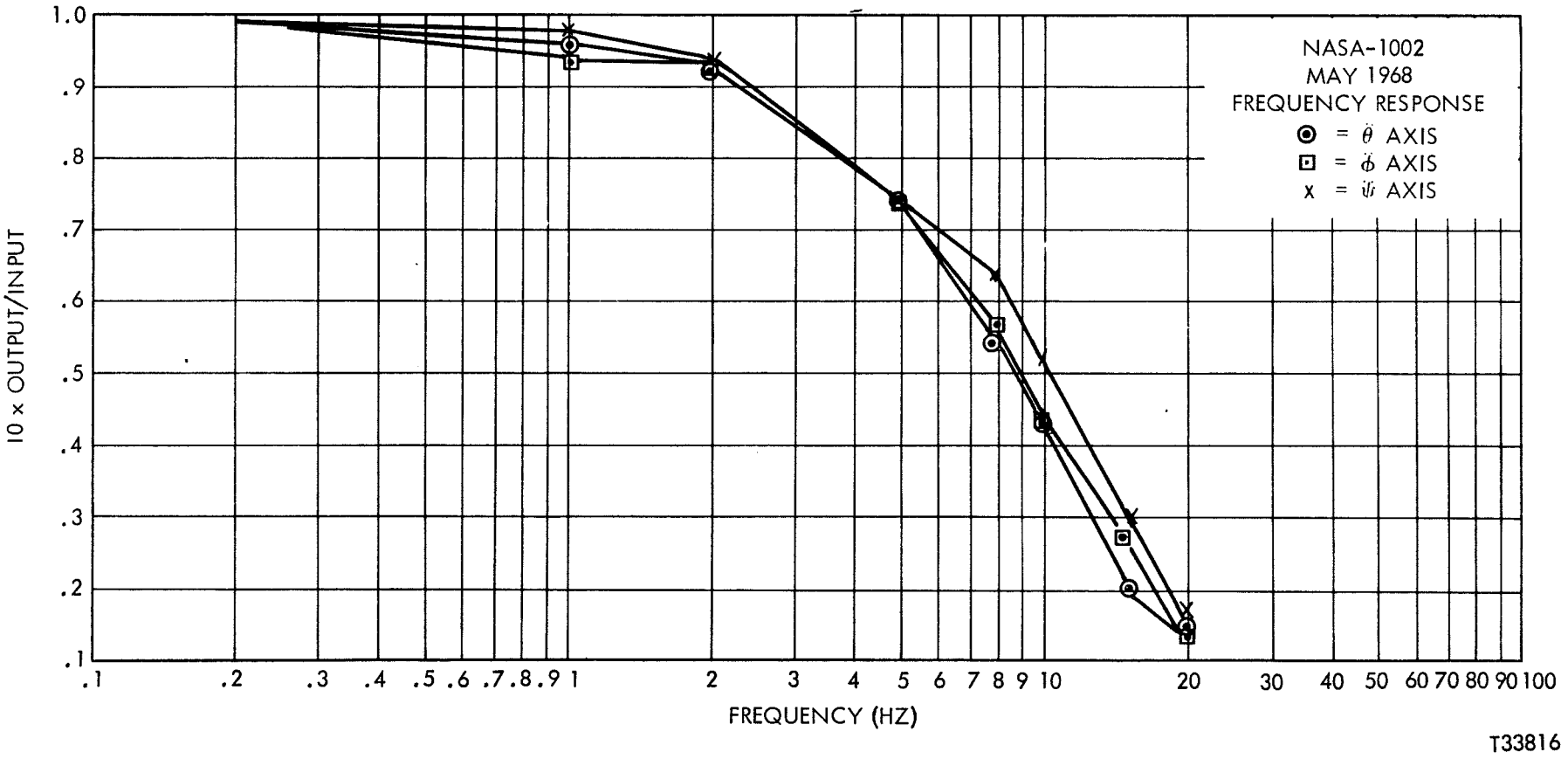


Figure 17. NASA-1002 Frequency Response

3.2.4 Vibration

There was no degradation of performance when the systems were exposed to the vibration environments described above. There were no resonant frequencies detected during monitoring of either the direct or cross axis.

4. OPERATION AND MAINTENANCE

The envelope drawing for mounting the three axes angular accelerometer and the system schematic are included in the Appendix of this report.

4.1 Start-up Procedure

This is a delicate, inertial-quality angular accelerometer. Handle it with care and do not expose it to severe shocks. The system should be stowed in a protective container whenever it is in transport or in storage.

Following are the start-up procedures for the system.

A. Check out the power supplies to be sure they provide +28V dc ± 4V dc and 115V ac ± 5V, 400 Hz ± 20 Hz, Y connected.

B. Insert three #6 screws through the holes in the mounting bosses and gently but firmly push the system's two alignment pads against the A/V alignment surfaces, then tighten the #6 screws to 3 ± 1/2 in. -lb. torque.

C. Plug in the J1 and J2 connectors. This actuates the system electronics and the device is now on. See Page 27 for Connector Pin Designations.

D. Monitor the float centering signal (Pin 6) for three separate channels of 48 kc signal. At first this signal will be approximately 20V peak to peak. As the float centers, the voltage will approach the null value of approximately 1.5 volts.

E. The system requires from 5 to 15 minutes, depending on the initial thermal conditions and the surrounding environment temperatures, to properly center and be ready for operation.

4.2 Adjustments

4.2.1 Scale Factor Adjustment

Provisions for changing the instrument output scale factors have been included in the design of the capture loop card (A6). Scale factor can be changed in an individual axis loop simply by varying the values of two resistors. These resistors will be referred to in this discussion as R_{SF} and Ri.

Gain of the power amplifier stage, hence the capture loop, is established by the gain set resistor Ri. The value of R_{SF} regulates the amount of current that is fed back to the accelerometer torquer. The instrument is

ANGULAR ACCELEROMETER INTERFACE

Pin	No.	Signal	Form	Level	Scaling	Freq. (HZ)	Z_{in}(min)	Z_{load}(min)
J1	1	Pwr. Rtn.	AC	0	--	400	--	--
	2	Pwr. In	AC	115V	--	400	1350	--
	5	Pwr. In	DC	+28V	--	DC	93	--
	6	Pwr. Rtn.	DC	0	--	DC	--	--
	7	Chassis Gnd.	--	0	--	--	--	--
J2	1	Pitch out ($\ddot{\theta}$)	DC	0 to $\pm$10V	1.6 V/R/S^2*	DC	--	300
	2	Pitch T. P.	AC/DC	0 to $\pm$100V	16 V/R/S^2**	0 to 10 Hz***	10K	--
	4	Roll out ($\ddot{\phi}$)	DC	0 to $\pm$10V	1.6 V/R/S^2*	DC	--	300
	5	Roll T. P.	AC/DC	0 to $\pm$100V	16 V/R/S^2**	0 to 10 Hz***	10K	--
	6	Float 150 Amp. Output	AC	1.5 to 20 V. P. P.	--	500 AZ mod V bits d 45 KC	--	1 MEG.
	8	Yaw out ($\ddot{\psi}$)	DC	0 to $\pm$10V	1.6 V/R/S^2*	DC	--	300
	9	Yaw T. P.	AC/DC	0 to $\pm$100V	16 V/R/S^2**	0 to 10 Hz***	10K	--
	12	Sig. Gnd.	--	0	--	--	--	--

