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LTVR Project No. 08460
FLIGHT PROTOTYPE ELECTROSTATIC
BALLISTIC PENDULUM
Final Report
October 1968
NASA Manned Spacecraft Center
Houston, Texas
Contract NAS 9-7290

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Houston, Texas

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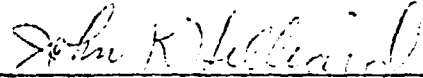
LTVR Project No. 08460

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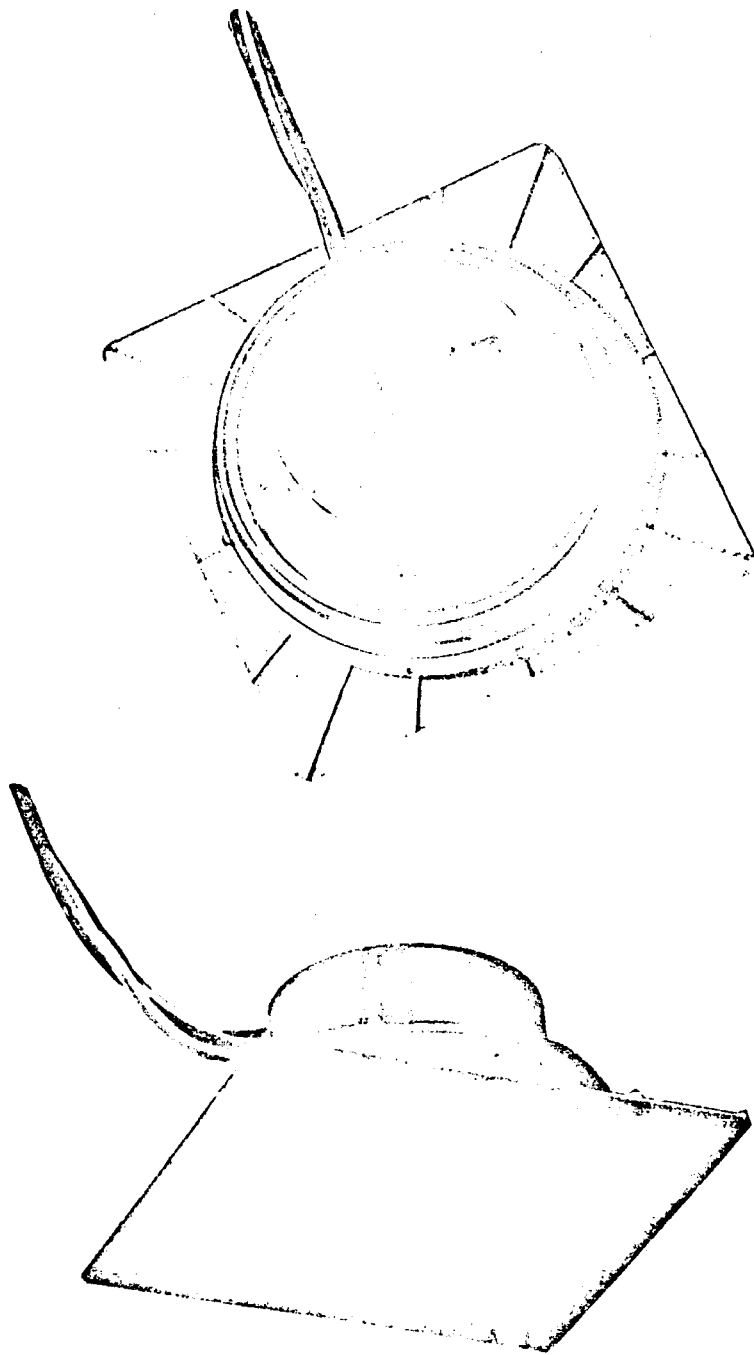
I. INTRODUCTION

In August, 1967, the LTV Research Center, Western Division, was awarded a contract from the NASA Manned Spacecraft Center for the design, development and fabrication of two copies of a flight prototype Electrostatic Ballistic Pendulum momentum transducer for subsequent integration into the flight prototype ALSEP meteoroid detector. The program originally was to have been completed in six months; however, extensions in the scope of the contract, undertaken in consultation with the technical monitor and at no additional cost to the government, resulted in a more extended effort.

Scientists at the LTV Research Center, Western Division have long been actively engaged in the design, fabrication and testing of hypervelocity microparticle momentum transducers, and have previously fabricated production units or feasibility models which span the momentum range from 10^{-7} dyne-seconds to 1000 dyne-seconds, or ten orders of magnitude in momentum. This experience was utilized to the fullest on this program, although the concurrent requirements of long term stability and reliability combined with the capability of operating in the extremes of the lunar environment necessitated significant sophistication of the design and the development of procedures which allowed the application of relatively new technologies to the basic transducer design. The program was executed under a limited QA/QC procedure which provides the basis for flight qualification.

The complete sensor/electronics package, as delivered to the Manned Spacecraft Center, is shown in Figure 1.

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FLIGHT PROTOTYPE ELECTROSTATIC BALLISTIC PENDULUM MOMENTUM TRANSDUCER

Figure 1.

II. SUMMARY

The program has culminated in a transducer package which meets all the objectives of the contract. That is, the transducer has a total weight of 20 grams with an impact surface approximately 5 cm x 5 cm, detects momentum over the design range with the desired signal to noise ratio, and operates over the required temperature range with no spurious outputs due to thermal expansion. In addition, the components, structure, materials and manufacture of these flight prototype EBP's are such as to demonstrate that subsequent flight EBP's fabricated from the drawings and specifications included in this report will pass the ALSEP flight qualification tests when mounted in the lunar meteoroid detector.

III. SENSOR SYSTEM

A. Operational Concept

The EBP combines two principles of operation: electrostatic transduction and the ballistic pendulum technique of momentum measurement.* The condenser microphone is an example of electrostatic transduction, wherein a parallel plate air dielectric capacitor is formed by a movable electrode (the diaphragm, or membrane) and a stationary electrode (the backplate). When the proper electrical circuitry is connected to the capacitor thus formed, deflection of the diaphragm produces an electrical output, the peak value of which is directly proportional to the peak value of the average diaphragm displacement.

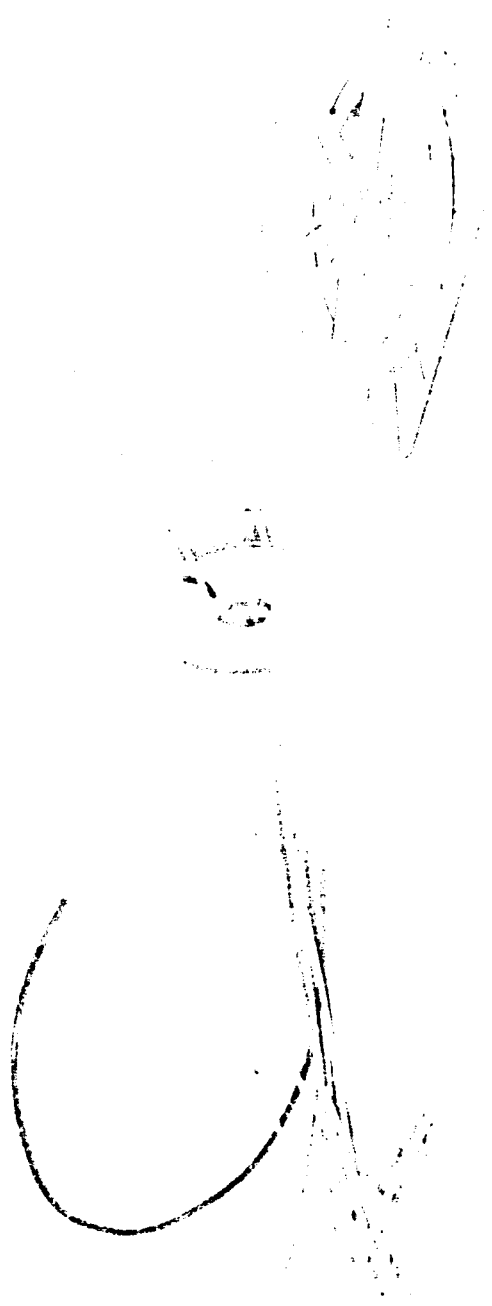
In the classical ballistic pendulum, a projectile impacts and is contained within a suspended mass. The subsequent deflection of this mass is proportional to the projectile momentum, pendulum mass, and pendulum restraining force.

The EBP combines these two principles by attaching a mass (called the impact plate) to the diaphragm of a capacitive transducer. Thus the peak electrical output voltage is proportional to the momentum imparted to the impact plate by an impacting particle. The flight prototype EBP fabricated under this contract is shown in Figure 2.

If a particle of momentum mv collides with the plate and sticks without rebounding (perfectly inelastic collision), momentum mv is imparted to the plate. If the same particle collision is

* See, for example, Goldsmith, W., Impact, Arnold Co., London, 1960.

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FLIGHT PROTOTYPE EBP WITH ELECTRONICS REMOVED

Figure 2.

If perfectly elastic, a momentum $2mv$ is imparted to the plate. If fragments of the plate material are ejected from the impact plate, as is generally the case with hypervelocity impacts (particle velocity greater than sound velocity in the plate material), the momentum imparted to the plate may be considerably greater. This variation in momentum imparted to the plate is referred to as the accommodation coefficient of the plate, α . Thus for any collision which is not perfectly inelastic, a momentum αmv is imparted to the plate, where mv is the momentum of the incident particle just prior to impact. The quantity α is generally determined experimentally in a hypervelocity particle accelerator for a given impact plate material and configuration.

An equation for the EBP momentum sensitivity is derived in Appendix A of this report, and is given by:

$$S = \frac{\Delta E}{mv} = \frac{\alpha E_0}{2\pi f_0 d_0 M} \frac{\text{volts}}{\text{dyne second}}$$

where

- ΔE = output voltage
- mv = incident particle momentum
- α = accommodation coefficient
- E_0 = polarizing voltage
- f_0 = resonant frequency of the sensor
- d_0 = interelectrode spacing
- M = impact plate mass

B. Sensor Design and Fabrication

The basic design of the electrostatic ballistic pendulum had been developed previously by LTV Research Center, Western Division, (see Final Report for Contracts NAS9-5623 and NAS9-6566) and shown to function as described by the sensitivity equation given above. The primary objectives of this program, then, were to increase reliability, reduce weight, allow operation over the required temperature extremes (both from the standpoint of operational integrity and without spurious signals from "creak" or "ping" induced by differential thermal expansion), and to provide for remote calibration. All of these factors interact in one way or another, and each presented unique design problems, as discussed in the following paragraphs.

Due to the stringent weight requirement of 20 grams for the entire sensor and electronics, amounting to only 5 grams per square inch of impact surface, it was necessary to use a skeletal main frame, or housing. This took the form of a spoked wheel, as shown in the cut-away view of Figure 3. The outer diameter is 1 5/8 inches and the spokes are 1/8 inch high by 30 mils wide. A 5 mil deep recess on the top of the spokes locates the backplate insulator, which in turn centers the backplate. The spokes were formed by electrical discharge machining.

The backplate insulator is 5 mil thick Kapton* polyimide, chosen as the only material with suitable insulating properties over the environmental extremes whose coefficient of thermal expansion closely matches that of aluminum. The insulator is centered by the recess on the spokes, and the backplate is centered by the insulator.

* DuPont Trade Mark

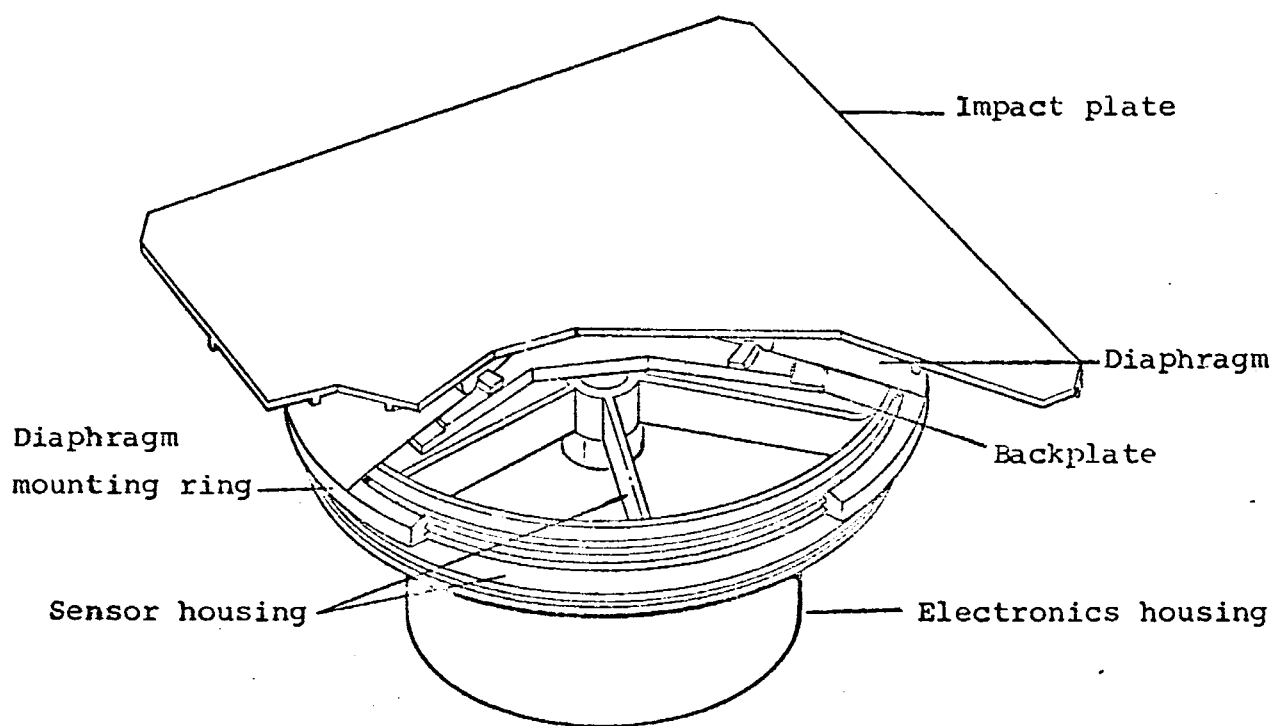


Figure 3. Cut-away View of EBP

Finding a suitable means of attaching the internal calibration electrode to the backplate so the two electrodes are coplanar without significantly increasing the sensor weight (i.e. 0.5 grams or less) presented some problems. The most satisfactory solution which evolved was to laminate the electrode to the backplate as shown in Figure 4. The insulators are Kapton Type F film, which is Kapton* polyimide film coated with Teflon* FEP fluorocarbon film. The assembly is laminated in a platen press to form an integral unit. The calibration electrode area has been minimized and the insulator thickness maximized to reduce the shunt capacitance between the backplate and calibration electrode; that which remains has been accepted as an inevitable consequence of the design. This shunt capacitance acts to reduce both the sensor sensitivity and the calibration signal amplitude.

The diaphragm is electron beam welded to the diaphragm mounting ring (see Figure 5) for both strength and time-temperature stability under stress. Severe problems were encountered in developing a suitable welding process, and arose in the following manner.

The diaphragm is pre-tensioned in the welding fixture to force it into intimate contact with the diaphragm mounting ring. (The welding surface of this ring is at a 15° angle so that the resultant force on the joint will be a shear rather than a peel when the diaphragm is tensioned to the operating point.) This assembly is rotated under the beam to effect the weld, the process requiring approximately 2 seconds with a 150 KV beam at 1 ma. These parameters all interact, and were selected after considerable experimentation as yielding the most acceptable weld. A significant amount of heat is introduced into the assembly during the