*Adjustable to 100 V/R/S^2

** Will Vary with output scaling
always 10 time output scaling

*** Same as output filter characteristic

supplied with resistor values for Ri and Rsf that yield a scale factor of three radian/sec.^{2} for a 5 volt output or 0.6 rad/sec.^{2}/volt. A plot of the values for both Ri and Rsf versus output scale factor is given in Figure 18. The scale factor ordinate of the plot is scaled in terms ofa 5 volt output. If a particular scale factor is desired, the corresponding value of Rsf is read vertically on the left scale while that of Ri is read on the right scale. For example; if the desired scale factor is three rad/sec.^{2}/5 volts, the corresponding value of Rsf is about 900Ω as read from the plot. The value of Ri is about 12.5KΩ. It should be noted that the plot for Rsf is given in two parts. The left section of the plot uses the compressed scale indicated by the values given in parentheses. To insure thermal stability of the scale factor, precision wire wound resistors should be used for Rsf. The resistors corresponding to Ri and Rsf for the various loops are tabulated below. Their physical location on the card is illustrated in Figure 19.

	$\ddot{\phi}$	$\ddot{\theta}$	$\ddot{\psi}$
Ri	R1	R11	R18
Rsf	R3	R13	R20

4.2.2 Trim Pot Adjustments

There are six screw-driver adjustable resistors located on the top edges of the three plug-in printed circuit boards as shown in Figure 20. For this discussion these trim pots will be referred to as the following.

1. R_A, R_B, and R_C on A6 Board: The Capture Electronics
2. R_D on A5 Board: The Temperature Control
3. R_E and R_F on A3 Board: The Excitation Supply.

4.2.2.1 Bias Null

Three of the adjustable resistance pots, R_A, R_B and R_C, are on the accelerometer capture loop electronics card, A6, and are designated as R_6, R_{15}, and R_{22} respectively on the Capture Loop Schematic Diagram which is in the Appendix Envelope. These trim-pots provide output null adjustment for the bias of the three orthogonal axis of the system. The trim-pots designation and their respective axis of adjustment are listed below:

R_A - ϕ Axis

R_B - θ Axis

R_C - ψ Axis

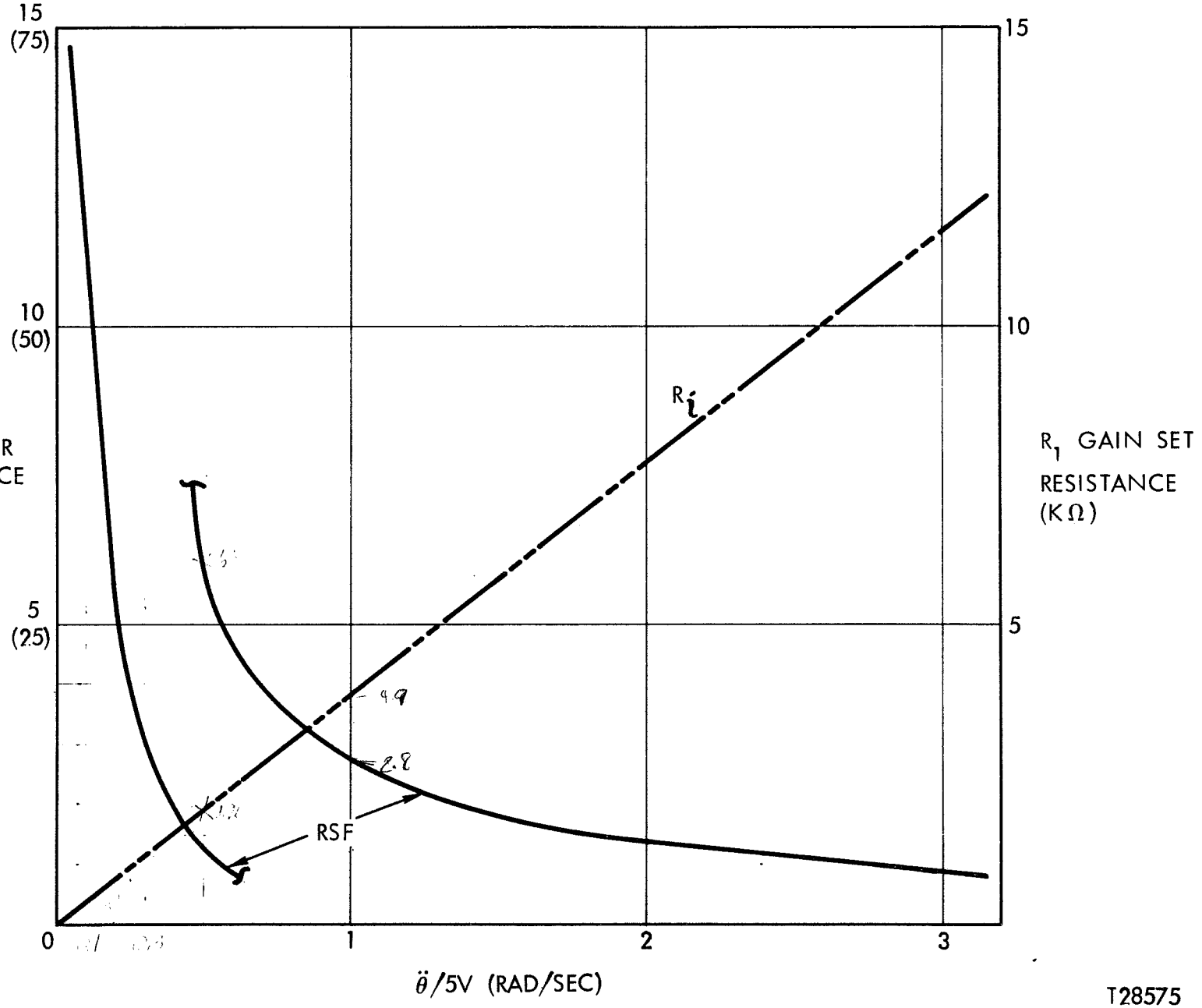


Figure 18. NASA 3 Axis Accelerometer - Scale Factor Change Requirements

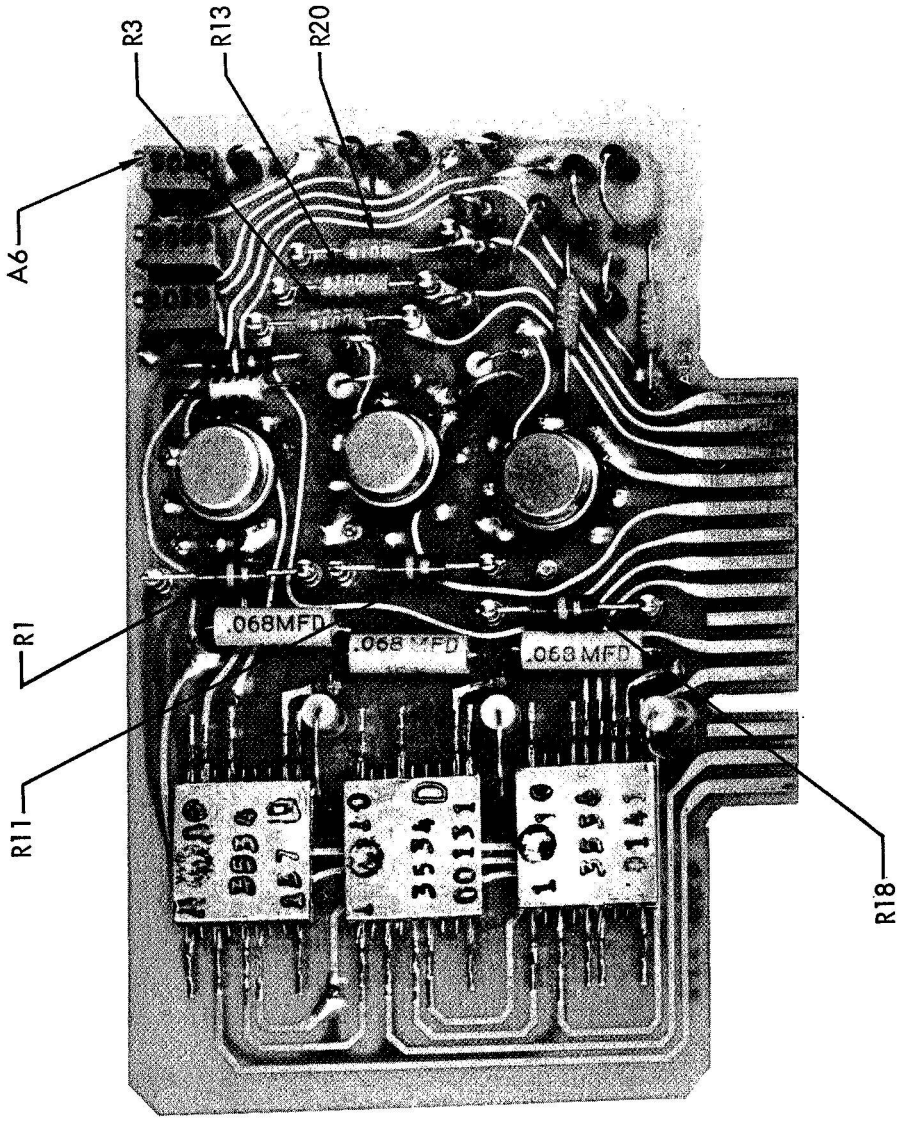


Figure 19. Location of Scale Factor Set Resistors

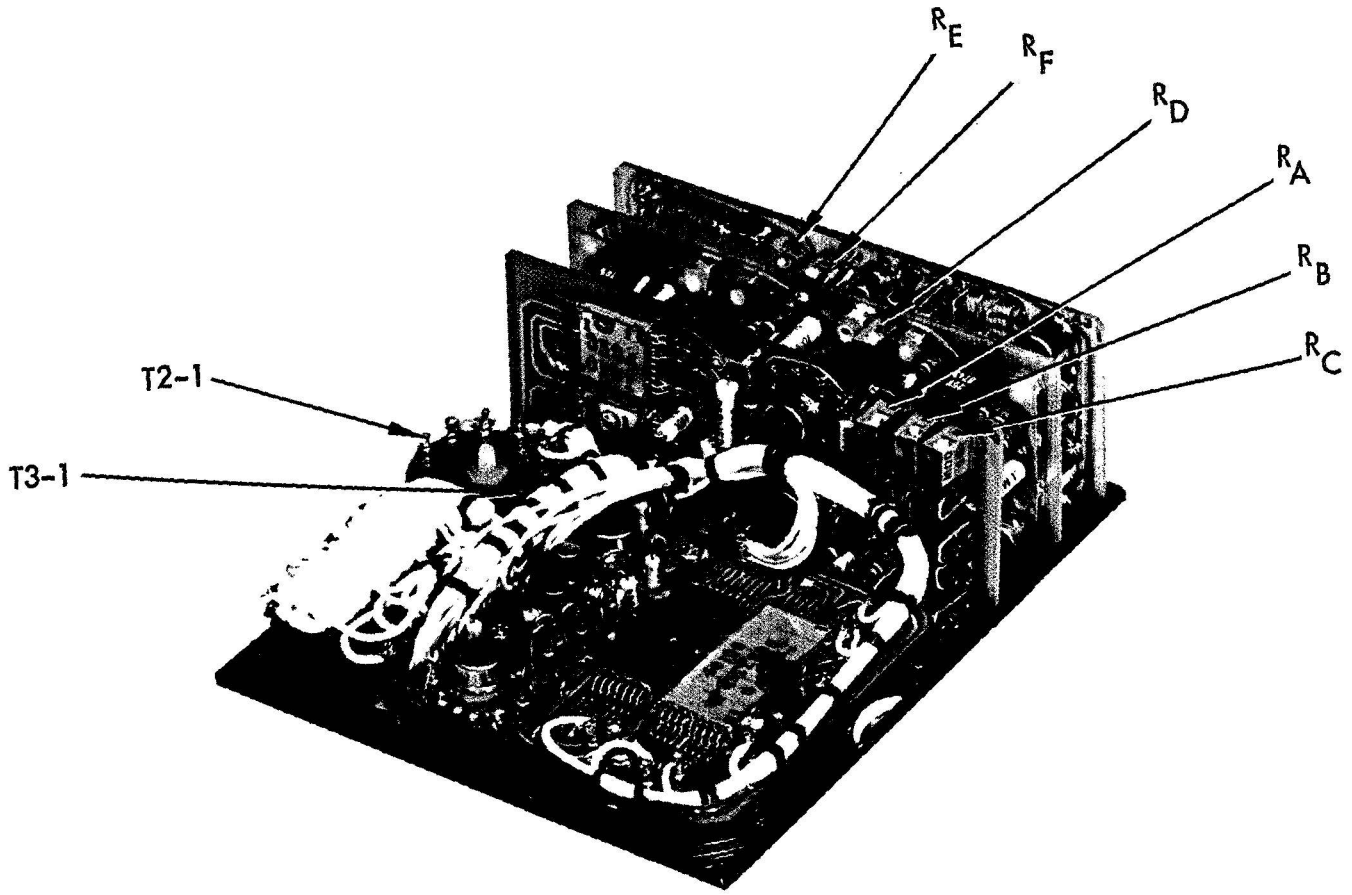


Figure 20. Internal View of 3AS

4.2.2.2 Temperature Control

The plug-in printed circuit board A5 contains the temperature control electronics along with the output filters and the trim-pot R_D. R_D is designated as the adjustable 15KΩ, R_3, on the schematic in the Appendix Envelope. This adjustable resistor is in one leg of a bridge circuit and provides fine adjustment of the temperature set point. The temperature of the sensor can be adjusted through the range of +170°F to +180°F with the trim-pot. If an additional range of adjustment is required, the other resistors in the bridge network which are hard wired discrete components can be changed.

4.2.2.3 Excitation

The amplitude of the 12 KHz and 48 KHz excitation voltages can be adjusted at trim-pots R_E and R_F which are located on printed circuit board A3. These two pots are represented in the schematic of the power supply, located in the Appendix Envelope, as R_1 and R_6. Hence, R_E maybe changed to adjust the 12 KHz amplitude and R_F adjusts the 48 KHz supply. The proper amplitude for both signals at the transformer primaries (T2-1 and T3-1) is 5 VRMS $\pm$2%. The location of terminals T2-1 and T3-1 are shown in Figure 20 and they are identified with black stenciled numbers on the actual terminal board in the system.