* DuPont Trade Mark

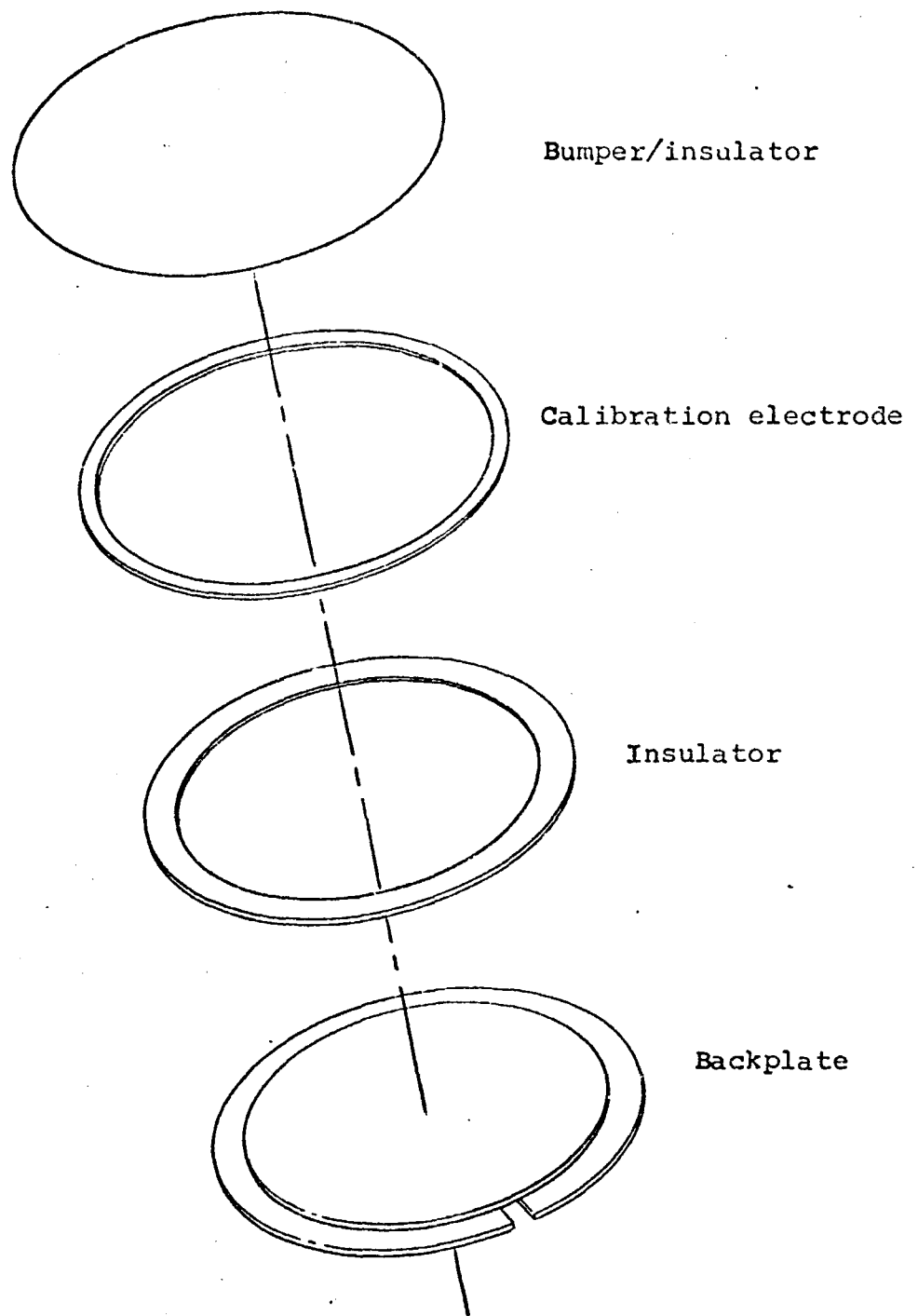


Figure 4. Exploded View - Backplate - Calibration Electrode Assembly

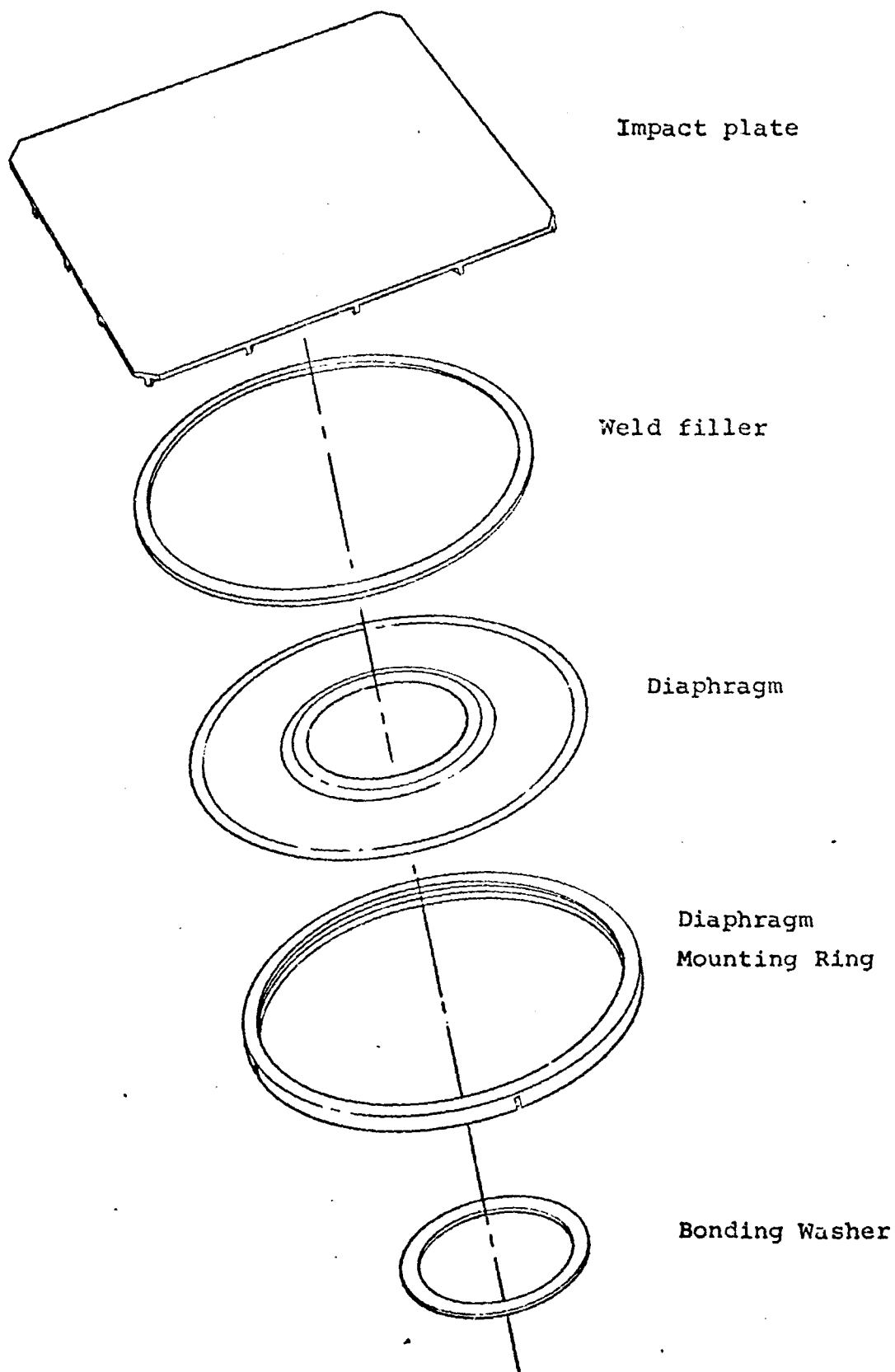


Figure 5. Exploded View - Diaphragm - Impact Plate Assembly

welding cycle. Consequently, the sector of the diaphragm which is welded first is joined to the ring in a relatively cool and tensioned condition, while that sector which is welded last is hotter and hence more relaxed. The end result is that the tension is not circumferentially symmetrical, so that the sensor displays a multimode amplitude vs frequency response similar to two strongly coupled harmonic oscillators. The output from a bead drop then exhibits a ragged modulated waveform. Even this could be "calibrated in" at the first peak if it were not for the fact that the amplitude is a function of the angular position of the impact.

Many changes were made to the welding fixture to improve the heat transfer, with significant but yet insufficient improvement. Additionally, the diaphragm mounting ring size was doubled when it was found the weight could be spared. With the latest fixturing approximately one diaphragm assembly out of ten was found acceptable.

Several possible solutions to this problem were pursued: segmental welding, where a section (e.g., 45°) is welded at a time, with the welding sequence alternating from one side of the ring to the other; the possibility of improving the heat sink provided by the welding fixture; the use of one mil material for the diaphragm. It was found that the heavier material behaved much better during the welding operation due to the increased heat capacity. The effects of using one mil material as opposed to half mil upon the operational characteristics of the sensor were investigated analytically, and it was shown that a relatively minor adjustment of parameters resulted in the same operational characteristics as obtained with half mil material.

Segmental welding was not successful due to the difficulty of maintaining the beam focus at the start and stop of each segment. Consequently, the weld became too wide at the extremities of each segment, and in many cases burned through the diaphragm material. Several diaphragms were welded in this manner, and the later attempts showed definite improvement over the first ones as the operator gained experience. Thus, it may have been possible to develop this technique to a point where satisfactory welds could be obtained, but the process appeared to be more art than science, so the approach was dropped.

Careful consideration was given to the possibility of further modification of the welding fixture to improve thermal transfer from the diaphragm weld zone to the fixture. With the exception of minor changes, no improvements were possible without imposing prohibitively close dimensional tolerances on the diaphragm mounting rings and the mating parts of the fixture.

In view of the large amount of time and money involved in obtaining acceptable units by this process, serious consideration was given to joining the diaphragm to the diaphragm mounting ring with epoxy. Therefore, a program was conducted to optimize cleaning and bonding procedures for use with Narmco Materials Division (Whittaker Corp.) #7343/7139 epoxy system. A diaphragm assembly was not fabricated with epoxy, however, because a technique was found for producing satisfactory assemblies by electron beam welding. A local electron beam welding job shop installed an attachment to their machine which interrupts the beam many times a second. This pulsed electron beam effects the weld in the same elapsed time, so consequently considerably less energy is imparted to the assembly, resulting in much less heat buildup. Several excellent diaphragms were welded by this process with only 20% of marginal acceptability.

Prior to welding a rather elaborate cleaning procedure is followed to remove contamination, impurities, and oxides from the aluminum. Although it has not been proven necessary, it is felt that the use of such procedures is justified considering the time and expense involved in reaching the point of acceptance or rejection. The procedure we follow is given below.

Pre-Weld Cleaning Schedule - 2024 Aluminum
(No more than 12 hours prior to welding)

1. Detergent in hot water; agitate and watch closely - withdraw when covered with bubbles so as not to over-etch.
2. Distilled water rinse; dry.
3. Toluene in ultrasonic cleaner.
4. Acetone rinse.
5. Distilled water rinse.
6. Clean with Allied Research Isoprep #35:
 - (a) Heat water to 130°F; mix 40 gm/l
 - (b) Immerse 15 seconds at 180°F with agitation
7. Distilled water rinse.
8. Deoxidize with Allied Research Prod. Isoprep #188:
 - (a) Mix 120 gm/l
 - (b) Immerse 2 minutes at 70-100°F with agitation
9. Distilled water rinse
10. Dip 10 seconds in 10% solution nitric acid at 160-180°F
11. Boiling distilled water rinse; air dry.

Following the welding, the assemblies are immediately heat treated to the -T4 condition in an argon atmosphere with an argon quench. The diaphragms are then punched and formed, heat treated to the -T6 condition (in air, since this is a low temperature treatment), and joined to the impact plate assembly by bonding. These processes are discussed in detail in the following paragraphs.

As indicated above, the diaphragm, which is one mil (25 micron) type 2024 aluminum, is heat treated to the -T4 condition. When 2024 aluminum is solution heat treated in air, intergranular oxidation normally penetrates to a depth on the order of one mil. Nevertheless, samples of material were heat treated in this manner by a local vendor, with the result that rather severe oxidation and even some pinholes were formed. This problem can be overcome by performing the operation in an inert atmosphere. After some searching a vendor was located who seemed competent and was willing to attempt this. After some developmental effort, he did successfully accomplish this objective with samples of diaphragm material. Thermocouples attached to the sample holder assured adequate temperature control (high enough for the constituent elements to go into solution, but not high enough to produce grain boundary melting and hence brittleness), a range of approximately $\pm 4^{\circ}\text{F}$. In addition, quench rates of several hundred degrees per second were achieved with an argon quench, thus assuring minimal intergranular corrosion. Tensile tests showed yield strengths of 45 Kpsi, normal for T4 material. The diaphragms are precipitation hardened after the punching and forming operation, and result in a diaphragm of T6 temper except in the critical area of the inner stretching lip, which is expected to be the stronger T851 temper.

The center of the diaphragm is punched and contoured as shown in Figure 5, and the center of the impact plate is provided with a matching contour. This is done primarily to provide a uniform radius over which the inner periphery of the diaphragm is stretched when tensioned to the operating point, ensuring circumferentially uniform tension and hence the desired frequency response characteristic. Originally it was intended to electron beam weld the diaphragm assembly to the impact plate. However, attempts to do so met with total failure. Shrinkage occurring in the weld zone

caused the impact plates to buckle, rendering the parts completely unusable. Only two pieces were tried since it was apparent that the problem was fundamental rather than simply a matter of weld parameters or heat control. It was therefore decided to bond the impact plate to the diaphragm with Narmco Materials Division (Whittaker Corp.) #7343/7139 epoxy system. It was found that the integrity of the bond was very strongly dependent upon the cleaning procedure used for the aluminum. The best technique found was to use detergent and solvent cleaning followed by a chemical bath, although the bond strength depended strongly upon the type of chemical bath used. The optimum procedure was found to be as follows, where all water rinses are with distilled water and all solvents and chemicals reagent grade:

1. Clean in hot detergent
2. Water rinse; dry
3. Ultrasonically clean in Xylene
4. Acetone rinse; water rinse; dry
5. Chemically clean by dipping for 5 minutes with stirring in a 170 to 175°F solution of:
 - 800 ml water
 - 180 ml concentrated nitric acid
 - 100 gm sodium sulfate
6. Hot water rinse; air dry

The bond should be effected immediately after the last cleaning step. This procedure, followed by the bonding procedure recommended by the epoxy manufacturer (Whittaker Corp., Narmco Materials Division) was found to produce a satisfactory bond.

C. Electronics Description

The EBP electronics provides for impedance translation, signal amplification, and system calibration of the EBP.

A schematic diagram is included in Section X. A block diagram of the electronics that also shows the electrical interface is included as Figure 6.

Design characteristics of the electronics are:

- a) Low noise operation
- b) Low power consumption
- c) Simplicity
- d) High reliability

Operation of the circuit is as follows.

Electrically, the EBP sensor's capacitance is shunted across the input to the field effect transistor (Q1) impedance converter or preamplifier. This capacitance is biased to +350V through R2 and R3, thus dc blocking capacitors (C3 and C4) are used to connect the sensor to the preamplifier.

The preamplifier is especially designed for temperature stability and low noise performance. The bandwidth of the amplifier is chosen to be as narrow as possible to minimize noise effects.

The output of the preamplifier is fed to a two-stage low noise transistor amplifier. The stage consisting of Q2A and associated circuitry is used as a voltage amplifier. A so-called "bootstrap" circuit is used to increase this stage's input impedance.

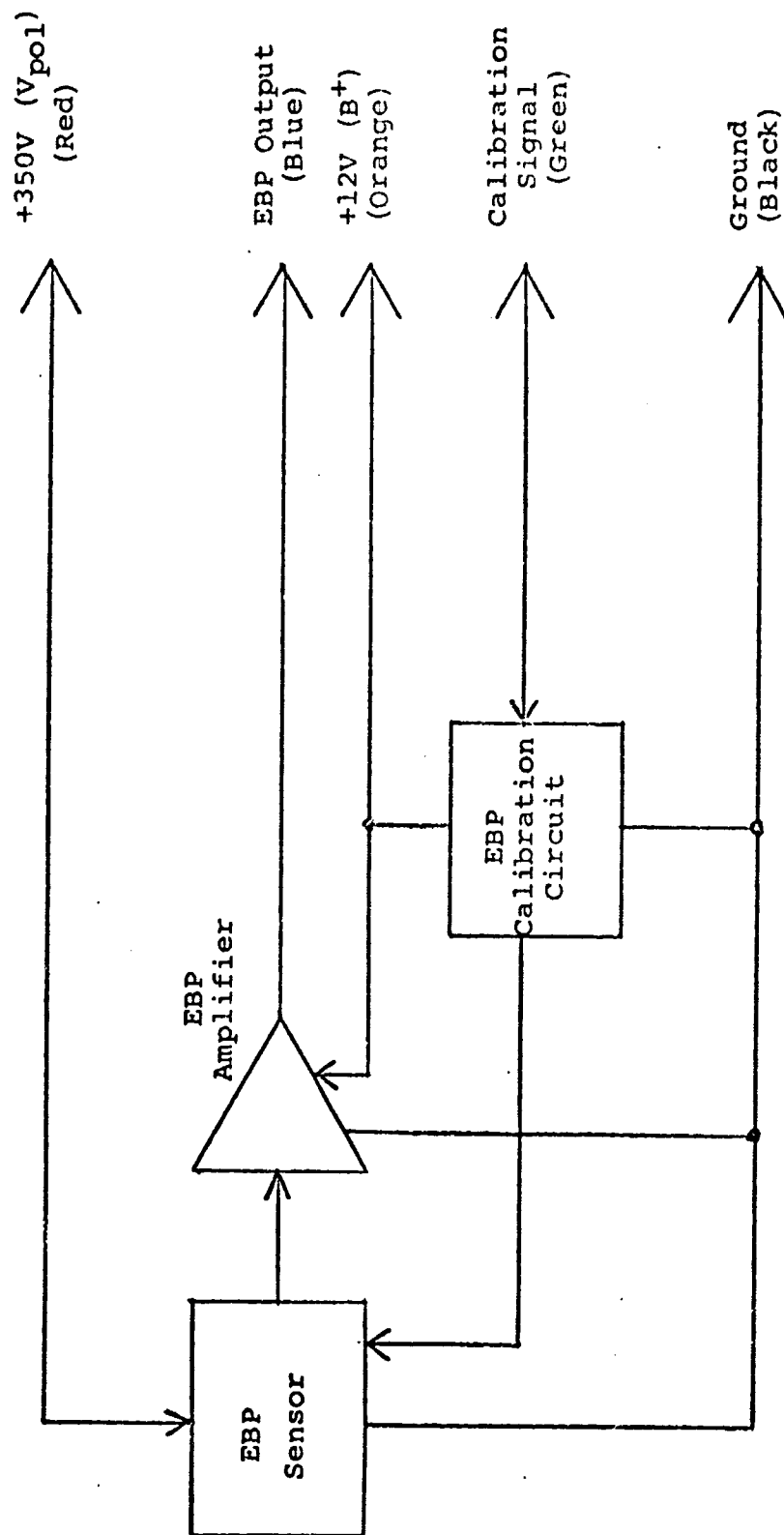


Figure 6 . Flight Prototype EBP Sensor
Block Diagram of Sensor System

The output signal from Q2A's collector is transformed to a lower impedance level by emitter follower Q2B. The signal is then capacity coupled to the output.

The calibration circuitry composed of Q3 and associated components provides, upon demand, a known impulse amplitude to the EBP sensor, and thus allows system calibration by producing an output signal from the EBP amplifier.

Application of a positive going input pulse to the "calibration command" input will, by turning Q3 on, apply a constant voltage pulse to a small conducting annular ring rigidly mounted on and insulated from the EBP sensor stationary back electrode which effectively forms a small capacitance to the sensor's diaphragm.

The pulse voltage thus applied is interpreted by the sensor as an impact and the resultant signal is supplied at the amplifier's output.

The output signal generated by the system is an exponentially damped sine wave. The momentum information is contained in the amplitude of the first positive peak of the waveform.

Table I contains the specifications and interface requirements for the EBP electronics.

TABLE I

EBP Electronics Characteristics

1. Output Characteristics

A. Output voltage range	0.3 mV pk to 1V pk
B. Output impedance	400 ohms nominal
C. Output frequency	200 Hz
D. Output load requirement	10 k Ω $\pm$ 5%
E. Broadband Noise (re: output)	-84 dBv
F. Transient Response (% first peak error)	20% typical
G. -3 dB points	85 & 1900 Hz typical

2. +12 Volt Requirements

A. Current	0 to 1 ma
B. Voltage tolerance	$\pm$ 2% maximum
C. Maximum power consumption	Less than 6 mw
D. Ripple	Less than 10 mV peak to peak
E. Output impedance	Less than 10 ohms dc to 10 kHz

3. +350 Volt Requirement

A. Current	0 to 6 μ A
B. Voltage tolerance	$\pm$ 1% maximum
C. Ripple	Less than 0.4 V peak to peak
D. Output impedance	Less than 50 ohms dc to 200 Hz

4. Calibration Signal Requirements

A. Amplitude	0 to 10 volts pk ($\pm$ 5%)
B. Current requirement	1 ma peak
C. Rise and fall times	1 μ sec
D. Duration	500 μ sec

5. Temperature Range (Operating)

-65[°] to +250[°] F

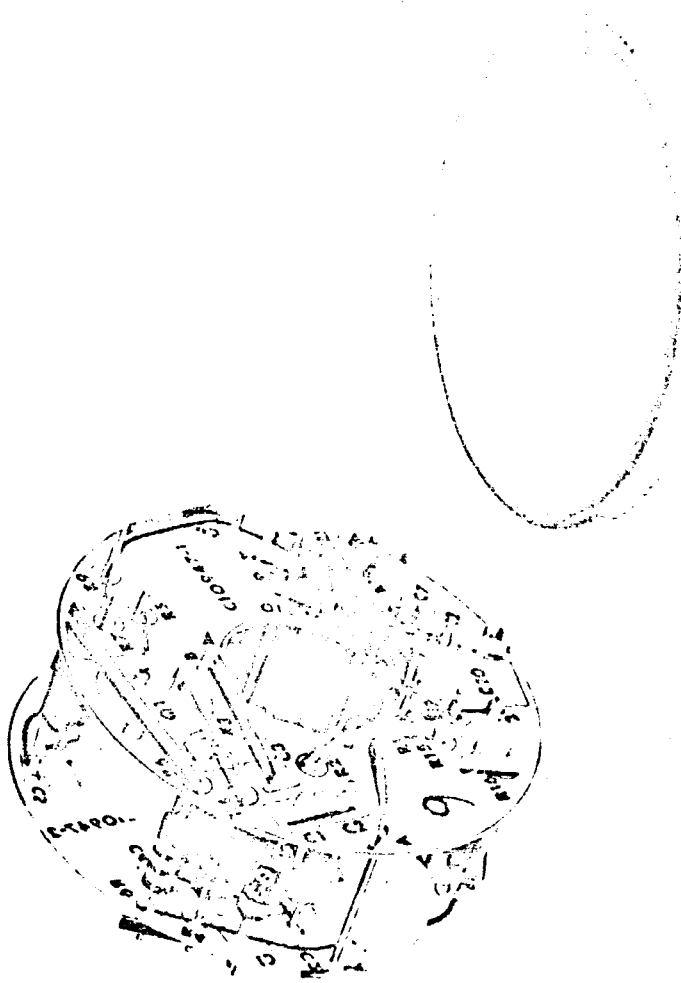
The electronics, which are mounted on two small circular mylar circuit boards and arranged in a cordwood configuration, are encapsulated to eliminate microphonics and aid mechanical rigidity. Figure 7 shows the module prior to encasement and potting. The basic simplicity of both the electrical and mechanical design of the electronics assures ease of production and results in a high degree of performance uniformity among manufactured units.

Components selected for the electronics are chosen on the basis of:

- a) Environmental requirements
- b) Electrical and mechanical characteristics
- c) Size requirements

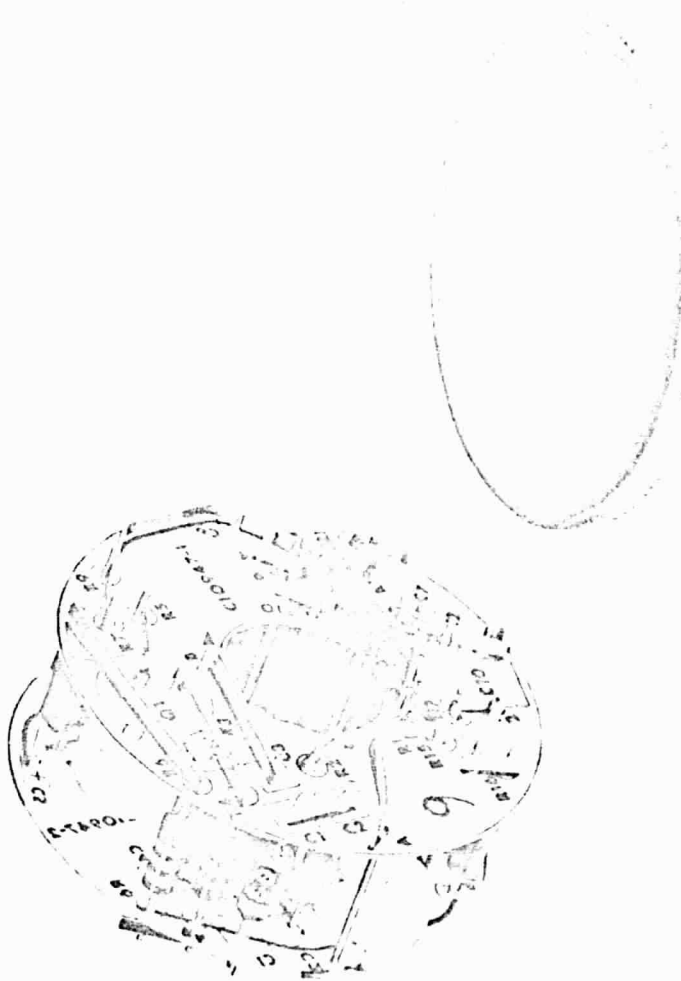
Studies and subsequent testing have conclusively indicated that the components chosen for the electronics are capable of meeting the system's operational requirements. LTV Research Center, Western Division, has performed a circuit analysis on the electronics to assure reliable performance and electrical reproducibility (see Section X).