4.2.3 Adjustable Output Filter

Output filters are provided in the electronics of each axis to limit the maximum output frequency to 10 Hz. The filter is essentially an active filter whose design utilizes the characteristics of certain R-C networks in the input and feed back circuits of an operational amplifier to produce the desired break frequency and roll off. A schematic of the filter is given in Figure 21. The transfer function for this circuit is

$$\frac{o}{i} = \frac{Af}{Ai} \left[\frac{1}{(1+\tau_1 S)(1+\tau_2 S)(1+\tau_3 S)} \right]$$

where:

$$Af = R3$$

$$Ai = 2\,R1 + R2$$

$$\tau_1 = R3\,C1 = 15.9 \times 10^{-3} \text{ sec}$$

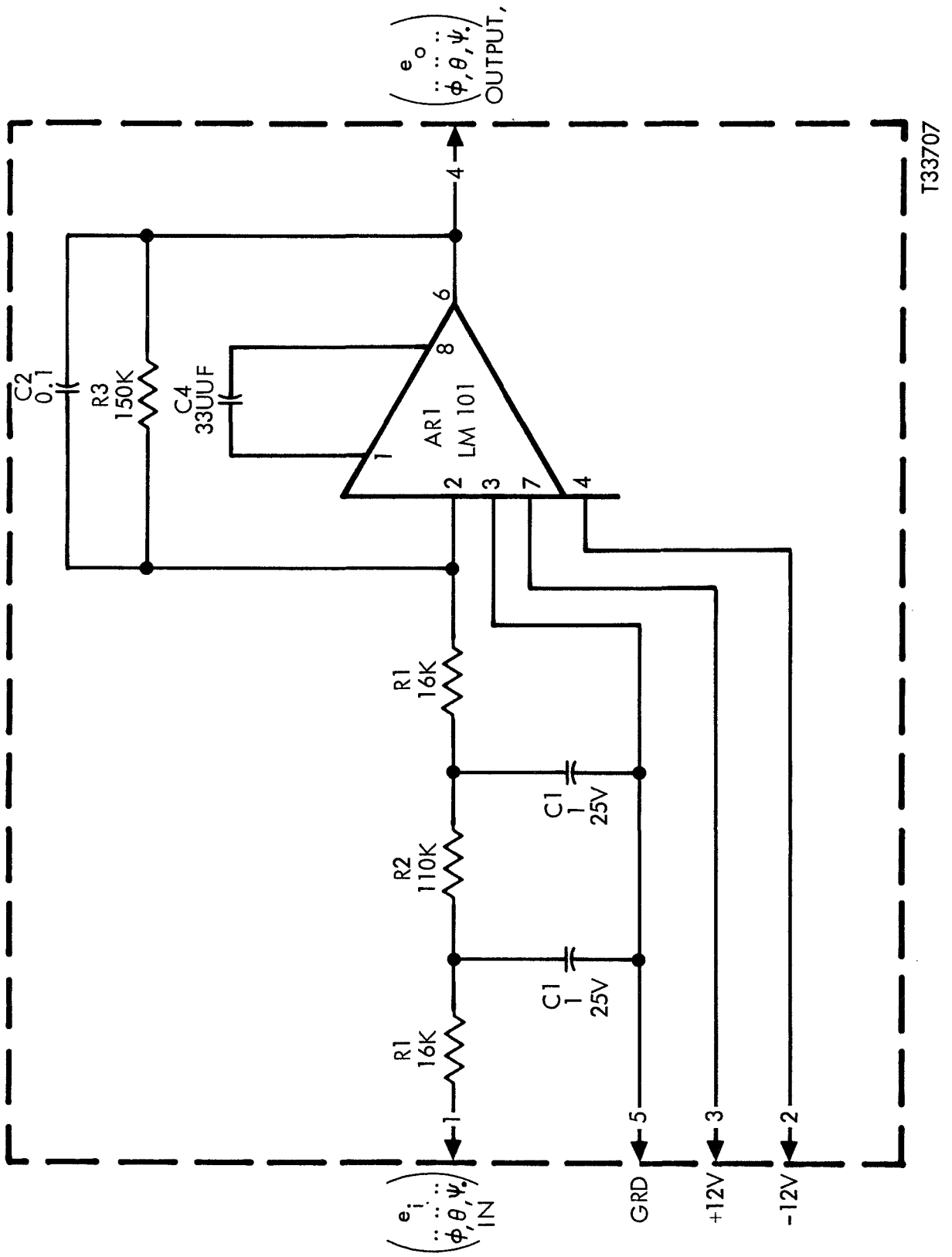


Figure 21. Output Filter Schematic

$$\tau_2 = \frac{R1\ R2\ C1}{R1 + R2} = 13.7 \times 10^{-3} \text{ sec}$$

$$\tau_3 = R1\ C1 = 15.9 \times 10^{-3} \text{ sec}$$

The time constant shown above result in an effective break frequency at 10 Hz and a roll off of -60 db/decade (-18 db/octave). The break frequency of any individual axis may be moved as desired by simply changing the value of the capacitance. Range of the break frequency location is limited only by the physical size of the capacitance.