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FLIGHT PROTOTYPE EBP WELDED ELECTRONICS MODULE

Figure 7.



FLIGHT PROTOTYPE EBP WELDED ELECTRONICS MODULE

Figure 7.

IV. TESTING AND CALIBRATION

A. General

The test and calibration procedures are detailed in the following LTV Research Center, Western Division, Quality Control Bulletins: QC846-1, Revision B; QC846-2; QC846-3; QC846-4, Revision A; QC846-5, Revision A; QC846-6. Only major operational tests will be discussed in this section; Test Data Sheets for the delivered sensors are included in Appendix C.

B. Thermal Environment

The test apparatus used to simulate the lunar environment is shown in Figures 8 and 9. The philosophy behind the arrangement of this apparatus was that the thermal environment the instrument will experience on the lunar surface should be simulated as closely as possible. In achieving this objective then, the entire sensor is subjected to an upper temperature of +250°F, while at the lower temperature extreme the electronics package is maintained at a minimum temperature of -65°F while the impact surface is exposed to a -270°F external environment. The thermal gradient throughout the sensor package then reaches an equilibrium value determined by the thermal conductivity and radiation of the sensor and sensor mounting plate. (In actuality this is more severe than would actually be experienced by the sensor due to the reflectance of the thin films which will be in front of the sensor in the actual experimental package.)

The heater plate and the cold/hot plate are heated by electrical resistance type heaters. The cold plate is cooled by a liquid nitrogen coil. Temperature is monitored by iron-constantan

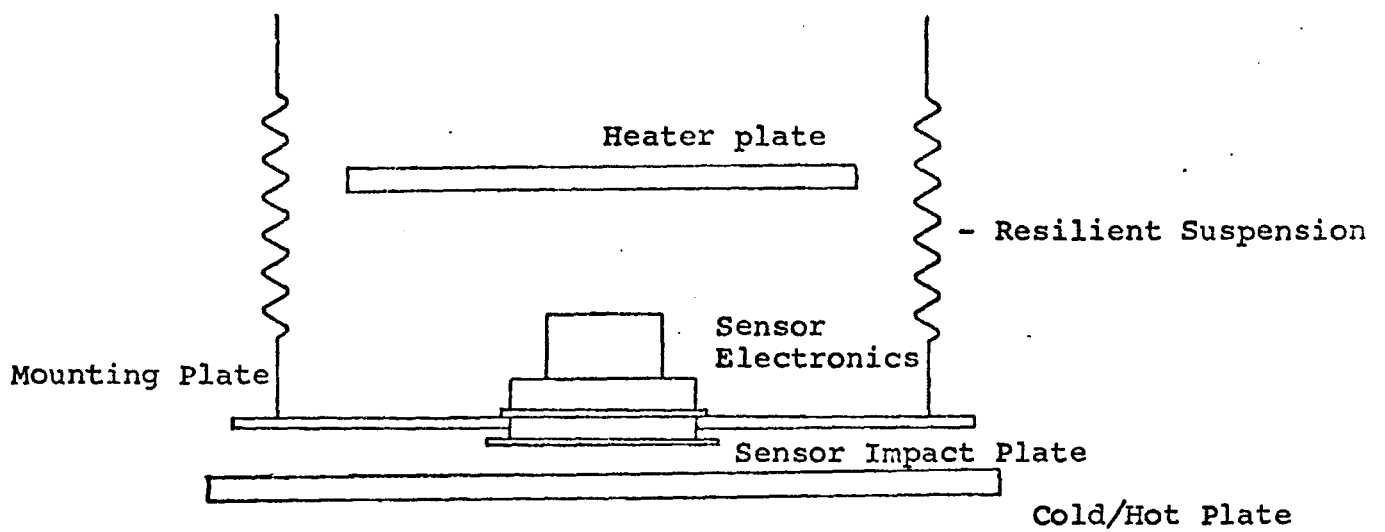
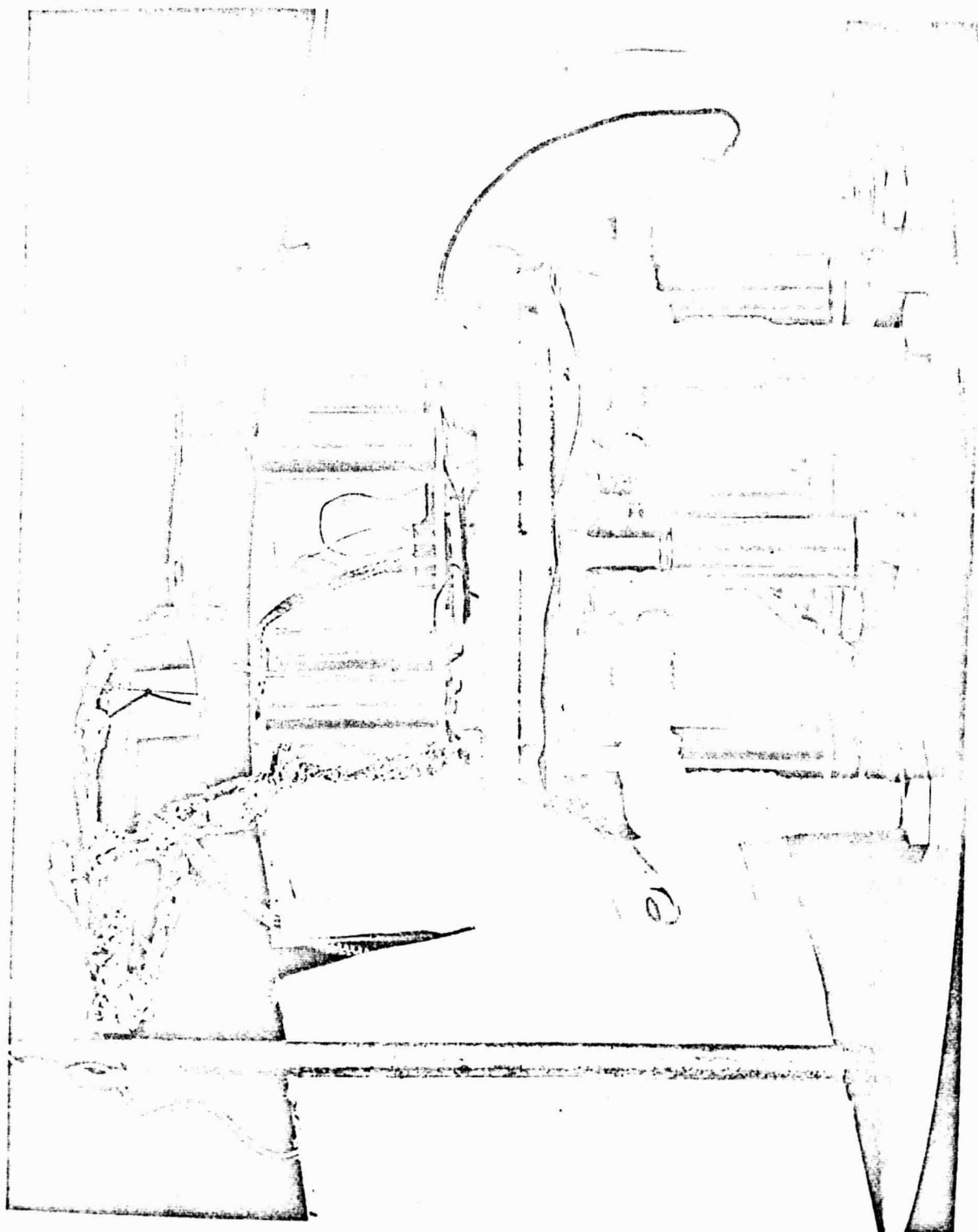


Figure 8. Physical Arrangement of Thermal Environment Test Apparatus



THERMAL ENVIRONMENT TEST APPARATUS
(RADIATION SHIELD PARTIALLY REMOVED)

Figure 9.

thermocouples attached to the sensor mounting plate and to the cold/hot plate. The actual test is carried out as described in LTV Research Center, Western Division, Quality Control Bulletin QC846-4, Revision A.

C. Electronics

The test and calibration procedure for the electronics package is detailed in the following Inspection Procedure Checklist (QC846-2).

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 LING-TENGO-VOUGHT, INC.
 1859 S. MANCHESTER AVE., ANAHEIM, CALIF. 92803

**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-6	CONTRACT NO. NAS 9-7290	VENDOR	
DRAWING NO. C-10902	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
B 1.0	Resistance Point 6 to ≥ 1 G ohm.	GR Megohmmeter 100V Bias				
1.1	Resistance - Point 6 - gnd. ≥ 10 G ohm					
B 1.2	Resistance - Point to gnd. ≥ 10 G ohm					
2.0	<u>Ambient Temperature Test</u> 1. Apply + 350 $\pm$ 15VDC between 6 and gnd. 2. Apply + 12 $\pm$.10V between 5 and gnd. 3. Ground 2. 4. Connect 10k $\pm$ 5% resistor from 4 to gnd. 5. Attach 50 $\pm$ 2.5pf dummy sensor to B and gnd. 6. Measure power supply current. Must be $\leq$ 0.45 ma.	1. +350VDC power supply 2. + 12VDC power supply 3. Voltmeter HP 412A 4. Ammeter 5. 10k 5% resistor 6. 50pf dummy sensor with series driving capability				

PREPARED BY: <i>Kenneth E. Echorn</i>	DATE: <i>Jan. 23, 1968</i>	INSPECTOR	COMPL. DATE
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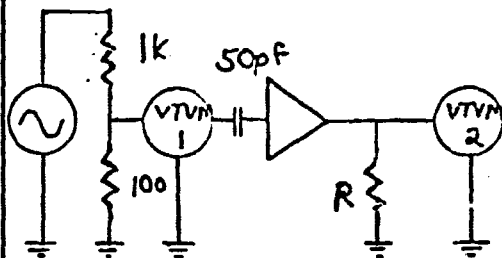
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 1859 S. MANCHESTER AVE., ANAHEIM, CALIF. 92803

**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE
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DRAWING NO. C-10902	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS: Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
3.0	1. Apply 24.5 mV r.m.s. 400Hz sine wave to dummy sensor through divider network as shown below. This level = 0dB on VTVM #1	1. See 2.0 2. Hewlett Packard Audio Signal Generator Model 200CD 3. 2-HP AC-VTVM Model 4000 4. 1K resistor 5. 100 ohm resistor				
3.1	Record power supply input current.					
3.2	Record VTVM # 2 level in dB relative to VTVM #1 Gain = 21 ± 2 dB					



PREPARED BY: Kenneth Eilson DATE: Jan. 23, 1968 INSPECTOR: _____ COMPL. DATE: _____

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 CHECKLIST**

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-6	CONTRACT NO. NAS 9-7290	VENDOR	
DRAWING NO. C-10902	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book.

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	V
4.0	Remove resistor R (10k)	1. See step 3.0				
4.1	Record VTVM#2 level $-V_2$					
4.2	Connect 9.5k $\pm$ 1% resistor in place of R					
4.3	Record new level of VTVM#2 $-V_2$					
4.4	$Z_o = \left(\frac{V_1 - V_2}{V_2} \right) 9500 \text{ ohms}$ Where Z_o = output z V_1 = no load resistor reading V_2 = 9.5k load resistor reading Z_o must be $< 8 \text{ k ohms}$.					
5.0	Reconnect 10k resistor					
5.1	Check generator level (0dB = .0245V)					
5.2	Record VTVM #2 level.					
5.3	Decrease generator frequency until VTVM #2 shows a -3dB change from 5.2					
	Note: VTVM #1 level must be held constant.					
5.4	Record generator frequency					
	Must be $80 \pm 15\text{Hz}$					
6.0	Repeat section 5 increasing the generator frequency					
	- 3dB point must be $1800 \pm 800 \text{ Hz}$					

PREPARED BY: <i>Kenneth Eilman</i>	DATE: <i>Jan. 23, 1968</i>	INSPECTOR	COMPL. DATE
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LTV RESEARCH CENTER
WESTERN DIVISION
LINDENHOLM VOUCHER INC.
1859 S. MANCHESTER AVE., ANAHEIM, CALIF. 92803

INSPECTION
PROCEDURE
CHECKLIST

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-6	CONTRACT NO. NAS 9-7290	VENDOR	
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SPECIAL INSTRUCTIONS

Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book.

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
7.0	Connect oscilloscope to point 4	Oscilloscope				
7.1	Set generator to 250 Hz					
7.2	Increase generator level until negative portion of output waveform observed on scope begins to distort or clip.					
7.3	Record VTVM #2 level (Eng. Info. Only)					

PREPARED BY: <i>Kenneth E. Eason</i>	DATE: <i>Jan. 23, 1968</i>	INSPECTOR	COMPL. DATE
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LTV RESEARCH CENTER
 WESTERN DIVISION
 LING-TUNG-YOUNG INC.
 1859 S. MANCHESTER AVE., ANAHEIM, CALIF. 92803

**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☒ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-6	CONTRACT NO. NAS 9-7290	VENDOR	
DRAWING NO. C-10902	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book.

OPER. NO	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
8.0 8.1	Short input Record VTVM #2 level. Must be $< 100\mu\text{V}$ R.M.S. (broadband noise)					
9.0 9.1 9.2 9.3 9.4 9.5 9.6	Connect pulse generator to point 2. Connect oscilloscope to point 2. Apply $10 \pm 1\mu$ sec wide, 0 to $+10 \pm 1\text{V}$ square pulse. Measure pulse amplitude. Connect oscilloscope to point B. Negative going (+11 to 0V) pulse shall appear Measure rise and fall times. (Change sweep speed to 0.1μ sec/cm) Must be $< 10.0\mu\text{sec}$ 10% to 90% Measure and record amplitude. Must be $11.00 \pm .5\text{V}$ to $0.0 + 0.1\text{V}$ - 0.1	1. General Radio Pulse Generator Model <u>1217C</u> 2. Tektronix Oscilloscope Plug In Type W $2\mu\text{sec/cm}$ 20mV/cm Attenuator x 100				

PREPARED BY: <i>Kenneth E. Evers</i>	DATE: <i>Jan. 23, 1968</i>	INSPECTOR	COMPL. DATE
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LTV RESEARCH CENTER
WESTERN DIVISION
LINC-TEMCO-VOUGHT, INC.
1859 S. MANCHESTER AVE., ANAHEIM, CALIF. 92803

INSPECTION
PROCEDURE
CHECKLIST

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☒ LTVR FABR PART ☐
INSP. PROC. NO. QC 846-6	CONTRACT NO. NAS 9-7290	VENDOR	
DRAWING NO. C-10902	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book.

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓																										
10.0	<u>Temperature Tests</u> Place module in oven with appropriate shielding and test wires.																															
10.1	Repeat tests 2 to 7 and test 9 at the following temperatures ($\pm 5^{\circ}\text{F}$) <table><tr><th>Temp $^{\circ}\text{F}$</th><th>Test 9</th><th>Test 2-7</th></tr><tr><td>+40</td><td>x</td><td></td></tr><tr><td>-20</td><td>x</td><td></td></tr><tr><td>-65</td><td>x</td><td>x</td></tr><tr><td>0</td><td>x</td><td></td></tr><tr><td>+60</td><td>x</td><td>x</td></tr><tr><td>+120</td><td>x</td><td></td></tr><tr><td>+180</td><td>x</td><td></td></tr><tr><td>+250</td><td>x</td><td>x</td></tr></table>	Temp $^{\circ}\text{F}$	Test 9	Test 2-7	+40	x		-20	x		-65	x	x	0	x		+60	x	x	+120	x		+180	x		+250	x	x				
Temp $^{\circ}\text{F}$	Test 9	Test 2-7																														
+40	x																															
-20	x																															
-65	x	x																														
0	x																															
+60	x	x																														
+120	x																															
+180	x																															
+250	x	x																														

PREPARED BY: Kenneth Erikson	DATE 23 January 1968	INSPECTOR	COMPL. DATE
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D. Bead Drop Calibration

Both sensors delivered to NASA were calibrated by bead dropping. The detailed procedures are given in Quality Control Bulletin QC846-5, Revision A, and the apparatus used for this calibration is shown in Figure 10. The glass plate is rotated under the wiper to push beads off the plate onto the sensor. The glass plate is gold plated and grounded through the wiper to remove static charge from the beads. All calibrations were made with 1/64 inch diameter (0.0397 cm) synthetic sapphire beads weighing 1.31×10^{-4} grams, dropped from a height of approximately 1 cm.

To calibrate the sensor by bead dropping, one must calculate both the incident momentum of the bead and the rebound momentum. (Note that if the collision were perfectly elastic, the momentum imparted to the plate by a bead of mass m and velocity v would be $2mv$.) The rebound momentum can be determined by measuring the time interval between the initial impact and the second impact, after the first bounce. The relation giving the total momentum imparted to the sensor can be easily calculated from elementary mechanics formulas, and is

$$p = m \sqrt{2gh} + 1/2 mgt$$

where

p = momentum

m = mass of the bead

g = acceleration of gravity

h = height through which bead falls

t = bounce time

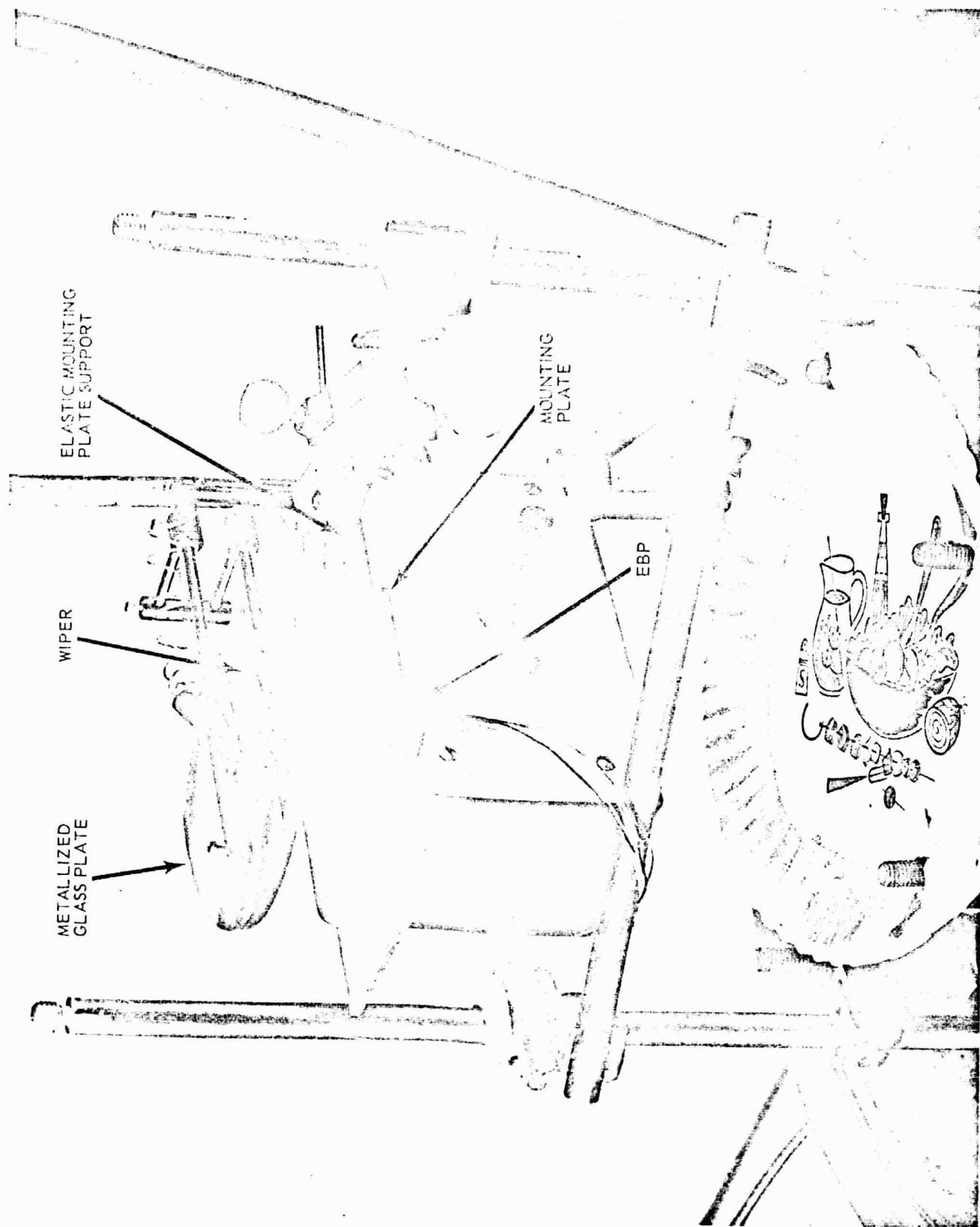


Figure 10. BEAD DROP CALIBRATION APPARATUS

One sensor* was calibrated at various locations on the impact plate, viz., center, corners and sides, to measure the variation in sensitivity with location of the impact on the impact plate. The data from this test are shown in Table II. The output voltage for these data was taken as the amplitude of the first positive peak of the sensor output, with no scaling used to compensate for the reduction in amplitude of the first peak (which results from the finite pass band of the electronics). An additional possible source of error for this particular set of measurements, in addition to those listed in the footnote below, is an uncertainty in the height measurement. This was caused by clearance in the bearings supporting the glass plate, allowing the plate to tip slightly during measurement. This was corrected on later data. Quality Control Bulletin QC846-5, Revision A, describes the calibration procedure in detail.

* This was an early engineering model sensor fabricated before the electron beam welding process had been optimized. Therefore, the diaphragm tension was not uniform (the diaphragm was actually somewhat wrinkled), so that the data from this calibration should be considered "worst case." It is anticipated that the delivered sensors will show much less variation. In addition, due to an inadequate sensor mounting plate suspension, rather severe vibrational noise was induced into the output, further reducing the accuracy.

TABLE II

Variation of Sensitivity with Impact Location **

Average Sensitivity of 79 Impacts = 6.44 v/dyne second

	Run	Sens	Dev.		Run	Sens	Dev.		Run	Sens	Dev.
Center	A 1*	6.3	.14		B18	6.51	.07		E 4*	5.21	1.23
	2	5.95	.81		19	6.79	.35		5*	5.09	1.35
	3*	4.54	1.90		20	6.54	.10		6*	5.09	1.35
	4*	7.4	.90	Side	C 1	6.3	.14		7*	5.37	1.07
	5	5.48	.96		2	6.36	.08		8*	4.55	1.89
	6*	5.17	1.27		3	6.59	.14		9*	5.16	1.28
	7	6.56	.12		4	6.53	.09		10*	4.84	1.60
	8*	7.2	.76		5	6.53	.09		11*	4.79	1.65
	9	6.5	.06		6	6.31	.13		12*	5.02	1.42
	10	7.67	1.23		7	7.1	.66	Corner	F 1*	7.57	1.13
Corner	B 1	6.41	.03		8	6.9	.46		2*	7.15	.71
	2	6.56	.12		9	6.86	.42		3*	6.96	.52
	3	6.35	.09		10	7.04	.60		4*	2.34	.90
	4	6.5	.06		11	6.6	.16		5*	7.02	.58
	5	6.06	.38	Center	D 1	7.2	.76		6*	7.4	.96
	6	6.46	.02		2*	5.48	1.04		7*	7.25	.81
	7	5.83	.61		3	5.85	.59		8*	7.16	.72
	8	5.87	.57		4	6.65	.21		9*	7.5	1.06
	9	6.29	.15		5	7.08	.64		10*	7.15	.71
	10	6.7	.26		6	7.2	.76		11*	7.38	.94
	11	6.74	.30		7	7.3	.94		12*	7.11	.67
	12	6.06	.38		8	7.02	.58		13*	7.5	1.06
	13	6.16	.28		9	7.06	.52		14*	6.91	.47
	14	6.4	.04		10	6.95	.46		15*	7.26	.82
	15	6.2	.24	Side	E 1*	5.23	1.21		16*	7.38	.94
	16	6.87	.43		2*	5.07	1.37				
	17	6.72	.28		3*	5.5	.94				

Average Sensitivity = 6.44 v/dyne sec.

Average Deviation from Average Sens = 0.63 = $\pm$ 9.8%Probable Deviation from Average Sens = 0.53 = $\pm$ 8.2%

** See footnote on page 35.

* Signal amplitude modulated by external vibrational noise

E. Remote Calibration

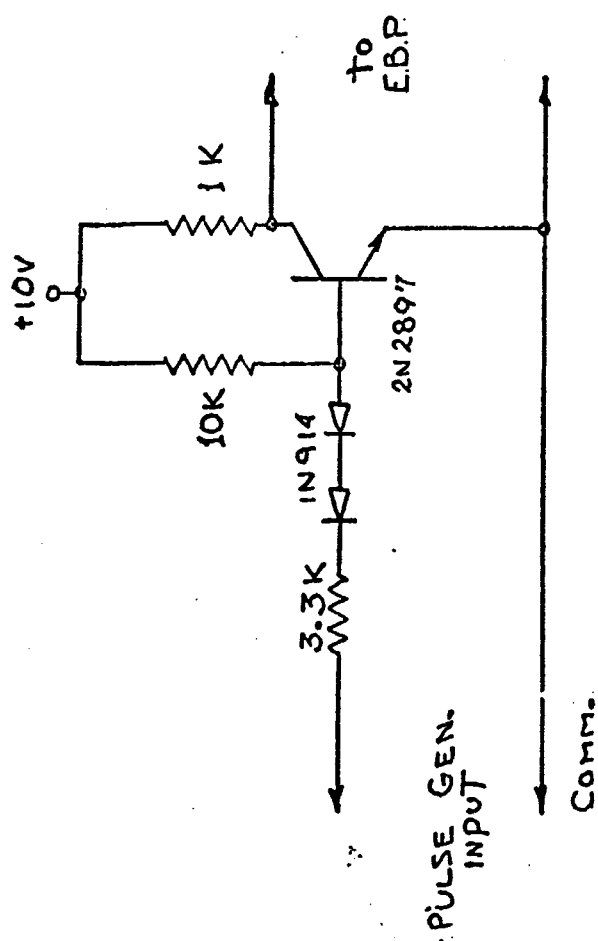
As described previously, remote calibration is accomplished by applying an electrostatic force which deflects the impact plate. If the duration of this force is less than one quarter of the natural period of the sensor, i.e., less than 1.25 m sec, the sensor behaves as if it were struck impulsively. Therefore, the sensor output is identical to that obtained from an impact.

A general purpose pulse generator (General Radio Type 1217B) was used as the calibration signal source throughout the test series. Since this pulse generator has only negative going outputs, an interface circuit was designed that served to provide the following functions:

- a) Impedance conversion
- b) Level translation
- c) Constant output pulse height
- d) Signal inversion
- e) Waveform quality improvement

A schematic diagram of the pulse conditioning circuit is shown in Figure 11. The pulse generator input to this circuit must traverse from at least 0 to minus 3 vdc in order for the output to go from 0 to plus 10 vdc.

Due to feedthrough to the sensor input circuitry, the calibration pulse produces a large excursion in the sensor output signal at the onset of the normal damped sinusoid. A calibration cannot be obtained during the time of this disturbance, so we inserted a 20 millisecond delay in the readout instrumentation. For this purpose the delayed trigger function of the oscilloscope was used, as shown in Figure 12. The first positive going peak occurring after this delay was then taken as the output signal amplitude.



CONDITIONING CIRCUIT

Figure 11.

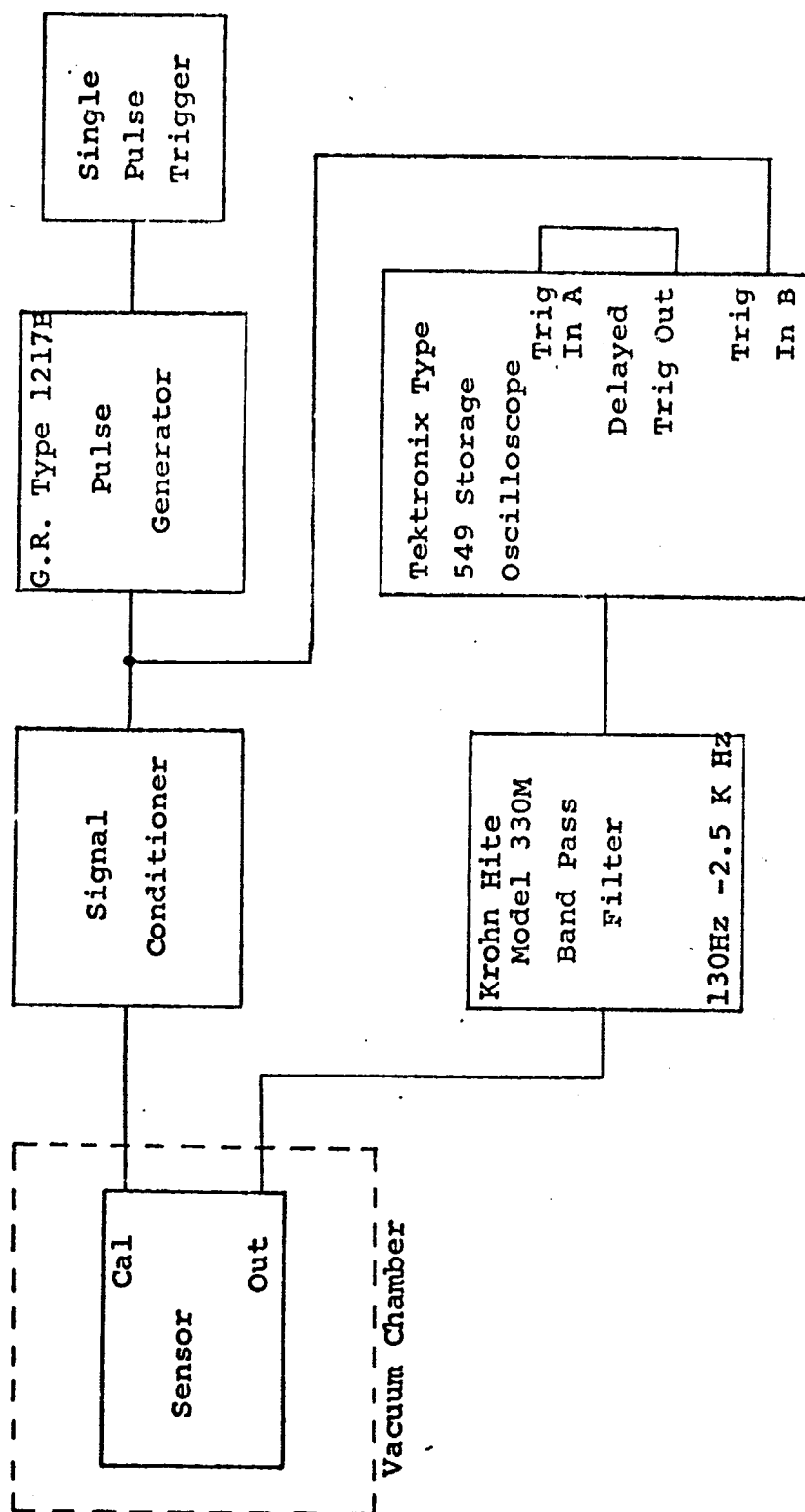


Figure 12. Block Diagram - Remote Calibration Read-Out Instrumentation

V. SENSOR SYSTEM SPECIFICATIONS

The operational specifications for the sensor system are nominally as shown in Table III below.

TABLE III

Momentum Range:	10^{-5} to 10^{-2} dyne-seconds
Signal to Noise Ratio (S/N):	14 dBV
Input Momentum at Unity S/N:	2×10^{-6} dyne-seconds
Maximum Input Momentum:	3×10^{-2} dyne-seconds
Sensitivity:	30 V/dyne-second
Output Voltage Range:	0.3 mv to 0.3 v peak
Maximum Output Voltage:	1.0 v rms
Output Impedance:	400 ohms
Operating Frequency:	200 Hz
Output Signal:	Damped Sinusoidal Burst
Operating Temperature Range:	-65°F to $+250^{\circ}\text{F}$
Operating Pressure:	10^{-2} torr or less
Remote Calibration Input:	10 v positive going rectangular pulse of 500 μsec duration.*
Remote Calibration Output:	Damped sinusoidal burst equivalent to an impact of 10^{-2} dyne-seconds momentum*, read as the amplitude of the first positive going peak occurring more than 20 m sec after pulse initiation
Weight:	20 grams
Impact Plate Size:	4.94 cm x 4.94 cm; corners clipped 0.16 cm
Impact Plate Material:	Type 2024 aluminum alloy
Overall Height:	2.24 cm

* Either the duration on the amplitude or both may be varied to obtain output signals of different equivalent input momentum.

TABLE III (Continued)

Mounting:	4.04 $\pm$ 0.01 cm diameter hole in a 0.32 cm thick aluminum plate. Indexing is provided by one 0.038 cm diameter pin on a 4.27 cm diameter bolt circle located at the center of one side.
Overload Protection:	An integral bumper precludes damage due to impacts of excessive momentum.
Shock and Vibration:	Will comply with NASA requirements for the ALSEP meteoroid detector package.

VI. CONCLUSIONS AND RECOMMENDATIONS

The sensor system delivered under this program fully meets the system operational requirements with regard to noise performance, ability to withstand environmental stresses, weight, and other pertinent parameters.

With but one exception, all changes and improvements that would be incorporated into a flight qualified version would be evolutionary. This exception is that we strongly recommend any future contract include funding to evaluate the use of ultrasonic ring welding to join the diaphragm and impact plate, and also the diaphragm to the diaphragm mounting ring. Successful development of this technique would result in a sensor with inherently improved reliability by eliminating the epoxy bond. Other minor mechanical changes would be made to reduce weight and simplify the design.

It is estimated that two grams could be saved through mechanical modifications to the basic design.

Evolutionary improvements to the basic electronics could be made in order to further improve inherent reliability and decrease size and weight.

Achievement of improved reliability would consist primarily of adding suitable circuitry to eliminate system failure in the event of a sensor short without degrading the system's performance.

Obtaining a substantial decrease in system size and weight would be accomplished by utilizing hybrid circuitry techniques. A size and weight reduction of 50% for the electronics (3 grams) can be

realized. Reliability considerations would have to be carefully studied in order to retain present levels of performance.

Other improvements would be made to the tooling and to the test and calibration fixtures to facilitate fabrication and testing.

VII. HANDLING, OPERATING AND STORAGE PROCEDURES

A. Handling

Care should be taken when handling the sensor, since by its very nature it is a delicate instrument. In particular, do not apply a torque or twisting force to the impact plate, or a force which tends to separate the impact plate from the sensor, although the sensor may be picked up by the impact plate without danger of physical damage.

Do not try to prevent the sensor from turning by holding the impact plate when tightening the mounting nut. Use a mounting hole of the proper diameter ($4.04 \pm .01$ cm; $1.590 \pm .004$ in.) and the index pin (0.038 cm; 0.015 in. diameter on a 4.27 cm; 1.684 in. diameter bolt circle).

Do not over-tighten the mounting nut. It is sufficient to snug it down with a light finger grip on the wrench provided. A rubber cement may be used to prevent the nut from loosening during vibration testing.

B. Operating

The sensor may be checked for operation at atmospheric pressure by applying the proper voltages and tapping the test fixture with a finger while monitoring the output on an oscilloscope. Do not leave the polarizing voltage on during pumpdown to the operating pressure. There is a critical pressure range from approximately 500 torr to 10 torr where voltage breakdown can occur; such a breakdown will destroy some of the active devices in the electronics. It is therefore recommended that the sensor

only be operated at atmospheric pressure or at a pressure of 0.01 torr or less. It should be noted that due to air damping the characteristic ringing will be damped out at room pressure so that no quantitative tests can be performed.

It is essential that vibration isolation be provided in any test fixture where the sensor output is to be monitored. The axial acceleration sensitivity is approximately 100 v/g. Therefore if measurements are to be made in the 10^{-3} dyne-second momentum range, for example, the ambient vibration at 200 Hz should be on the order of 10^{-4} g. Note that the electronics will saturate at approximately 10^{-2} g.

C. Storage

Due to the fact that the diaphragm is 25 micron type 2024 aluminum alloy, it is recommended that for prolonged storage the sensors be placed in a desiccator. This is particularly true when the location is near the ocean where corrosion is more severe. No other special storage procedures are required.

VIII. INTERFACE REQUIREMENTS

The input/output leads from the EBP system are color-coded as to function (called out in the appropriate assembly drawing) as follows:

<u>Color</u>	<u>Function</u>
Red	+350 OV
Black	Ground
Green	Calibration signal input
Orange	+12V
Blue	Signal output

Table IV lists typical interface specifications and requirements.

The EBP system output signal is a damped sinusoid. When monitoring the system sensitivity during remote calibration a time delay of 20 milliseconds (after application of the calibration pulse) shall be used in order to eliminate the feedthrough effect of the calibration pulse.

The sensor is designed to mount to a 0.32 cm (1/8 in) thick mounting plate. A nut and wrench is supplied to secure the sensor to the mounting plate. A $4.04 \pm .01$ cm ($1.590 \pm .004$ in) diameter hole is required for the sensor. An index pin is located on a line perpendicularly bisecting one side of the impact plate and on a circle of 4.27 cm (1.684 in) diameter. The index pin is 0.038 cm (0.015 in) in diameter.

TABLE IV

1. Output Characteristics

A. Output voltage range	0.3 mv pk to 1V pk
B. Output impedance	400 Ω @ 200 Hz
C. Output frequency	200 Hz
D. Output load requirement	10 k Ω $\pm$ 5%
E. Broadband noise (re: output)	-84 dBv
F. Transient response: % first peak error	20% typical at 200 Hz
G. -3dB frequency response	85 & 1900 Hz typical

2. +12 Volt Requirements

A. Current	0 to 1 ma
B. Voltage tolerance	$\pm$ 2% maximum
C. Maximum power consumption	Less than 6 mw
D. Ripple	Less than 10 mv peak to peak
E. Output impedance	Less than 10 ohms dc to 10 kHz

3. +350 Volt Requirement

A. Current	0 to 6 μ A
B. Voltage tolerance	$\pm$ 1% maximum
C. Ripple	Less than 0.4 V peak to peak
D. Output impedance	Less than 50 ohms dc to 200 Hz

4. Calibration Signal Requirements

A. Amplitude	0 to 10 volts pk ($\pm$ 5%)
B. Current requirement	1 ma peak
C. Rise and fall times	1 μ sec
D. Duration	500 μ sec

5. Temperature Range (Operating)

-65° to +250°F

APPENDIX A

Technical Report
O-71200/STR-144

MECHANICAL DESIGN CONSIDERATIONS
FLIGHT PROTOTYPE ELECTROSTATIC
BALLISTIC PENDULUM

August 1968

Technical Report
0-71200/8TR-144

MECHANICAL DESIGN CONSIDERATIONS
FLIGHT PROTOTYPE ELECTROSTATIC
BALLISTIC PENDULUM

August 1968

LTVR Project No. 08460

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VII. INTERNAL ELECTROSTATIC CALIBRATION.	17
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SUMMARY

This report derives the equations used in the mechanical design of the flight prototype Electrostatic Ballistic Pendulum (EBP) momentum transducer. Various tradeoffs are discussed in terms of operational parameters, and these parameters evaluated for the selected design constants. The EBP consists basically of an impact plate suspended close to a backplate by means of an annular aluminum membrane. The output is derived from the variations in capacitance resulting when the impact plate moves relative to the backplate. The device is designed to operate in vacuum (hence no air damping considerations) at the resonant frequency determined by the spring constant of the annular membrane and the mass of the impact plate.