Operational amplifier active filters of this type provide a one-to-one transfer of low frequency information signals while attenuating the undesirable higher frequency noise. In addition they present an output impedance of less than 30 ohm and in the design provide output short circuit protection. These filters are packaged as plug-in modules on the A5 P.C. board so that they can be easily removed and replaced. They are designated as P.C. Card A8 and are assigned the Teledyne part number 8007434.

4.3 Electronic Module Input/Output Specs

4.3.1 Printed Circuit Boards

There are four printed circuit boards in the NASA System. These are designated as A3, A5, A6 and A7 & have the Teledyne part numbers of 8007434 8007322, 8007441 & 8007331 painted directly upon the cards. Three of these modules are plug-in boards. Following are tables of the required inputs & the designed outputs for trouble shooting and maintenance of the plug-in boards.

Card A3: 12 KH & 48 KH Excitation Supply Part No. 8007434

Terminal	Input	Output
A12	+4.5 Vdc Test Pt.	
Key	Key	Key
A14		48 KH, 5 VRMS ± 5%
A15		12 KH, 5 VRMS ± 5%
B1	Grd	Grd
B14	-12 VDC	
B15	+12 VDC	

Card A5: Filter & Temperature Control Part No. 8007322

A1		$\ddot{\phi}$ - Out analog of angular acceleration
A2	$\ddot{\phi}$ -IN Unfiltered Restoring Voltage	
A3	AA1 Temp. Sensor (ΔΩ)	
A4	$\ddot{\theta}$-IN Unfiltered Restoring Voltage	
Key	Key	Key
A7		$\ddot{\theta}$ -Out Analog of angular acceleration
A10		0.8VDC (During Warm up) 13-17VDC (During Control)
A11	+ 12.5 Vdc ± 0.1 V	
		$\ddot{\psi}$ -Out Analog of angular acceleration
A13	- 12.5 Vdc ± 0.1 V	
A14	$\ddot{\psi}$- IN unfiltered restoring voltage	
A15	Grd (Signal)	Grd

Terminal	Input	Output
B1	+ 28 V dc	
B2	AA1 Temp Sensor (Δ Ω)	
B3	+ 16 to +20 Vdc	
Key	Key	Key
B7		DC to base of pwr trans.
B8	Grd (+28 V rtn)	Grd (+28 V rtn)
B10		DC to Base of transistor
B11		DC to collector
B13		DC to Base of transistor
B14		DC to collector
B15	-16 to -20 Vdc	

Card A6: Capture Electronics, Part No. 8007441

A1	$\ddot{\phi}$ mV in (12Kc)	
A2	$\ddot{\theta}$ mV in (12Kc)	
Key	Key	Key
A5	$\ddot{\psi}$ IN (12Kc)	
A6	12 Kc, 26 V rms	
A8	12 Kc, 26 Vrms	
A9	12 Kc, 26 V rms	
A11		$\ddot{\phi}$, $\ddot{\theta}$ & $\ddot{\psi}$ Output to filter, 20 V. P-P max.
A13		Analog restoring voltage to $\ddot{\phi}$ torquer
A14		Analog restoring voltage to $\ddot{\theta}$ torquer
A15		Analog restoring voltage to $\ddot{\psi}$ torquer
B1	-12 Vdc	
B2	Grd	Grd
Key	Key	Key
B12	+12 Vdc	
B13	Test Pt. 1- $\ddot{\phi}$ Axis	
B14	Test Pt. 2- $\ddot{\theta}$ Axis	
B15	Test Pt. 3- $\ddot{\psi}$ Axis	

Card A7: Part No. 8007331.

To trouble shoot the Float Centering Board, refer to Figure 22 for pin location and the table below for the input/output conditions:

Terminal	Input	Output
E1	48 Kc, 5 Vrms	
E2	-12 Vdc	
E3	+12 Vdc	
E4	*Float P.O. (48 Kc modulated)	
E5	Sig Grd	Sig. Grd
E6	48 Kc, 5 Vrms	
E7**		**30 to 200 Vdc to A forcer
E8**		**200 to 30 Vdc to C forcer
E9**	+190± 10 Vdc	
E10**		**30 to 200 Vdc to B forcer
E11**		**200 to 30 Vdc to D forcer
E12**		**30 to 200 Vdc to Up. forcer
E13**		**200 to 30 VDC to Lo. forcer
E14	Grd (Aux.)	Grd (Aux.)

4.3.2 MEMAs

Following is the list of MEMAs used in the 3AS accompanied by their respective input-output specifications for trouble shooting them. Included in the MEMA description is the part number and the Specification Control Drawing number. Spare or replacement MEMA's can be ordered under either of these numbers.

* Same signal as that found on J2 pin 6 labled on system schematic as Float is out.

** Also carries output of 48 Kc, 5 Vrms to forcer plates for translational pick off excitation to be used as error signal in float centering loop.