I. PARAMETERS DETERMINING SENSITIVITY

When a hypervelocity particle (i.e., the particle velocity is greater than the speed of sound in the impact plate) impinges upon the sensor the conservation of momentum requires that

$$\alpha mv = MV \quad (1)$$

where α = accommodation coefficient

mv = particle momentum

MV = impact plate momentum

Using equation (1) the kinetic energy T of the impact plate at the instant of impact may be expressed as

$$T = \frac{1}{2} MV^2 = \frac{1}{2} M \left(\frac{\alpha mv}{M} \right)^2 \quad (2)$$

At the first maximum deflection of the impact plate this energy is converted into potential energy U (assuming no resistive losses, ejection, spalling, etc.)

$$U = \frac{1}{2} K x^2 = \frac{1}{2} M \left(\frac{\alpha mv}{M} \right)^2 = T \quad (3)$$

from which the maximum displacement x is

$$x = \alpha mv \sqrt{\frac{1}{KM}} = \frac{\alpha mv}{2\pi f_o M} \quad (4)$$

where K = spring constant of the diaphragm and is defined by

$$f_o = \frac{1}{2\pi} \sqrt{\frac{K}{M}} = \text{resonant frequency of the spring-mass system.}$$

The electronic circuit arrangement maintains essentially constant charge on the capacitor formed by the backplate and the impact plate-diaphragm assembly. Therefore,

$$C_1 E_1 = C_0 E_0$$

where C_1 and E_1 refer to the capacitance and voltage across the capacitor at the point of maximum deflection, respectively, and C_0 and E_0 refer to the same quantities in the rest position. In this case E_0 is the d.c. polarizing voltage. The a.c. output voltage is

$$\Delta E = E_0 - E_1 = E_0 - \frac{C_0}{C_1} E_0 = E_0 \left(1 - \frac{C_0}{C_1} \right)$$

Since $C_0 = \frac{\epsilon_0 A}{d_0}$, where ϵ_0 = permittivity of free space
 d_0 = static electrode spacing

$$\Delta E = E_0 \left(1 - \frac{d_1}{d_0} \right) = E_0 \left(1 - \frac{d_0 - x}{d_0} \right) = \frac{E_0 x}{d_0} \quad (5)$$

The a.c. output voltage ΔE is therefore, from (4) and (5),

$$\Delta E = \frac{E_0}{d_0} \frac{\alpha m v}{2\pi f_0 M}$$

and the momentum sensitivity is

$$\text{Sens} = \frac{\Delta E}{mv} = \frac{\alpha E_0}{2\pi d_0 f_0 M} \quad (6)$$

Electronic noise imposes a lower limit on the sensitivity. Breadboard measurements show that the electronic broadband noise will be approximately 10^{-5} V at this stage of technology. If a minimum signal-to-noise ratio of 12 dbV is imposed upon the system, then the minimum signal (for an input momentum of 10^{-5} dyne sec) is 4×10^{-5} V. Therefore the minimum sensitivity is

$$\text{Sens}_{\min} = \frac{4 \times 10^{-5} \text{ V}}{10^{-5} \text{ dyne sec}} = 4 \text{ V/dyne-sec} \quad (7)$$

Size and weight limitations impose a maximum value on E_0 of 350 V due to the size of capacitors required in the electronics at current stage of technology. These two constraints then leave three parameters which may be chosen, subject to the restrictions discussed in the following sections. Equation (6) may now be put in the constraining form

$$4 \frac{\text{V}}{\text{dyne-sec}} \leq \frac{350 \text{ V}}{2\pi d_0 f_0 M}$$

$$\text{or} \quad d_0 f_0 M \leq 14 \frac{\text{gm cm}}{\text{sec}} \quad (8)$$

II. SPRING STRESS & RESONANT FREQUENCY

For a given impact plate mass M and diaphragm thickness t and radii $\frac{D_0}{2}$ and $\frac{D_1}{2}$ defined in Figure 1, the maximum allowable diaphragm stress $\sum_m$ will place an upper limit on the resonant frequency, f_{0m} .

Referring to the following diagram, let T = tension in dynes/cm to which the membrane is stretched. Since this tension is distributed uniformly throughout the membrane, material on opposite sides of a line segment ds will be pulled on with a force of Tds dynes.

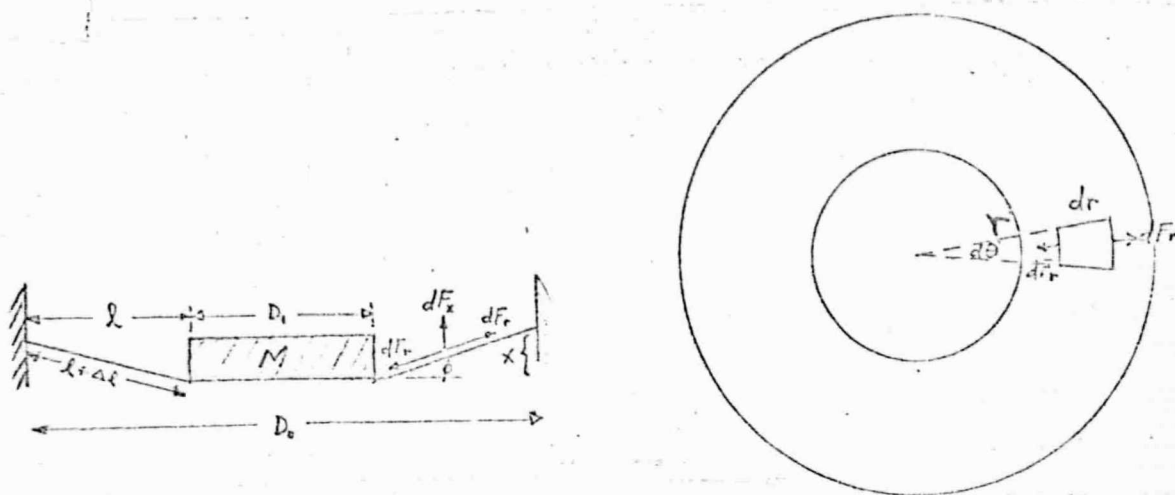


FIGURE 1

SCHEMATIC REPRESENTATION OF
IMPACT PLATE/MEMBRANE ASSEMBLY

M represents the impact plate mass.

D_1 and D_o represent the inner and outer membrane diameters, respectively.

x represents the peak vertical displacement of the impact plate due to a particle impact.

$$dF_r = Tr d\theta$$

$$dF_x = Tr \sin \phi d\theta$$

Therefore the net force acting on the impact plate in the vertical direction is

$$F = \int_0^{2\pi} T \frac{D}{2} \sin \phi d\theta = \pi T D_1 \sin \phi \text{ dynes}$$

For small displacements $\sin \phi \approx \tan \phi = \frac{2x}{D_0 - D_1}$

$$\therefore F = \frac{2\pi T x D_1}{D_0 - D_1}$$

$$\text{or, since } F = Kx, \quad K = \frac{2\pi T D_1}{D_0 - D_1} \quad (9)$$

and since stress = $\sum = \frac{T}{t}$,

$$K = \frac{2\pi \sum t D_1}{D_0 - D_1} \quad (10)$$

Therefore the resonant frequency may be expressed in terms of the stress and dimensions of the system:

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{K}{M}} = \left[\frac{\sum t D_1}{2\pi M (D_0 - D_1)} \right]^{\frac{1}{2}} \quad (11)$$

$$\text{or} \quad f_{0m} = \left[\frac{\sum_m t D_1}{2\pi M (D_0 - D_1)} \right]^{\frac{1}{2}} \quad (12)$$

Before establishing bounds for the quantities in this expression, a digression must be made to consider additional constraints imposed upon some of these same parameters, and their influence in equation (6).

The spectral distribution of electronic noise dictates that f_0 should be placed as high as possible. This implies that D_1 and t should be large, M small and D_0 as close to D_1 as possible.

Structural considerations essentially fix D_0 and M . The value of D_1 is intimately connected with the rocking mode of impact plate vibration, as discussed in a subsequent section. And, finally, inspection of equation (6) shows that f_0 should be as small as possible in order to maximize sensitivity, which is contradictory to the above considerations.

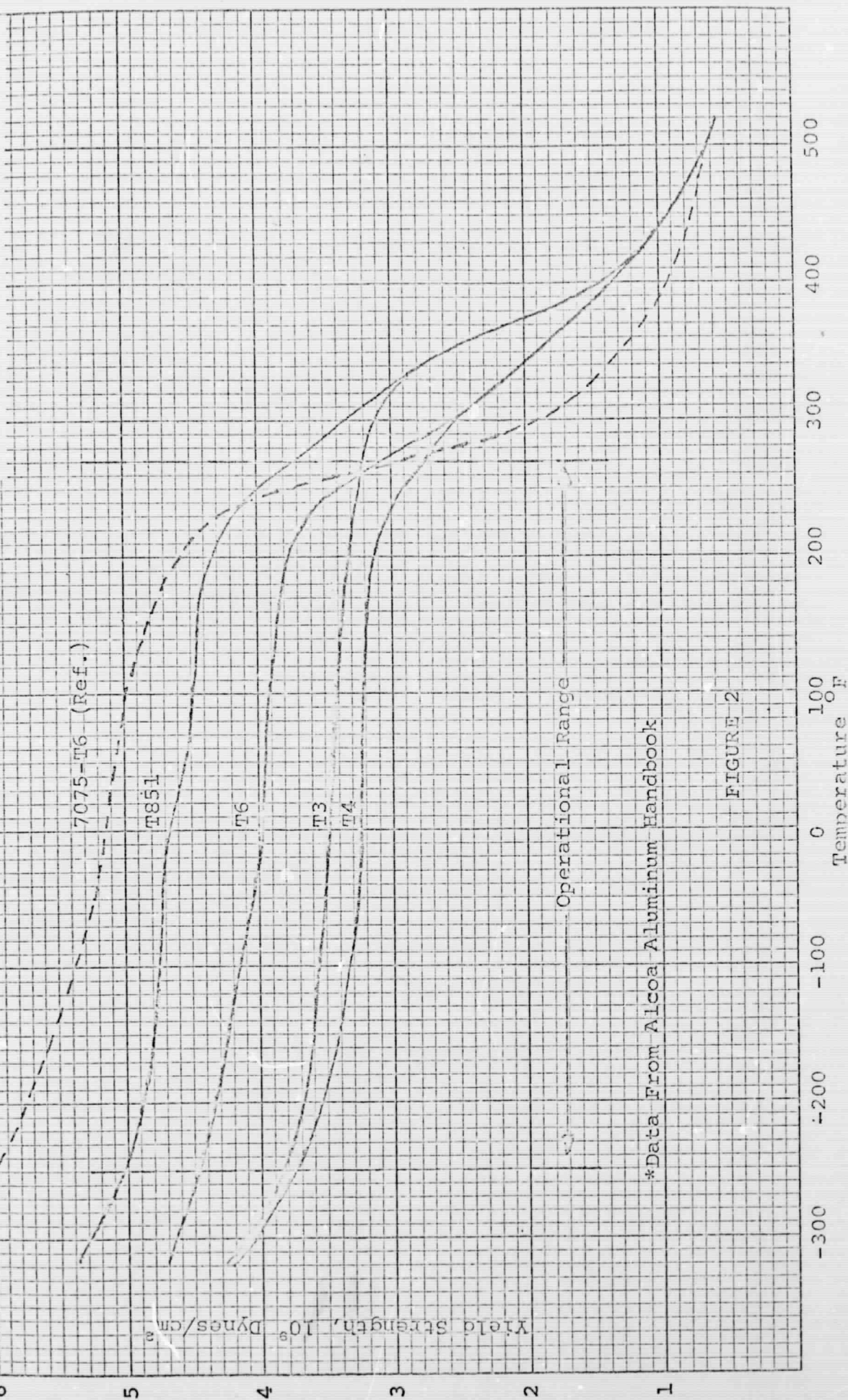
Therefore M should be minimized, since the sensitivity is inversely proportional to M while f_0 goes as the inverse square root of M . The outside impact plate dimensions are required to be 4.95 cm x 4.95 cm. Although a thickness of around .01 cm is sufficient to withstand a 10^{-2} dyne-sec hypervelocity impact momentum, mechanical considerations preclude this. A compromise has been reached by making the surface .04 cm thick with stiffening ribs on the lower surface to minimize warpage. With this configuration $M = 3.7$ gm.

Returning again to equation (6), if the sensitivity and f_0 are both to be as large as possible, then d_0 must be as small as practical. For reasons discussed in a subsequent section the minimum practical value for d_0 is 7.6×10^{-3} cm. Substituting these values for M and d_0 into equation (8),

$$f_0 \leq \frac{87.5 \frac{\text{gm cm}}{\text{sec}}}{2\pi \times 7.6 \times 10^{-3} \text{ cm} \times 4.8 \text{ gm}} = 382 \text{ Hz} \quad (13)$$

Returning now to considerations of stress, the maximum stress (i.e., yield strength) is a function of temperature and temper as illustrated in Figure 2. The diaphragm will be heat treated to T6 temper. The worst case yield strength of 2.9×10^9 dynes/cm² at 270°F will be used for all subsequent calculations.

Yield Strength Vs. Temperature
Aluminum Alloy, Type 2024*
Temper as a Parameter



*Data From Alcoa Aluminum Handbook

FIGURE 2

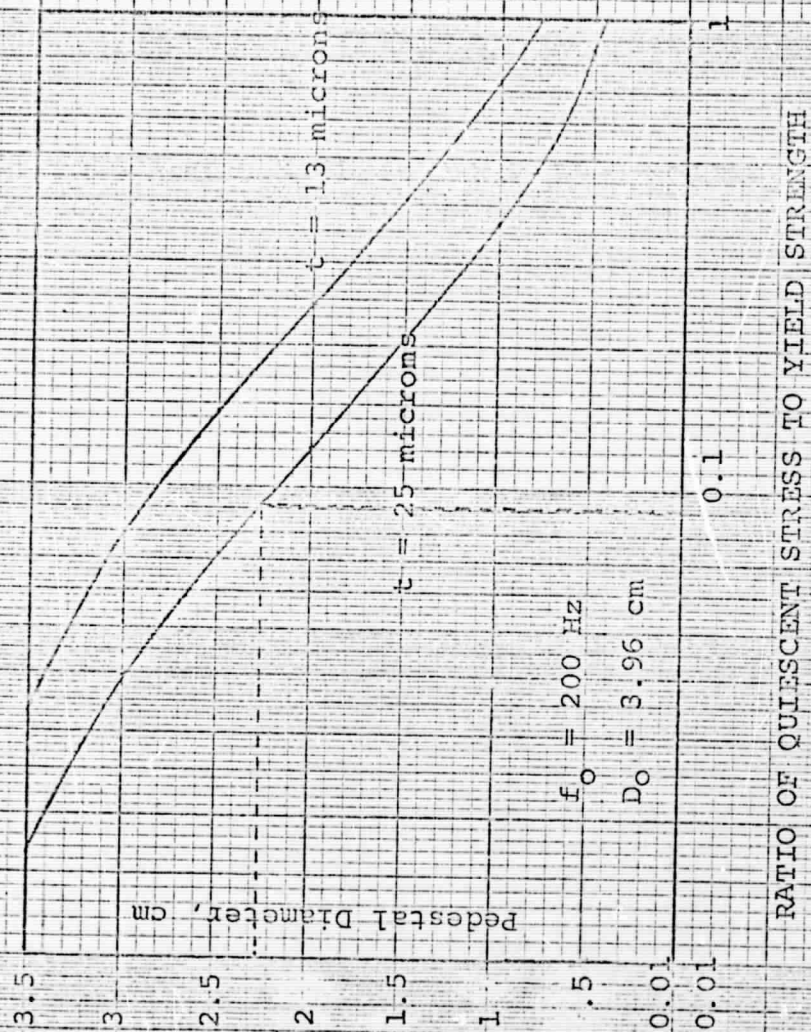
The value of D_0 is fixed at 3.96 cm primarily through structural design considerations. If equation (11) is rearranged as

$$\Sigma = \frac{2\pi M (D_0 - D_1) f_0^2}{tD_1}$$

it may be seen that for a given f_0 and D_0 the stress decreases with increasing pedestal diameter D_1 . This is illustrated in Figure 3. On the other hand, as discussed later the rocking mode frequency approaches the fundamental system resonance as D_1 increases and this is undesirable. And finally, the minimum value for D_1 should be such that D_1 is at least as large as the backplate diameter, which in turn is limited by the sensor capacitance required to provide a suitable source impedance to the electronics. Considering these factors then, D_1 is set a 2.3 cm.

The other two parameters which affect diaphragm stress are resonant frequency and diaphragm thickness, whose interaction is illustrated in Figure 4. Both 25 micron and 13 micron (1 mil and 0.5 mil) diaphragms were evaluated and 1 mil selected as the better compromise. The resonant frequency has been set at 200 Hz in order to maximize sensitivity and minimize diaphragm stress and hence improve long term stability.

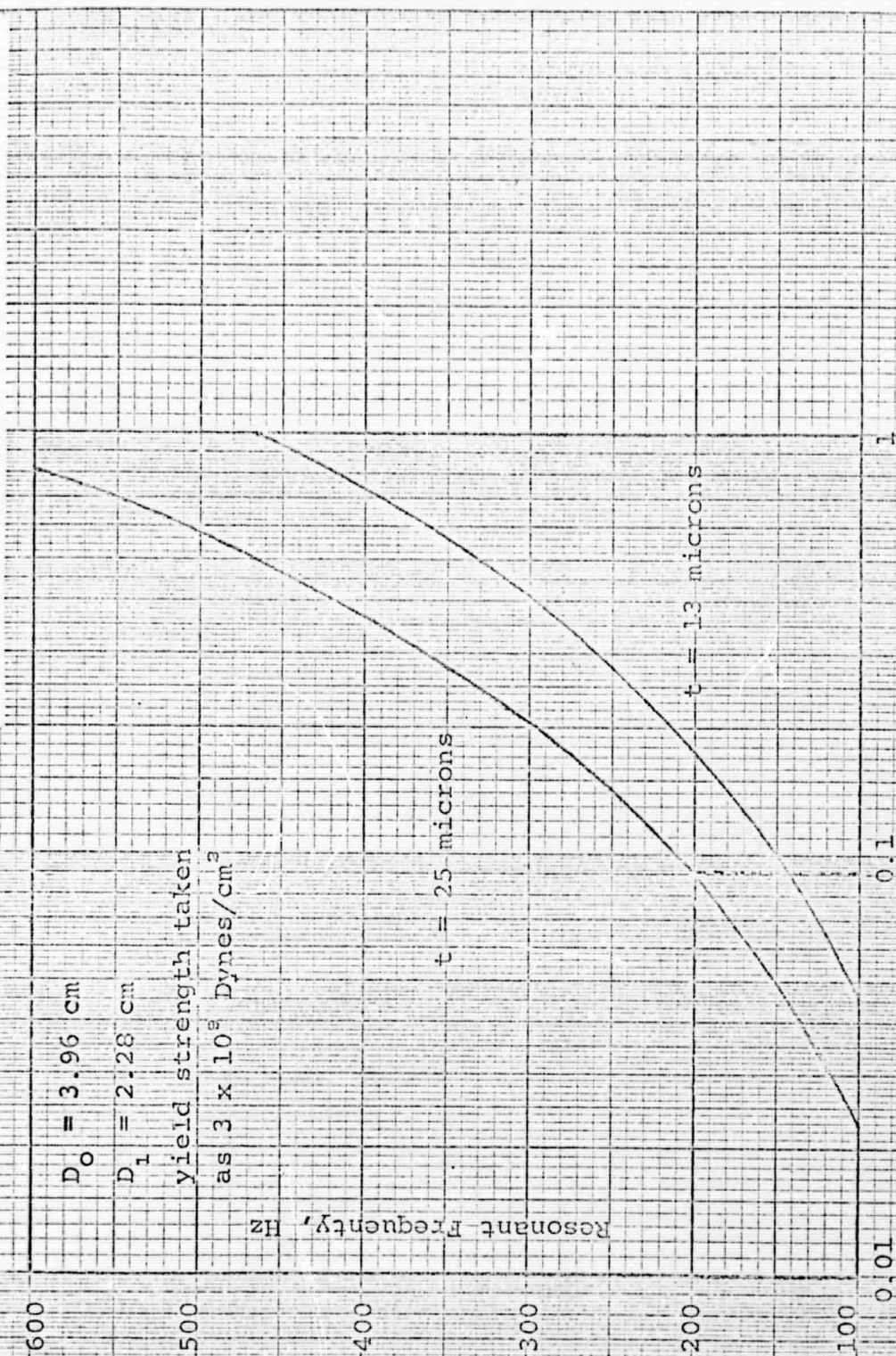
Stress Vs. Pedestal Diameter
Diaphragm Thickness As A Parameter



yield strength taken
as $3 \times 10^9 \text{ Dynes/cm}^2$

FIGURE 3

Diaphragm Stress Vs. Resonant Frequency Diaphragm Thickness As a Parameter



RATIO OF QUIESCENT STRESS TO YIELD STRENGTH

FIGURE 4

III. MAXIMUM DEFLECTION (BUMPER LOCATION)

Referring to Figure 1, we have

$$Y = \frac{\sum m}{S_m} \text{ and } S_m = \frac{\Delta l_m}{l} = \frac{\sum m}{Y}$$

where Y = Young's Modulus = 7.3×10^{10} dynes/cm² for 2024 Al.

S_m = maximum strain

$\sum m$ = maximum stress = yield strength

$$l = \frac{D_0 - D_1}{2}$$

Therefore,

$$\Delta l_m = \frac{l \sum m}{Y} \quad (14)$$

or

$$X_m = \left[(l + \Delta l_m)^2 \right]^{1/2} \approx \left[2l \Delta l_m \right]^{1/2} \quad (15)$$

Combining (14) and (15),

$$X_m = \left[\frac{2l^2 \sum m}{Y} \right]^{1/2} \quad (16)$$

where X_m = maximum vertical deflection.

Evaluating X_m ,

$$X_m = \left[\frac{2 \times (.838)^2 \text{ cm}^2 \times 2.9 \times 10^9 \frac{\text{dynes}}{\text{cm}^2}}{7.3 \times 10^{10} \text{ dynes/cm}^2} \right]^{1/2}$$

$$X_m = 7.5 \times 10^{-2} \text{ cm}$$

Using equation (15)

$$\Delta t_m = 3.55 \times 10^{-3} \text{ cm} = 35.5 \text{ microns}$$

From Figure 4, if we set $f_0 = 200 \text{ Hz}$ and $t = 25 \text{ micron}$, then under quiescent conditions $\sum_Q = 0.12 \sum_m$, and from equation (14)

$$\Delta t_Q = 4 \text{ microns}$$

where Δt_Q is the quiescent strain. Subtracting this from the maximum strain yields the available excess strain, or dynamic strain Δt_D :

$$\Delta t_D = \Delta t_m - \Delta t_Q = 31.5 \text{ microns}$$

Inserting this value Δt into equation (15) gives the vertical deflection which will produce a stress equal to the yield strength of the diaphragm when the resonant frequency is 200 Hz:

$$X_m = \left[2 \times 31.5 \times .838 \times 10^4 \right]^{1/2} = 7.25 \times 10^{-3} \text{ cm}$$

From the next section, an impacting particle will produce a maximum deflection of 0.025 micron for an accommodation coefficient of 1, or 0.125 micron for an accommodation coefficient of 5.

From a following section the electrostatic pull-in will be only 6.3 microns.

Thus there are no physically realistic restrictions on bumper spacing; let the bumper be placed on the backplate and spaced a distance of 25 microns from the lower surface of the impact plate.

IV. STRESS INDUCED BY AN IMPACTING PARTICLE

Ignoring the accommodation coefficient for the moment, equation (1) becomes

$$p = mv = MV$$

and from equations (2) and (3)

$$T = \frac{1}{2} M \left(\frac{mv}{M} \right)^2 = \frac{1}{2} K X_p^2$$

at the maximum of displacement. Hence X_p is the peak displacement produced by the impacting particle.

Therefore,

$$p = X_p \sqrt{MK}$$

or

$$X_p = \sqrt{\frac{p}{MK}}$$

Since $K = 4\pi^2 f_o^2 M$

$$X_p = \frac{p}{2\pi f_o M} = \frac{p}{\omega_o M} \quad (17)$$

Inserting the maximum value of 10^{-2} dyne sec for which the sensor is designed into (17),

$$X_p = \frac{10^{-2} \frac{\text{gm cm}}{\text{sec}}}{2\pi \times 250 \text{ sec}^{-1} \times 3.7 \text{ gm}} = .025 \text{ micron}$$

In light of section III preceding, this is insignificant in terms of X_m ; even if a value of 5 is assigned to α , X_p is only 0.125 micron.

V. ELECTROSTATIC PULL-IN

Neglecting fringing, the electrostatic force exerted upon the diaphragm-impact plate assembly is

$$F = KX_{es} = \frac{\epsilon_0 A E_0^2}{2d_0^2}$$

$$X_{es} = \frac{\epsilon_0 A E_0^2}{8\pi^2 d_0^2 f_0^2 M} \quad (18)$$

Again choosing $f_0 = 200$ Hz, and $d_0 = 76$ microns*, $A = 3.9$ cm² and $E_0 = 350$ V,

$$X_{es} = \frac{8.85 \times 10^{-12} \frac{cb^2}{nt \cdot m^2} \times (350)^2 V^2 \times 3.9 \text{ cm}^2}{8\pi^2 \times (7.6)^2 \times 10^{-8} \text{ cm}^2 \times (200)^2 \text{ sec}^{-2} \times 3.7 \text{ gm}}$$

$$= 62.6 \times 10^{-10} \frac{nt \cdot sec^2}{gm \cdot cm^2} = 62.6 \times 10^{-5} \text{ cm}$$

= 6.26 microns, which is negligible.

* As given in Section III, the bumper-to-impact plate spacing is 25 microns. If the bumper material has a dielectric constant of 3 and is 150 microns thick, then the effective spacing d_0 is 75 microns.

VI. FORCES OF ACCELERATION

Let there be an acceleration of N times gravity applied to the sensor along its sensitive axis.

$$F = NMg = KX_g$$

$$X_g = \frac{NMg}{K} = N \frac{g}{\omega_o^2} \quad (19)$$

where $\omega_o = 2\pi f_o$ and X_g is the displacement produced by this acceleration. If $f_o = 200$ Hz, $\omega_o = 1.25 \times 10^3$, and

$$X_g = N \frac{980 \frac{\text{cm}}{\text{sec}^2}}{1.58 \times 10^6 \text{ sec}^{-2}} = N \times 6.2 \times 10^{-4} \text{ cm}$$

$$= N \times 6.2 \text{ microns}$$

Let this acceleration be $10 g$'s:

$$X_g = 62 \text{ microns}$$

which is insignificant, producing an increase in strain of only (from eq. 15) $\Delta \epsilon_g = X_g^2 / 2l = 23 \times 10^{-6} \text{ cm} = 0.23 \text{ micron}$, or less than a 6 percent increase in stress over the quiescent value.

VII. INTERNAL ELECTROSTATIC CALIBRATION

Self calibration will be accomplished by applying an electrostatic impulsive force (of duration less than one-fourth the natural period of the sensor) to the impact plate by means of an electrode attached to, but insulated from, the backplate. Let the impulse imparted to the impact plate be equivalent to a momentum of 10^{-3} dyne sec.

$$p = 10^{-3} \text{ dyne sec} = \int_0^t F(t') dt' = Ft$$

where F is the force exerted by a square voltage pulse of duration t , with $t < T/4$ where T is the natural period of the sensor = 4 m sec.

$$p = Ft = \frac{\epsilon_0 a v^2 t}{2d^2}$$

where v = amplitude of the voltage pulse
 a = area of the calibrating electrode
 d = interelectrode spacing
 p = equivalent momentum

Note that no polarizing voltage is used and that the effects of fringing and shunt capacitance have been neglected. To get an idea of the required electrode size, let $d_0 = 75$ microns, $v = 10$ v and $t = 10^{-4}$ sec, then the electrode area required to simulate a 10^{-3} dyne second impact is

$$a = \frac{2pd_0^2}{\epsilon_0 v^2 t} = \frac{2 \times 10^{-3} \text{ dyne sec} \times (7.5)^2 \times 10^{-6} \text{ cm}^2 \times 10^{-5} \frac{\text{nt}}{\text{dyne}}}{8.85 \times 10^{-12} \frac{\text{cb}^2}{\text{nt m}^2} \times 10^2 v^2 \times 10^{-4} \text{ sec}}$$

$$= .13 \text{ cm}^2$$

VIII. ROCKING MODE

An off-center impact may excite a rocking mode of vibration in the impact plate. The frequency of this mode may be calculated from Newton's second law

$$\vec{J} = \dot{\vec{L}} \quad (20)$$

where

$\vec{J}$ = moment of the restoring force, or torque
 $\dot{\vec{L}}$ = rate of change of angular momentum, the dot denoting differentiation with respect to time

(The arrow is used to indicate that these are vector quantities)

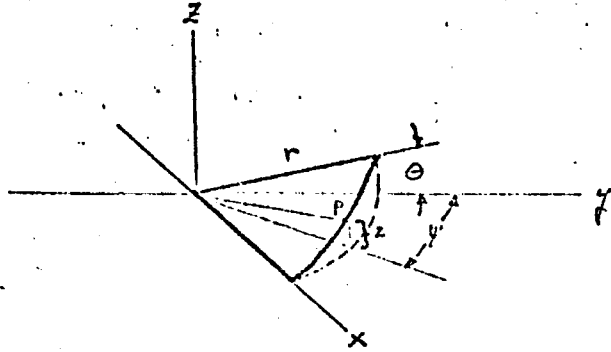


FIGURE 5

Figure 5 illustrates the parameters used to represent one quadrant of the impact plate pedestal which has been rotated about the x-axis by an angle θ . From the figure, it is seen that the vertical displacement z of the spring at an arbitrary point P on the periphery is given by

$$z = r \sin \theta \cos \psi$$

The incremental restoring force dF at this point is

$$dF = \frac{K}{2\pi} z d\psi = \frac{Kr}{2\pi} \sin \theta \cos \psi d\psi \quad (21)$$

where K is the spring constant defined in equation (4) and is divided by 2π to give the value per unit of angle ψ .

From Figure 5 and equation (21) the incremental torque is

$$dJ = r \cos \psi dF = \frac{Kr^2}{2\pi} \sin \theta \cos^2 \psi d\psi$$

Since the integrand is an even function, J can be determined by integrating over one quadrant and multiplying by 4:

$$J = \frac{2Kr^2}{\pi} \sin \theta \int_0^{\frac{\pi}{2}} \cos^2 \psi \, d\psi = \frac{Kr^2}{2} \sin \theta$$

For small angular displacements, $\sin \theta \approx \theta$, so that

$$J = \frac{1}{2} Kr^2 \theta$$

or, since $K = M\omega_0^2$

$$J = \frac{1}{2} M\omega_0^2 r^2 \theta \quad (22)$$

where M is the impact plate mass and ω_0 the system resonant frequency defined in equation (4) for planar motion along the z -axis.

The angular momentum of the impact plate is

$$L = I\omega$$

so that

$$\dot{L} = I\dot{\omega} = I\ddot{\theta} = \frac{1}{12} Mb^2 \ddot{\theta} \quad (23)$$

where

b = length of one side of the impact plate

I = moment of inertia of the impact plate

Substituting (22) and (23) into (20),

$$\frac{1}{12} M b^2 \ddot{\theta} + \frac{1}{2} M \omega_0^2 r^2 \theta = 0$$

or

$$\ddot{\theta} + \omega_0^2 \frac{6r^2}{b^2} \theta = 0 \quad (24)$$

The change in sign occurs because the vectors of equation (20) are oppositely directed.

Equation (24) is the differential equation of a simple harmonic oscillator of resonant frequency

$$\omega_r^2 = \omega_0^2 \frac{6r^2}{b^2} = \omega_0^2 \frac{3}{2} \frac{D_1^2}{b^2}$$

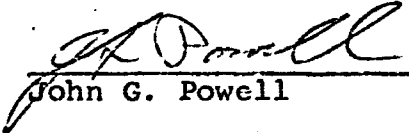
or

$$f_r = f_0 \sqrt{1.5} \frac{D_1}{b} \quad (25)$$

For the dimensions discussed previously ($D_1 = 2.3$ cm, $b = 4.95$ cm),

$$f_r = 0.57 f_0$$

Therefore the rocking mode has a frequency of approximately one-half the fundamental system frequency. The electrical output from the rocking mode will be very small since the symmetry of the system causes the average displacement variations to be second order effects.


John G. Powell

APPENDIX B

**FLIGHT PROTOTYPE ELECTROSTATIC
BALLISTIC PENDULUM
ENGINEERING ELECTRONICS
ANALYSIS**

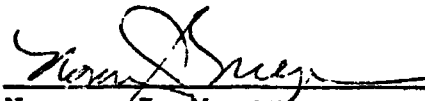
FLIGHT PROTOTYPE ELECTROSTATIC BALLISTIC PENDULUM

ENGINEERING ELECTRONICS ANALYSIS

Contract No. NAS 9-7290

NASA Manned Spacecraft Center
Houston, Texas

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INTRODUCTION

This analysis is divided into four (4) parts. Part 1 defines the performance parameters to be analyzed and develops the general equations to determine those parameters. Part 2 is composed of numerical and graphical solutions of the performance parameters. Part 3 is a presentation of empirical data and Part 4 consists of a comparison of calculated and measured data together with conclusions obtained concerning expected system performance based upon the analysis.

PART 1

The EBP amplifier performance parameters of interest are:

- a) Input impedance
- b) Output impedance
- c) Voltage gain
- d) ac response

Figure 1 is a schematic of the EBP electronics.

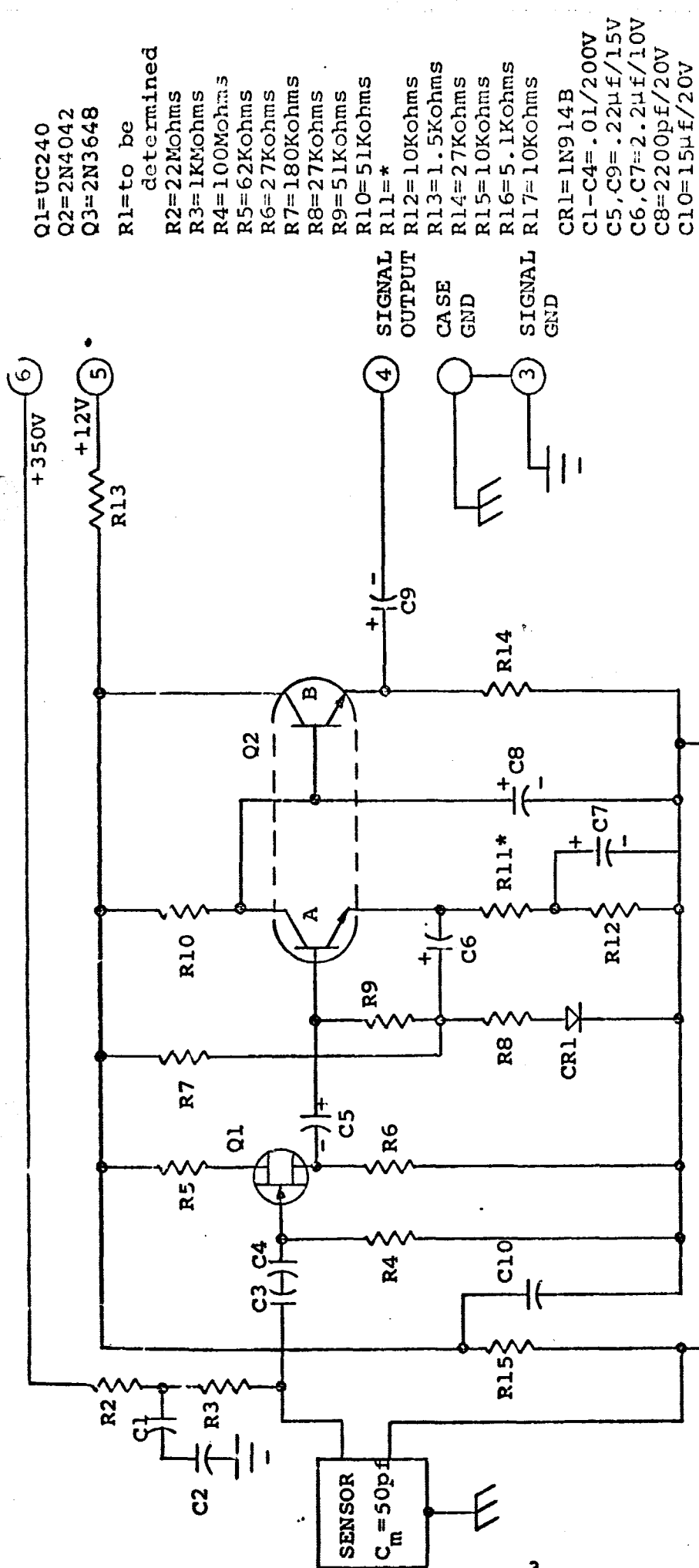
The equation development is approached by dividing the amplifier section into three (3) sub-sections:

- a) FET input stage
- b) Bipolar voltage gain stage
- c) Output emitter follower stage

For each of the three (3) sub-sections, the following parameters are of interest:

- a) Z_i , input impedance
- b) Z_o , output impedance
- c) K_v , voltage gain

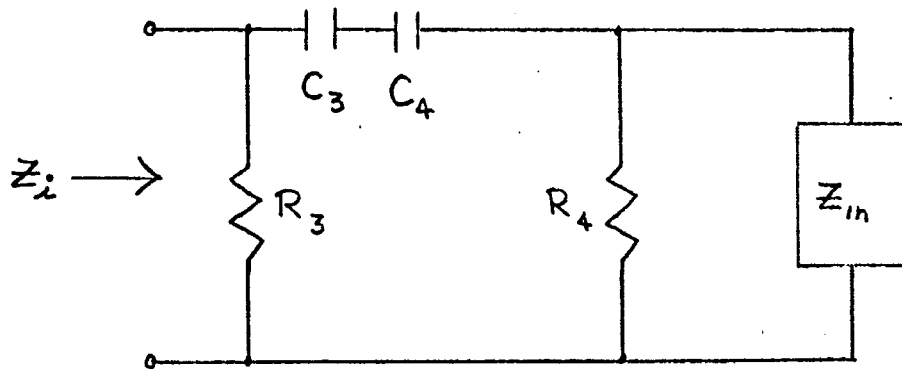
From the above information, it will be possible to calculate the overall ac response.



* SELECTED VALUE (Nom 2.4Kohms)

Figure 1

A. INPUT IMPEDANCE - FET INPUT STAGE



Equivalent circuit of EBP input

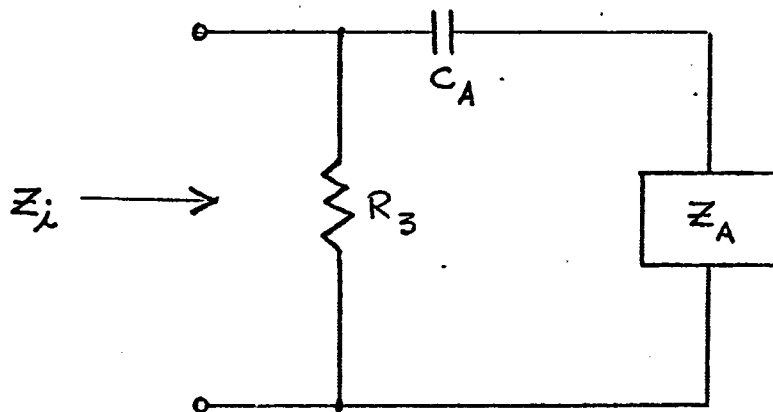
Assumptions: $R_3 > X_{C_1} = X_{C_2}$ at frequency of interest

Z_{in} is FET input impedance.

Let parallel combination of R_4 and Z_{in} be Z_A

Let series combination of C_3 and C_4 be C_A

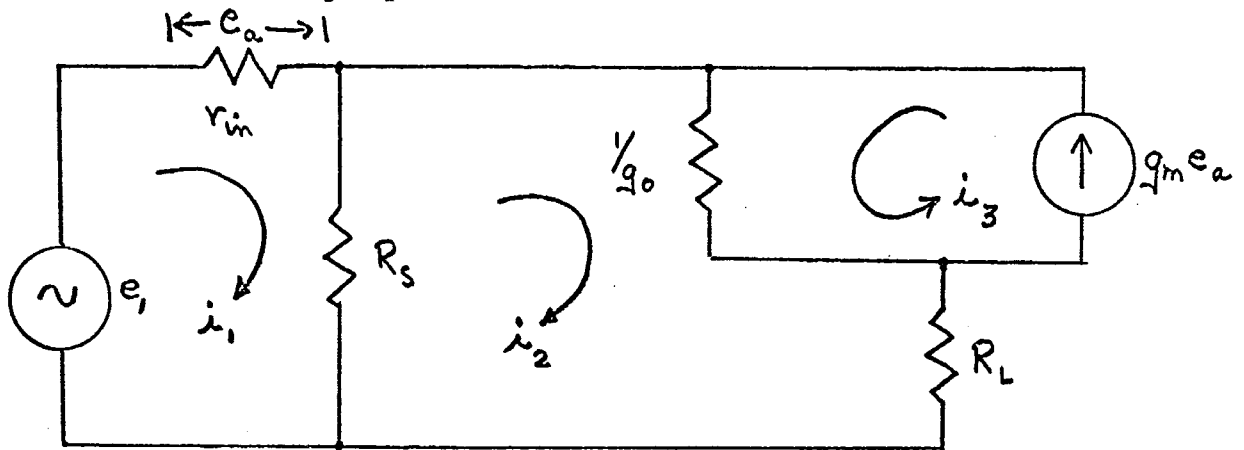
New equivalent circuit is then;



For the above figure, the LaPlace Transform of the time dependent function is;

$$Z_i(S) = (R_3) \frac{\left[Z_A + \frac{1}{C_A S} \right]}{R_3 + Z_A + \frac{1}{C_A S}} \quad (1)$$

The input impedance of the FET source follower may be found by use of the following equivalent circuit



Equivalent circuit for FET source follower circuit

Assumption: load impedance presented to source follower's output is high compared to R_s , the source resistor.