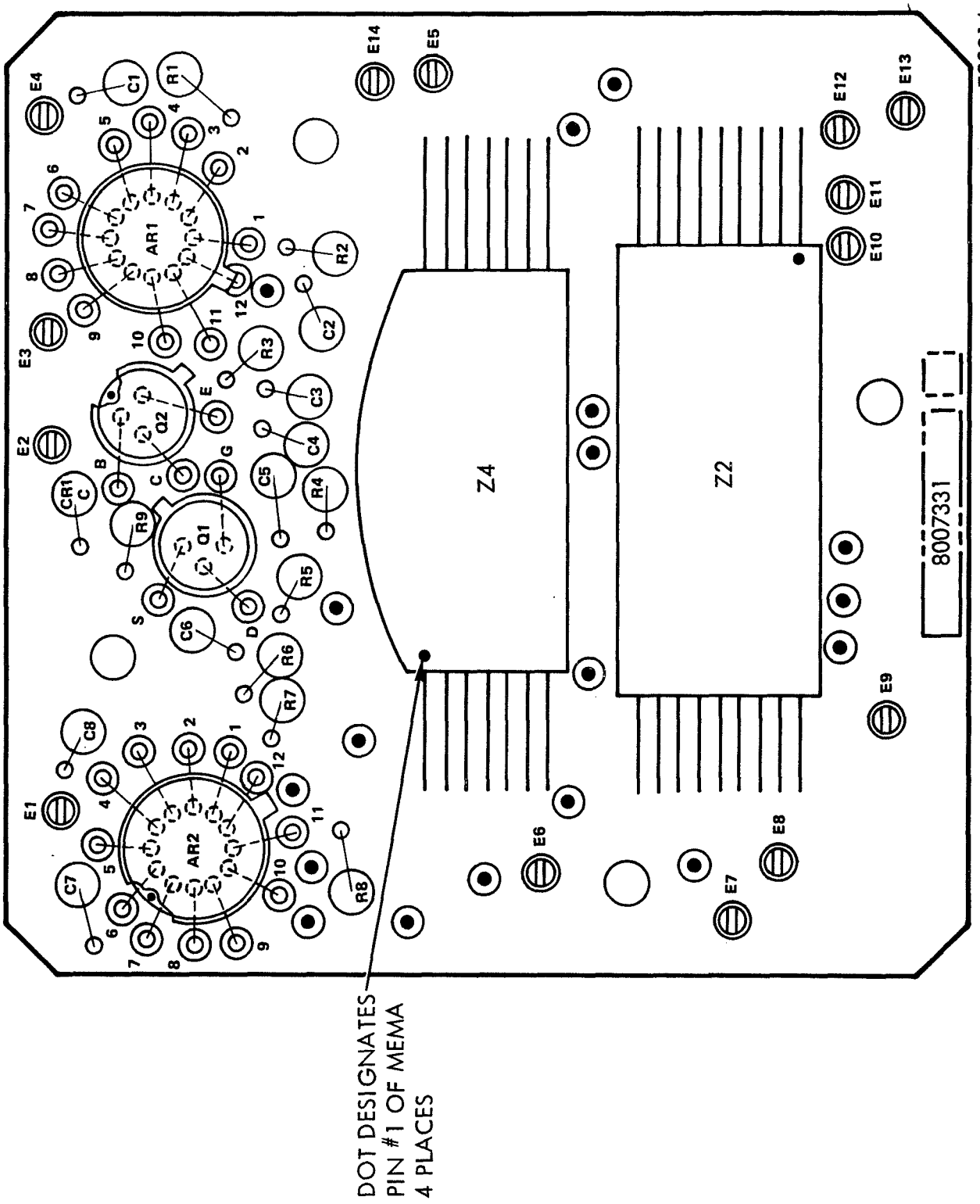


Figure 22. Float Centering Electronics Board Layout

8003516: Pickoff Isolation Amplifier, SCD 7104612. See Figure 23 for the physical configuration:

Terminal	Input	Output
1	GRD	GRD
2	15 mV @ Null Input (12KC Carrier)	
3	+ 12 Vdc	
4	- 12 Vdc	
5	GRD	GRD
6		@ 100° ±10% Output = Input ±10% (SF. ≃ 240mV/MRAD ±20%)

8003978: 48KC Isolation Amplifier, SCD 7104626. (See Figure 23.)

Terminal	Input	Output
2	GRD	GRD
3	+12 Vdc	
4		Output=Input ±20% @ 180° ± 10°
5	-12 Vdc	
6	15mV @ null (48KC carrier)	

The above MEMAs are mounted directly on the center ring of the sensor while those listed below are mounted on the P.C. card designated.

8004755: 48KC Source, SCD 7104623, mounted on A3. See Figure 24 for the physical configuration of the MEMA.

Terminal	Input	Output
1	+4 Vdc	
2	384.000 KC	
3		Distorted Sq. Wave out of Phase with Pin 9.
4	GRD	GRD
5	384.000 KC	
6		Test Pt. 192 KC
7		Test Pt. 96 KC
8	GRD	GRD
9		4±.5V, 48KC Square