The 3 loop equations for the above circuit are:

$$a) \quad e_1 = i_1 (r_{in} + R_s) - i_2 R_s$$

$$b) \quad 0 = -i_1 R_s + i_2 \left(R_s + \frac{1}{g_o} + R_L \right) + i_3 \left(\frac{1}{g_o} \right)$$

$$c) \quad g_m e_a = i_3$$

$$e_a = i_1 r_{in} \quad \text{then;}$$

$$i_1 g_m r_{in} = i_3$$

Simplifying:

$$e_1 = i_1 (r_{in} + R_s) - i_2 R_s$$

$$0 = i_1 (g_m r_{in} \frac{1}{g_o} - R_s) + i_2 (R_s + R_L + \frac{1}{g_o})$$

From determinant theory:

$$\Delta = (r_{in} + R_s) (R_s + R_L + \frac{1}{g_o}) + R_s (g_m r_{in} \frac{1}{g_o} - R_s)$$

$$\Delta i_1 = e_1 (R_s + R_L + \frac{1}{g_o})$$

$$\frac{e_1}{i_1} = Z_{in} = \frac{r_{in} (R_s + R_L + \frac{1}{g_o} + R_s g_m / g_o) + R_s (R_L + \frac{1}{g_o})}{R_s + R_L + \frac{1}{g_o}}$$

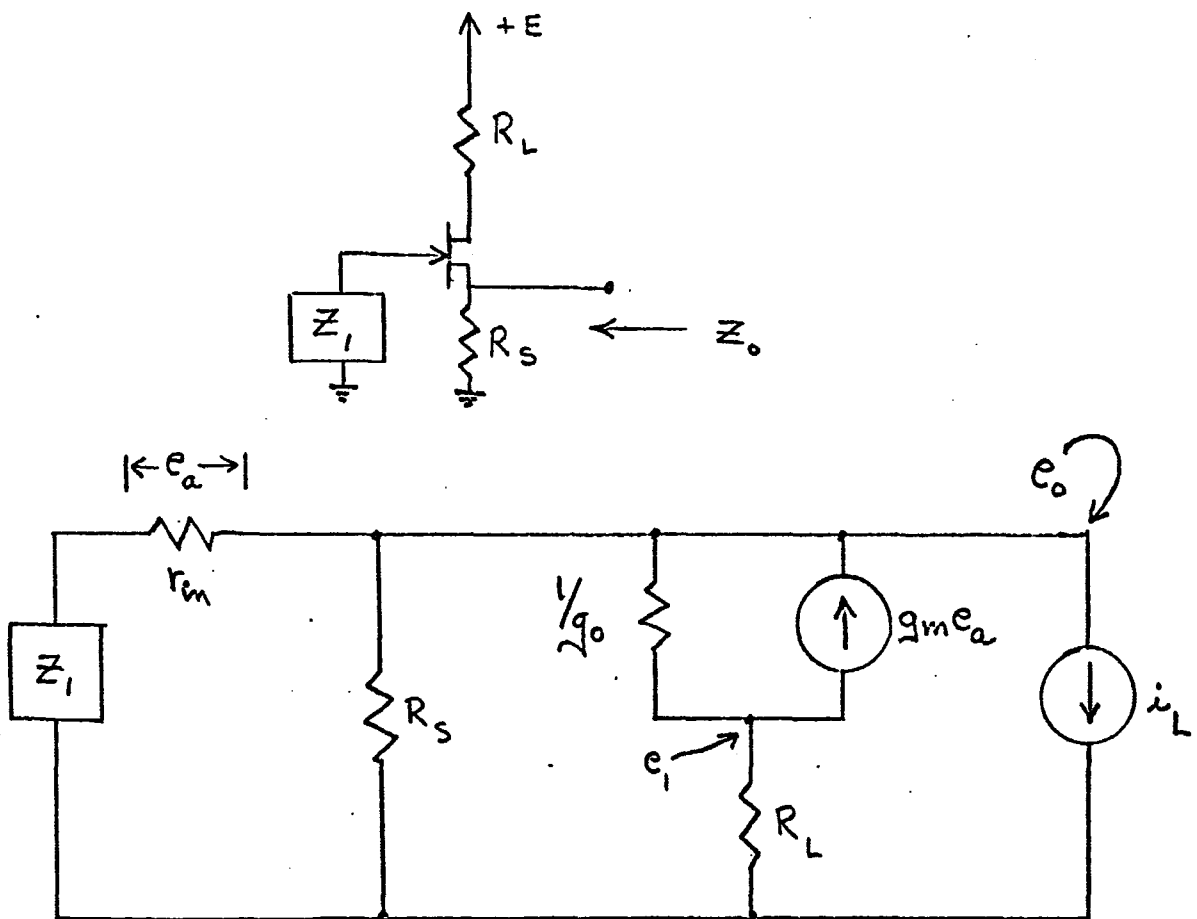
$$Z_A = R_4 \left[\frac{r_{in} (R_s + R_L + \frac{1}{g_o} + R_s g_m / g_o) + R_s (R_L + \frac{1}{g_o})}{R_s + R_L + \frac{1}{g_o}} \right] \quad (2)$$

$$R_4 + \frac{r_{in} (R_s + R_L + \frac{1}{g_o} + R_s g_m / g_o) + R_s (R_L + \frac{1}{g_o})}{R_s + R_L + 1/g_o}$$

Combining equations (1) and (2) allows the net amplifiers input impedance to be found.

The system's total input impedance may be found by adding the effect of the sensors capacitance to the amplifiers input impedance.

B. OUTPUT IMPEDANCE - FET INPUT STAGE



Equivalent of circuit to be analyzed.

Assumption: capacitance effects of device are of second order importance.

The 2 node equations for the above equivalent circuit are:

$$1) \quad i_L = - \frac{e_1}{R_L} - \frac{e_o}{R_s} - \frac{e_o}{Z_1 + r_{in}}$$

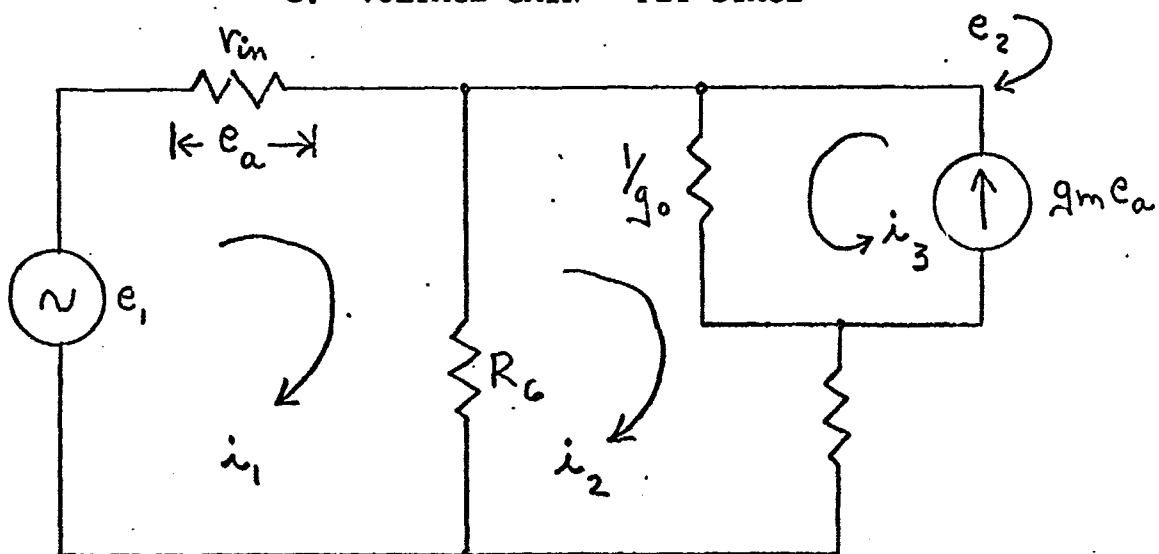
$$2) \quad \frac{-e_1}{R_L} = \frac{g_m (-e_o) r_{in} + (e_1 - e_o) g_o}{Z_1 + r_{in}}$$

From 2)
$$e_1 = e_o \left(\frac{g_m r_{in}}{Z_1 + r_{in}} + g_o \right) \frac{1}{(1/R_L + g_o)}$$

substituting into 1) and simplifying;

$$Z_o = \frac{e_o}{i_L} = - \left[\frac{(1 + R_L g_o) (Z_1 + r_{in}) R_s}{(1 + R_L g_o) [(Z_1 + r_{in}) + R_s + R_s g_o (Z_1 + r_{in})] + g_m r_{in} R_s} \right] \quad (3)$$

C. VOLTAGE GAIN - FET STAGE



Solve for $\frac{e_2}{e_1}$;

$$e_1 = i_1 (r_{in} + R_s) - i_2 R_s$$

$$0 = i_1 (g_m r_{in} \frac{1}{g_o} - R_s) + i_2 (R_s + R_L + \frac{1}{g_o})$$

from which

$$\Delta = (r_{in} + R_s) (R_s + R_L + \frac{1}{g_o}) + R_s (g_m r_{in} \frac{1}{g_o} - R_s)$$

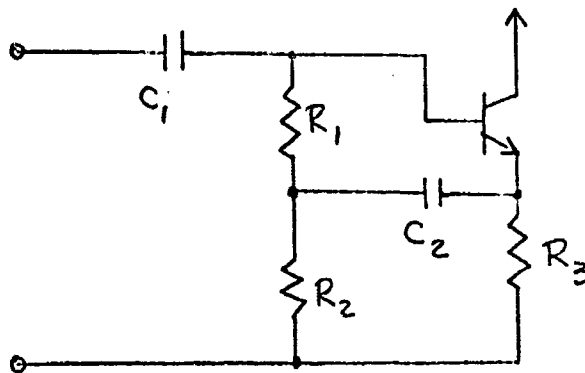
$$\Delta i_2 = e_1 (g_m r_{in} / g_o - R_s)$$

$$\Delta i_1 = e_1 (R_s + R_L + \frac{1}{g_o})$$

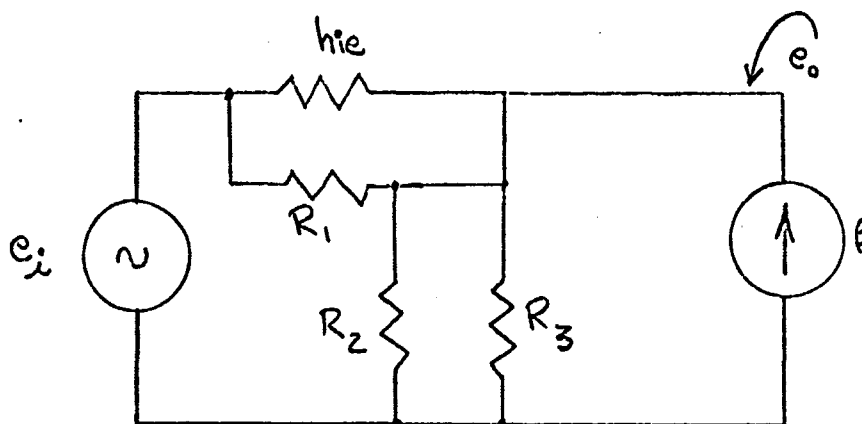
$$\frac{R_s (\Delta i_2 - \Delta i_1)}{e_1} = \frac{\left[g_m r_{in} / g_o - R_L - \frac{1}{g_o} \right] R_s}{(r_{in} + R_s) (R_s + R_L + \frac{1}{g_o}) + R_s (g_m r_{in} / g_o - R_s)}$$

$$K_v = \frac{e_2}{e_1} = \frac{R_s (g_m r_{in} / g_o - R_L - \frac{1}{g_o})}{r_{in} (R_s + R_L + \frac{1}{g_o} + R_s g_m / g_o) + R_s R_L + R_s / g_o} \quad (4)$$

D. INPUT IMPEDANCE - BIPOLAR GAIN STAGE



Assume C_1 and C_2 are bypassed at the frequencies of interest.



h parameter equivalent circuit

The circuit equation is:

$$(e_i - e_o) \left(\frac{\beta}{h_{ie}} + \frac{1}{R_1} \right) \approx \frac{e_o}{R_3} + \frac{e_o}{R_2}$$

$$e_i \frac{(R_1 \beta + h_{ie})}{R_1 h_{ie}} = e_o \left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{R_1 \beta + h_{ie}}{R_1 h_{ie}} \right)$$

The input impedance is given by:

$$Z_i = \frac{e_i}{(e_i - e_o)} \frac{R_1 h_{ie}}{(R_1 + h_{ie})} = \frac{e_i}{i_{in}}$$

$$e_o = e_1 \left(\frac{R_1 \beta + h_{ie}}{R_1 h_{ie}} \right) \quad (4A)$$

$$\frac{1}{R_2} + \frac{1}{R_3} + \frac{R_1 \beta + h_{ie}}{R_1 h_{ie}}$$

$$Z_i = \frac{R_1 h_{ie} \left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{R_1 \beta + h_{ie}}{R_1 h_{ie}} \right)}{\left(\frac{1}{R_2} + \frac{1}{R_3} \right) (R_1 + h_{ie})} \quad (5)$$

E. VOLTAGE GAIN - BIPOLAR GAIN STAGE

The expression for the emitter follower voltage gain was developed in the last section (Equation 4A). The common emitter voltage gain is then given by

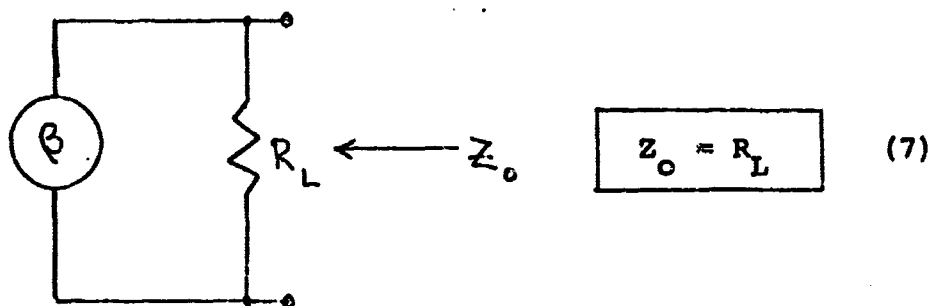
$$K_v = \frac{R_1 \beta + h_{ie}}{R_1 h_{ie}} \times \frac{R_L}{R_3} \quad (6)$$

$$\frac{1}{R_2} + \frac{1}{R_3} + \frac{R_1 \beta + h_{ie}}{R_1 h_{ie}}$$

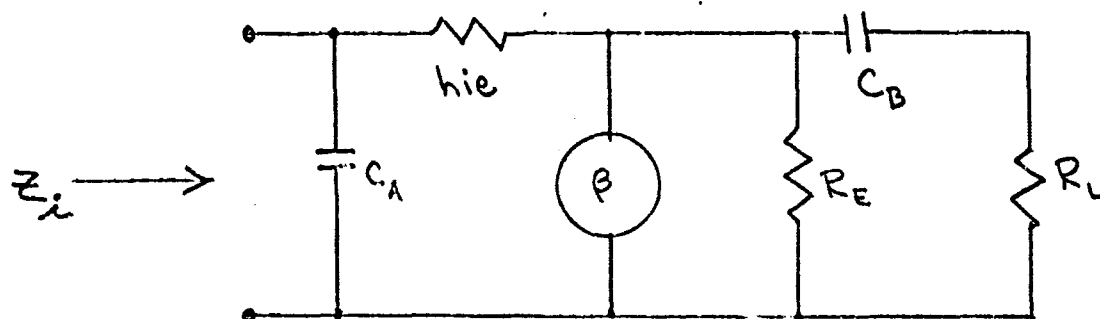
where R_L is the collector resistor.

F. OUTPUT IMPEDANCE - BIPOLAR GAIN STAGE

Practically, the output impedance of this stage is the collector resistance since it is in series with the collector current generator as shown below.

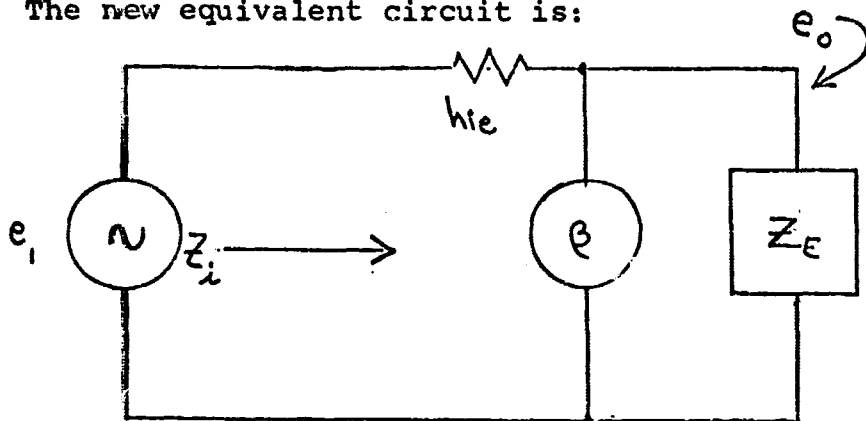


G. INPUT IMPEDANCE - OUTPUT EMITTER FOLLOWER STAGE



Let the combination of R_E , R_L , and C_B be Z_E ; also neglect C_A which will be included later.

The new equivalent circuit is:



$$Z_i = \frac{e_1}{i_1} = \frac{e_1 h_{ie}}{e_1 - e_o}$$

The circuit's node equation is:

$$\left(\frac{e_1 - e_o}{h_{ie}} \right) (\beta + 1) = \frac{e_o}{Z_E}$$

From which:

$$e_o = e_i \frac{(\beta+1) Z_E}{(\beta+1) Z_E + h_{ie}}$$

Then:

$$Z_i = (\beta+1) Z_E + h_{ie}$$

$$Z_E \text{ is always } > \frac{R_E R_L}{R_E + R_L} = R_A$$

$$Z_i \approx (\beta+1) R_A + h_{ie} \approx \beta R_A$$

Network is also shunted with C_A which when included in the input impedance expression becomes:

$$Z_i \approx \frac{\beta R_A}{\beta R_A C_A S + 1}$$

(8)

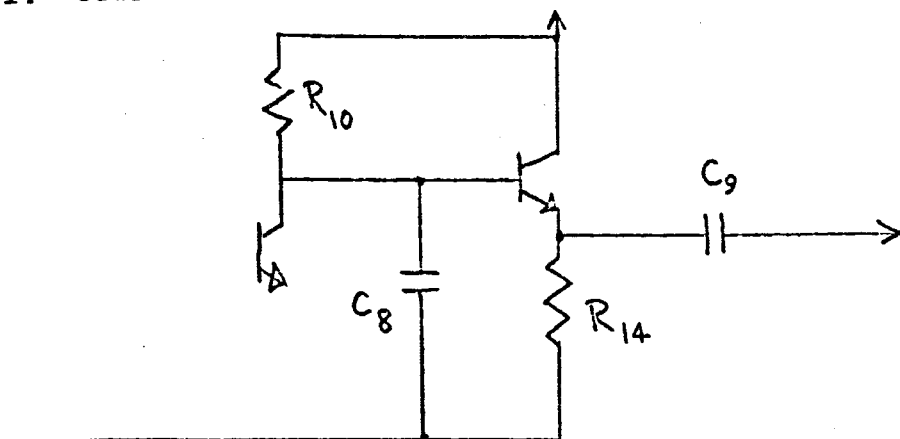
H. VOLTAGE GAIN - EMITTER FOLLOWER OUTPUT STAGE

The voltage gain for the emitter follower is very near unity since h_{ie} is always much less than the product of β and the effective load impedance. (See Equation 4A.)