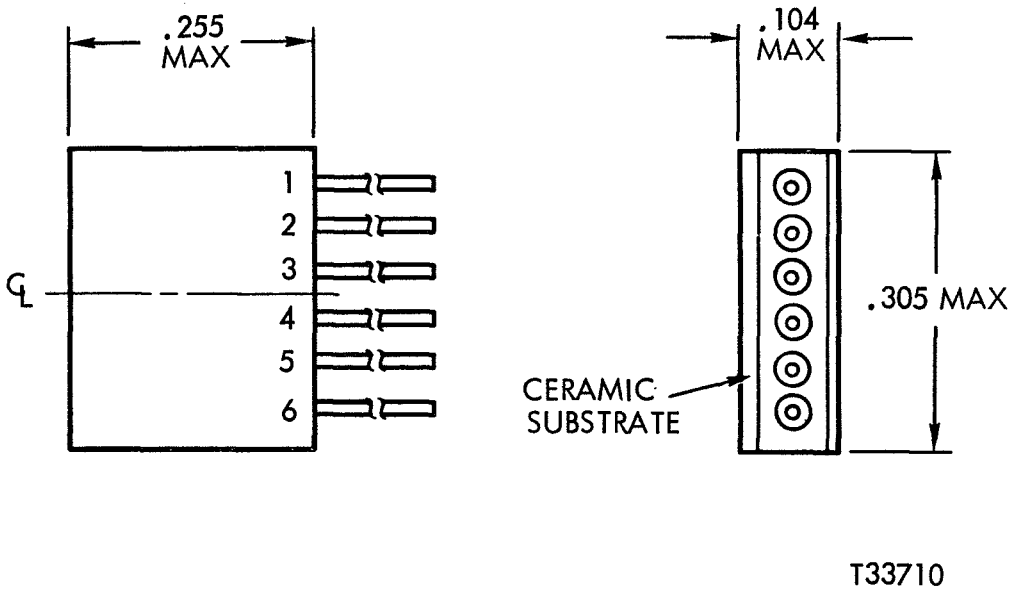


Figure 23. Physical Dimensions and Lead Location of Sensor Mounted MEMA

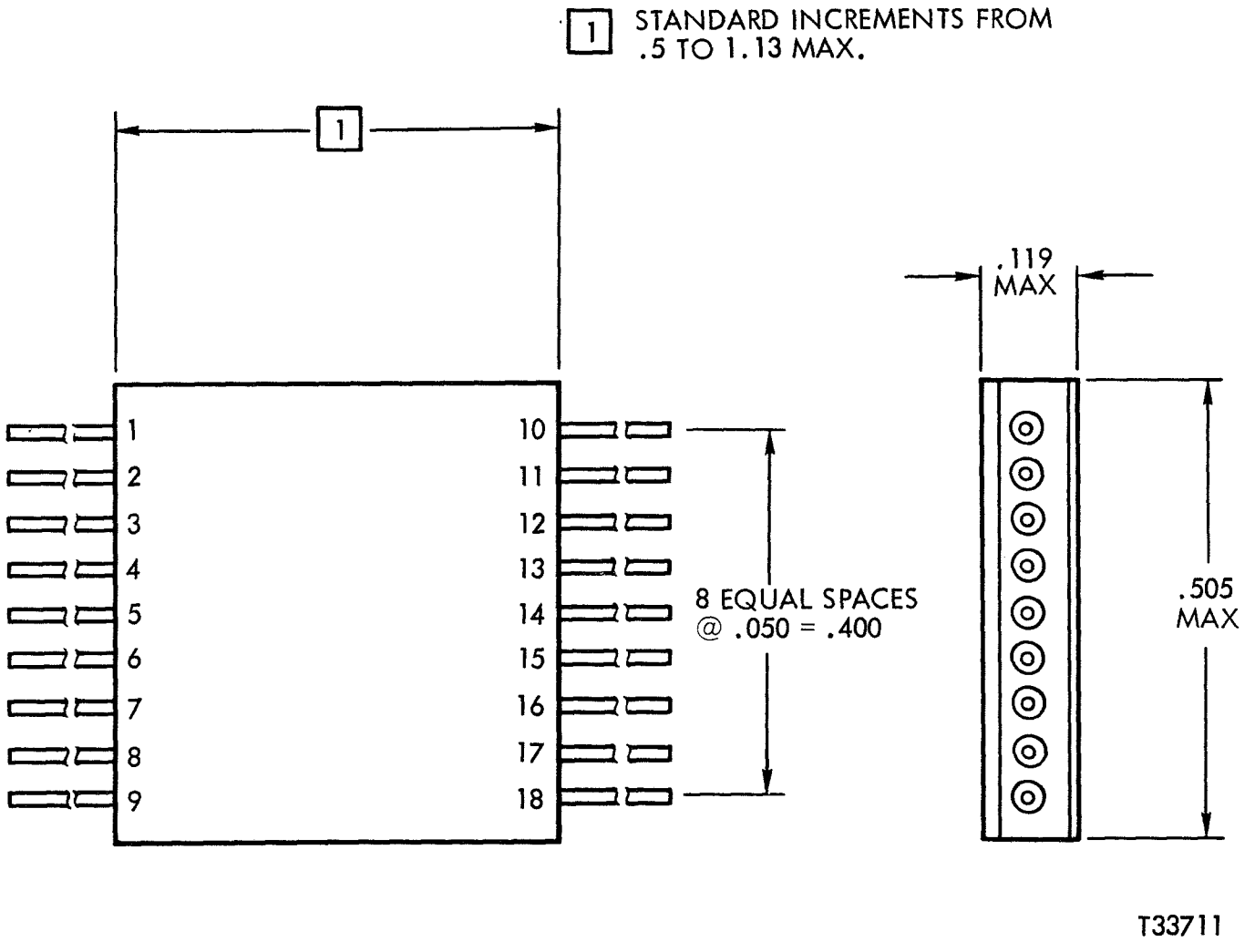


Figure 24. Physical Dimensions and Lead Location of Dual-Ended MEMAs

8002937: 12KC/48KC Filter, SCD 7104633, mounted on A3. See Figure 25 for physical configuration and terminal location.

Terminal	Input	Output
4	GRD	GRD
7	Test Pt., 48KC	
9	Input, 4V @ 48 KC (Sq.)	
11		Output, 48KC @ 11 Vp.p
14	+12 Vdc	
16	Test Pt., 12 KC	
18	Input, 4V @ 12KC (Sq.)	
20		Output, 12KC @ 11 Vp.p
22	-12 Vdc	

8004048: 48KC/12KC Power Supply (Buffer), SCD 7104635, mounted on A3. See Figure 24.

Terminal	Input	Output
1		12KC Test Pt.
3		12 KC Test Pt.
5		12 KC Test Pt. Out to base of pwr. Transistor, 12 KC
9	-12 Vdc	
10	Input, 12KC, 11 VP-P.	
12		Out to base of pwr Transistor, 12 KC
14	+12 Vdc	
16	+12 Vdc	
18	GRD	GRD

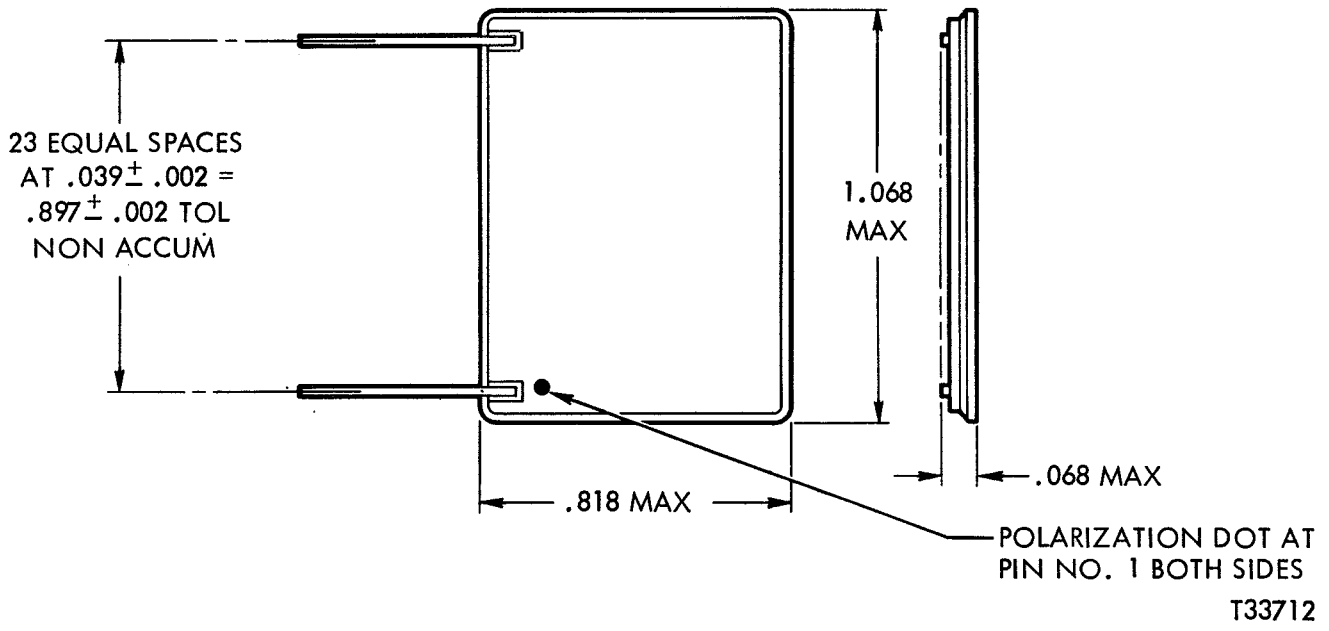


Figure 25. Physical Dimensions and Lead Location for Single-Ended MEMA

8003534: Servo Amp. Mod. 1, SCD 7104606; three are mounted on A6. Figure 24 shows the physical configuration and pin locations.

Terminal	Input	Output
1	GRD	GRD
3	Input=Output /50 Amp. (8003516)	
5	GRD	GRD
6	-12 Vdc	
9	12KC Ref @ 26 VRMS	
13	+12 Vdc	
17		Output=(RMS Input x 8) Vdc.

8003567: Servo Amp Mod 3, SCD 7104607; three are mounted on A6. See Figure 24.

Terminal	Input	Output
3	+12 Vdc	
5	GRD	GRD
6	Test Pt.	
7	Test Pt.	
8	GRD	
9	Input-Output of 8003534	
10		Output=(Input x 10 ± 20 %) Vdc
12	-12 Vdc	

8003582: Sampling Switch Logic, SCD 7104603, mounted on A7: See Figure 26 for the physical configuration and pin location.

Terminal	Input	Output
1	Input: 5VRMS, 48KC	
3		Output: 3 Symetrical square waves, 0 to 4±IV, 120° Apart, @ 800 Hz.
4		
5		
8	+12 Vdc	
11	GRD	GRD

8003550: Sampling Switch, SCD 7104618, mounted on A7. See Figure 24.

Terminal	Input	Output
1	Input, 800 Hz Sq. from 8003582	
5		
8		
2		Sample output, switching from +70 - 12 Vdc as associated input switches from GRD to OPEN.
14		
9		
11		5VRMS, 48KC Excitation with 11, 13, 16 in Ø when 12, 15, 17 are out-Ø with respect to input 1, 5, & 8, respectively.
12		
13		
15		
16		
17		
3	+12 Vdc	
7	-12 Vdc	
10 & 18	GRD	GRD
16	5VRMS, 48 KC	
4	5VRMS, 48 KC	
9		

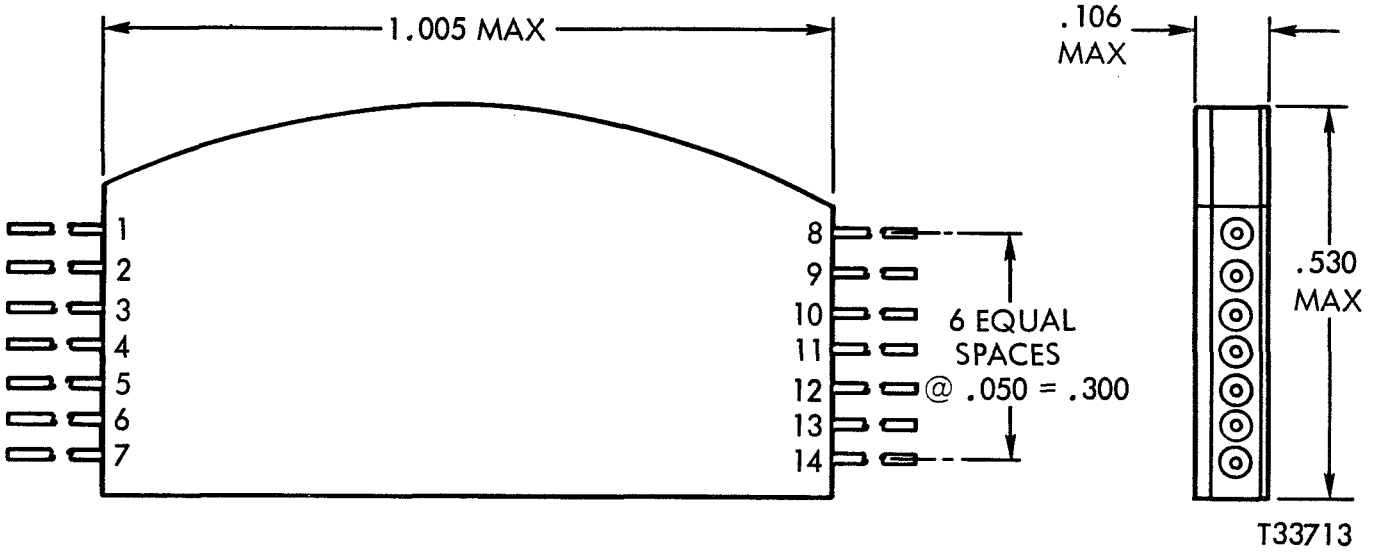


Figure 26. Physical Dimensions and Lead Location of Sampling Switch Logic MEMA

80057352: Forcer Driver, SCD N/A, two mounted on A7. See Figure 24. The Z1 Forcer Driver, as shown in the schematic in the Appendix, was modified so that only one-half of the circuitry is utilized. This is a standard MEMA requiring two channels of operation on the Teledyne An/ASN-82 Inertial Navigation System which was adapted to the NASA requirements. Following is the input-output characteristics of the two channel MEMA, which reflects the mechanization of the Z2 Forcer Driver. For trouble-shooting the modified Z1 MEMA refer to the Schematic and the following table.

Terminal	Input	Output
1 2 12 14		0 to 200 Vdc and 5VRMS, 48KC Excitation bursts to forcer plates, in sensor.
18	GRD	GRD
10	190 ± 10 Vdc	
11	+ 12 Vdc	
17	-12 Vdc	
3 7 13 16	5VRMS, 48KC Excitation signal out of 8003550.	
6 5	Plus or minus 12 Vdc Sample output from 8003550	
4 8	Float analog error, Vdc (Trans. Displacement) signal	

4.4 Maintenance

The system has been designed and built in a modular configuration for ease of maintenance; however, it is suggested that repairs be performed at Teledyne or a Teledyne authorized repair depot. Maintenance should be limited to preliminary trouble shooting and the adjustments described in Section 4.2. Under no circumstances should the forcer-driver card and/or sensor be removed from the case or repaired in any way in the field.

If a malfunction occurs in the system, carefully remove the system cover with the power OFF. Energize the system with the cover off and proceed to isolate the malfunction by verifying the signals at the points indicated in Section 4.3.

If the necessary output signals as described in Section 4.3 are not available under test conditions, the related printed circuit board may be removed and returned to Teledyne for a replacement or repair. However, if the P.C. boards are functioning properly as discrete modules it is suggested that the entire system be returned to Teledyne for repair.

There is no period maintenance or replacement required on the system. However, it is suggested that the spare P.C. cards be available for field repair or depot maintenance on the two NASA systems in order to minimize repair turn-around time. The size of the suggested spares inventory is dependent upon the number of systems in use and the desired turn-around time.

# Spares	Module
1	A 3 Board: Reference Supply
1	A 5 Board: Filter & Temp Control
1	A 6 Board: Capture Loop
1	A 7 Board: Float Centering
1	8003516 Isoamp MEMA
1	8003978 Float Isoamp MEMA