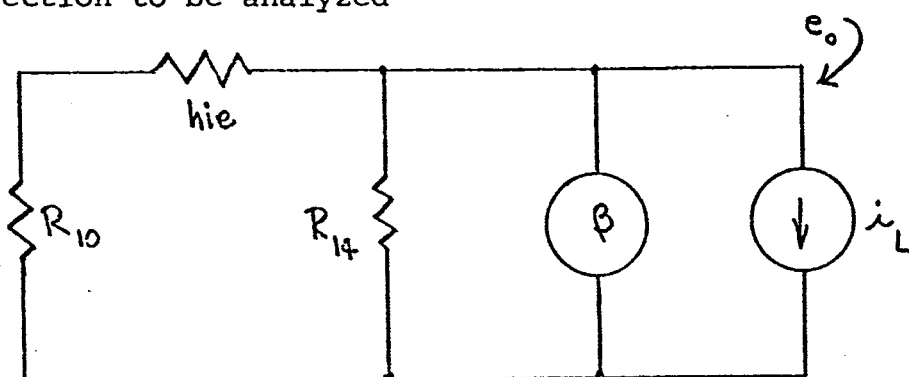
$$K_V \approx 1$$

(9)

I. OUTPUT IMPEDANCE - EMITTER FOLLOWER OUTPUT STAGE



Circuitry section to be analyzed



Equivalent circuit of analyzed circuit (neglects C_8 and C_9)

$$i_1 (\beta + 1) = \frac{-e_o}{R_{14}} + i_L$$

$$e_o = i_1 (R_{10} + h_{ie})$$

$$\frac{(\beta+1) e_o}{R_{10} + h_{ie}} = \frac{-e_o}{R_{14}} + i_L$$

$$e_o \left(\frac{\beta+1}{R_{10} + h_{ie}} + \frac{1}{R_{14}} \right) = i_L$$

$$Z_a = \frac{e_o}{i_L} \approx \frac{R_{10} + h_{ie}}{\beta}$$

If C_9 is now included in the circuit

$$Z_o \approx Z_a + \frac{1}{C_9 S} = \frac{Z_a C_9 S + 1}{C_9 S} \quad (10)$$

The performance equations developed in this section will be summarized here. New element designations are keyed to the schematic of Figure 1 for uniformity.

A. INPUT IMPEDANCE - FET INPUT STAGE

$$Z_{i_1}(S) = \frac{(R_3) \left(Z_A + \frac{1}{C_A S} \right)}{R_3 + Z_A + \frac{1}{C_A S}}$$

Where

$$\frac{1}{C_A} = \frac{1}{C_3} + \frac{1}{C_4}$$

$$Z_A = R_4 \left[\frac{r_{in} (R_6 + R_5 + 1/g_O + R_6 g_m/g_O) + R_6 (R_5 + 1/g_O)}{R_6 + R_5 + 1/g_O} \right]$$

$$\frac{R_4 + \frac{r_{in} (R_6 + R_5 + 1/g_O + R_6 g_m/g_O) + R_6 (R_5 + 1/g_O)}{R_6 + R_5 + 1/g_O}}{R_6 + R_5 + 1/g_O}$$

B. OUTPUT IMPEDANCE - FET INPUT STAGE

$$Z_{O1} = \left[\frac{(1 + R_5 g_O) (Z_1 + r_{in}) R_6}{(1 + R_5 g_O) (Z_1 + r_{in}) + R_6 + R_6 g_O (Z_1 + r_{in}) + g_m + r_{in} R_6} \right]$$

Where

$$Z_1 \approx \frac{R_4}{R_4 C_M S + 1}$$

C. VOLTAGE GAIN - FET INPUT STAGE

$$K_V = \frac{R_6 (g_m r_{in}/g_O - R_5 - 1/g_O)}{r_{in} (R_6 + R_5 + 1/g_O + R_6/g_O) + R_6 R_5 + R_6/g_O}$$

D. INPUT IMPEDANCE - BIPOLAR GAIN STAGE

$$Z_{i2} = \frac{R_9 h_{ie} \left(\frac{1}{R_A} + \frac{1}{R_{11}} + \frac{R_9 \beta + h_{ie}}{R_9 h_{ie}} \right)}{\left(\frac{1}{R_A} + \frac{1}{R_{11}} \right) (R_9 + h_{ie})}$$

E. OUTPUT IMPEDANCE - BIPOLAR GAIN STAGE

$$Z_{O_2} \approx R_{10} \quad \text{if } 1/h_{oe} > 10R_{10}$$

F. VOLTAGE GAIN - BIPOLAR GAIN STAGE

$$K_{V_2} = \frac{\frac{R_9 \beta + h_{ie}}{R_9 h_{ie}}}{\frac{1}{R_A} + \frac{1}{R_{11}} + \frac{R_9 \beta + h_{ie}}{R_9 h_{ie}}} \times \frac{R_{10}}{R_{11}}$$

$$\text{where: } R_A \approx \frac{R_8 R_7}{R_8 + R_7}$$

G. INPUT IMPEDANCE - EMITTER FOLLOWER OUTPUT STAGE

$$Z_{i_3} \approx \frac{\beta R_A}{\beta R_A C_8 S + 1}$$

where:

$$R_A = \frac{R_L R_{14}}{R_L + R_{14}}$$

H. OUTPUT IMPEDANCE - EMITTER FOLLOWER OUTPUT STAGE

$$Z_{O_3} = \frac{Z_a C_9 S + 1}{C_9}$$

where:

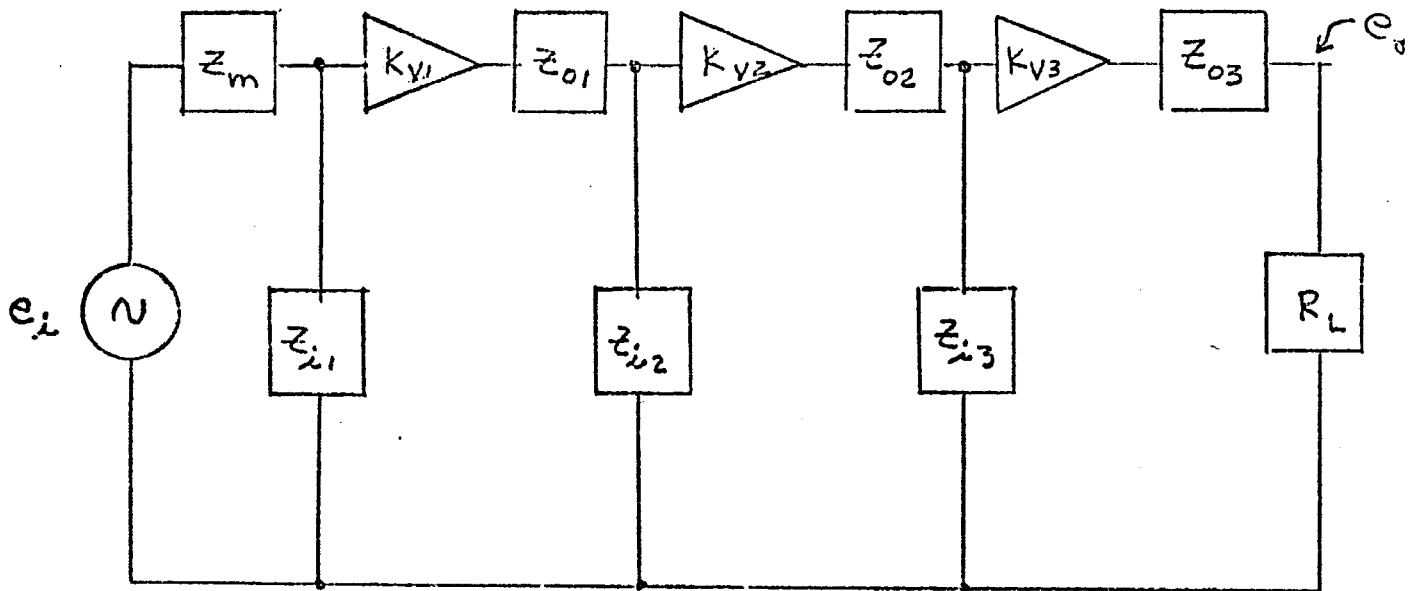
$$Z_a = \frac{R_{10} + h_{ie}}{\beta}$$

I. VOLTAGE GAIN EMITTER FOLLOWER OUTPUT STAGE

$$K_{V_3} \approx 1$$

Part 2

The EBP amplifier's gain and frequency response may be found by dividing the circuit into the following equivalent block diagram:



Where the block elements are those derived in the preceding section.

Numerical Evaluation:

The component parameters used to evaluate the EBP's characteristics are found in Table I and are from manufacturers data sheets or laboratory measurements on representative components.

TABLE I

ANALYSIS PARAMETERS

Component	Parameter	V A L U E			Units	Comment
		Minimum	Nominal	Maximum		
C _M	Capacitance	-	50	-	pf	Transducer Capacitance
C1		.0075	.01	.012	μf	Based upon: + 22%, - 25%
C2			.01			
C3			.01			
C4			.01			
C5		.14	.22	.35		+60%/ - 35%
C6		1.4	2.2	3.5		
C7		1.4	2.2	3.5		
C8		1400	2200	3080	pf	+40%/ - 35%
C9		.14	.22	.35	μf	+60%/ - 35%
C10		9.75	15	21	μf	+40%/ - 35%
R1	Resistance	*	1x10 ⁹	*	Ω	*Assume + 10% tolerance
R2			22x10 ⁶			on + 5% initial tolerance
R3			1x10 ⁹			components
R4			1x10 ³			
R5			62x10 ³			
R6			27x10 ³			
R7			180x10 ³			
R8			27x10 ³			
R9			51x10 ³			
R10			51x10 ³			
R11			24x10 ²			
R12			10x10 ³			
R13			15x10 ²			
R14			27x10 ³			
R15			10x10 ³			
R16			51x10 ²			
R17			10x10 ³			

TABLE I

ANALYSIS PARAMETERS

(Continued)

<u>Component</u>	<u>Parameter</u>	<u>Minimum</u>	<u>Nominal</u>	<u>Maximum</u>	<u>Units</u>	<u>Comment</u>
CR1	v_f	.300	.5	.68	Volts	Based on $-2 \text{ mv}/\%_C$ T.C.
Q1	g_m	120	1200	-	μU	Estimate
	r_{in}	$3 \times 10^{+8}$	$3 \times 10^{+11}$	1×10^{12}	Ω	Manufacturers data
	g_o	50	50	50	μU	Estimate
	β	75	200	600		Manufacturers data
Q2 A	h_{ie}	11K	15K	21K	Ω	Calculated from operating point data
	V_{be}	.4	.6	.78	Volts	Based on $-2 \text{ mv}/\%_C$ T.C.
Q2 B	β	75	200	600		Manufacturers data
	h_{ie}	11K	15K	21K		Calculated from operating point data
	V_{be}	.4	.6	.78		$-2 \text{ mv}/\%_C + \text{T.C.}$
	β	5	-	150		Manufacturers data
Q3	V_{be}	.4	0.6	.8	Volts	$-2 \text{ mv}/\%_C + \text{T.C.}$

I. INPUT IMPEDANCE: Z_{i1}

A. Nominal

$$Z_A \approx 1 \times 10^8 \Omega$$

$$Z_i(s) \approx 1 \times 10^8 \frac{(s+2)}{(s+0.2)}$$

At frequencies of interest;
 $Z_i \rightarrow 1 \times 10^8 \Omega$

B. Minimum

Conditions: $Z_A \min \therefore$ all elements that make up Z_A are min

$$Z_A \approx 0.76 \times 10^8$$

$$Z_i(s) \approx 0.7 \times 10^8 \frac{(s+3.5)}{(s+0.27)}$$

At frequencies of interest;
 $Z \rightarrow 0.7 \times 10^8 \Omega$

C. Maximum

By inspection:

$$Z_i(s) \approx 1.10 \times 10^8 \Omega \text{ at frequencies of interest}$$

II. OUTPUT IMPEDANCE: Z_{o1}

A. Nominal

$$Z_1 + r_{in} = \frac{150 \times 10^7 s + 3 \times 10^{11}}{50 \times 10^{-4} s + 1}$$

$$Z_{01} \approx 2870 \frac{(S+276)}{(S+200)}$$

At frequencies of interest;
 $Z_{01} \rightarrow 2870 \Omega$

B. Maximum

$$Z_{01} \approx 5320 \frac{(S+276)}{(S+146)}$$

At frequencies of interest;
 $Z_{01} \rightarrow 5320 \Omega$

Assumes major effect on output impedance is g_m

C. Minimum

A low value of Z_{01} caused by a high value of g_m will not cause detrimental circuit performance due to the high value of Z_{i2} (shown later).

III. VOLTAGE GAIN: K_{V1}

A. Nominal

$$K_{V1} \approx 0.88$$

B. Minimum

$$K_{V1} \approx 0.38$$

(based primarily on low g_m)

C. Maximum

Limiting case is $K_{V1} = 1$

IV.

IMPEDANCE: Z_{i_2}

Nominal

For this circuit, even with best β 's, the resistor values are chosen such that

$$Z_{i_2} \approx \frac{R_3 R_1 \beta}{R_1 + h_{ie}}$$

$$\approx 370K \Omega$$

Minimum

$$Z_{i_2} \approx 138K \Omega$$

Maximum

This parameter is of no large.

But since the nominal Z_{i_2} is sufficiently

V

VOLTAGE GAIN: K_{V_2}

Nominal

$$K_V \approx \frac{R_L}{R_{11}} =$$

Minimum

$$K_{V_2} \approx 19.2$$

(resistor tolerances)

C. Maximum

$$K_{V_2} \approx 23.4 \quad (\text{Due to resistor tolerances})$$

VI. OUTPUT IMPEDANCE: Z_{O_2}

A. Nominal

$$Z_{O_2} \approx 51K$$

B. Minimum

$$Z_{O_2} \approx 46K \Omega \quad (\text{Due to } R_{10} \text{ tolerance})$$

C. Maximum

$$Z_{O_2} \approx 56K \Omega \quad (\text{Due to } R_{10} \text{ tolerance})$$

VII. INPUT IMPEDANCE: Z_{i_3}

A. Nominal

$$R_A = 7.3 \times 10^3$$

$$Z_{i_3} = \frac{4.53 \times 10^8}{S \times 310}$$

B. Minimum

$$Z_{i_3} \approx \frac{3.24 \times 10^8}{s+591}$$

C. Maximum

$$Z_{i_3} \approx \frac{2.3 \times 10^8}{s+163}$$

(Assumes $\beta = 600$)

VIII. OUTPUT IMPEDANCE: Z_{O_3}

A. Nominal

$$Z_{O_3} \approx \frac{7280 \times 10^{-8} s + 1}{22 \times 10^{-8} s}$$

B. Maximum

$$Z_{O_3} \approx \frac{1400 \times 10^{-7} s + 1}{14 \times 10^{-8} s}$$

C. Minimum

$$Z_{O_3} \approx \frac{3255 \times 10^{-8} s + 1}{35 \times 10^{-8} s}$$

Using the numerical data calculated in this section, the following polynomials in S are now obtained for the amplifier's response;

A. Nominal Gain Solution

$$K(S) = \frac{18.8 S^2 (8860)}{(S+200) (S+8860) (S+455)}$$

B. Maximum Gain Solution

$$K(S) = \frac{23.4 S^2 (1400)}{(S+182) (S+14000) (S+286)}$$

C. Minimum Gain Solution

$$K(S) = \frac{7.3 S^2 (7050)}{(S+286) (S+7050) (S+715)}$$

The above equations are sketched, using asymptotic approximation techniques in Figure 2.

ADDITIONAL SYSTEM PARAMETERS

A. Maximum Output Voltage

The maximum output voltage obtainable in the system is determined by the output emitter follower and associated components.

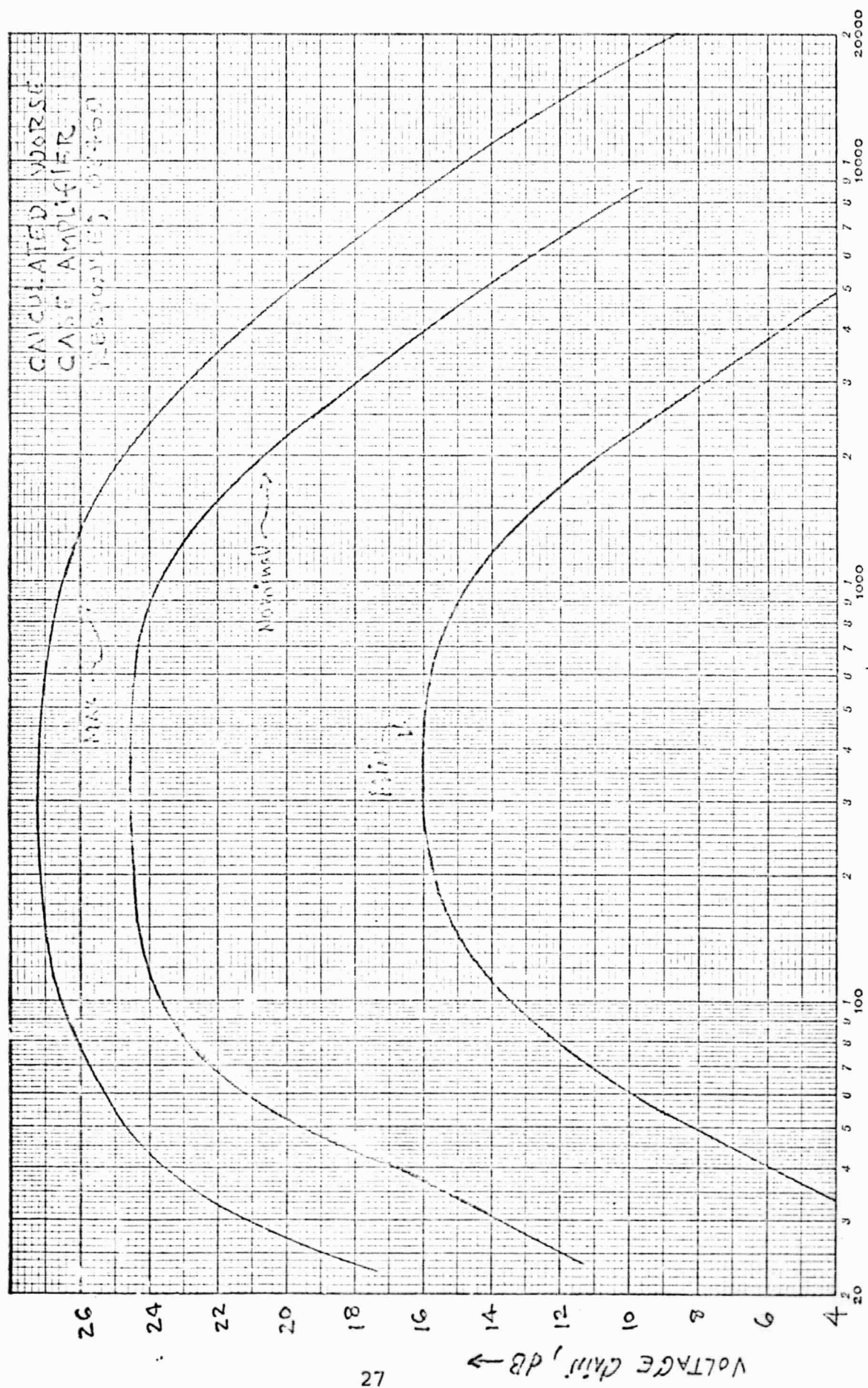


Figure 2.

The emitter of the last stage is held near 6 volts dc in the no signal case. The negative going portion of the output signal will be clipped if it exceeds a peak value of

$$\frac{6 R_L}{R_{14} + R_L} \approx 1.62 \text{ volts}$$

This corresponds to maximum undistorted output voltage of 1.15 volts rms.

B. Broad Band Noise

Reference 1* gives an expression for the system's broadband noise (referred to the system's input) in terms of its parameters.

The expression is

$$e_o = \sqrt{C f_2} \sqrt{\frac{Y^2}{(X+1)(Y+1)(X+Y)}}$$

Where

$$X = \frac{f_1}{f_2} \quad f_1 \text{ is amplifiers low frequency break}$$

$$Y = \frac{f_n}{f_2} \quad f_2 \text{ is amplifiers high frequency break}$$

$$C = 2\pi KTR \quad f_n \text{ is break frequency due to sensor capacity and } R_4$$

* Report No. 0-71200/7TR-122, "Broadband Noise Characteristics of First Order Bandpass Amplifiers," dated 15 August 1967.

From Figure 2 the worse case bandwidths are

$$f_1 = 45 \text{ Hz}$$

$$f_2 = 2200 \text{ Hz}$$

$$\text{For the amplifier } f_n \approx 32 \text{ Hz}$$

At 125°C (400°K)

$$C = 2\pi (1.38 \times 10^{-23}) (400) (1 \times 10^8) = 346 \times 10^{-14}$$

$$X = 0.0402$$

$$Y = .0286$$

From which;

$$e_o = 9.5 \mu\text{V} \approx -100 \text{ dBv}$$

For a sensor sensitivity of 5V/dyne-sec , this corresponds to a momentum threshold of $2.68 \times 10^{-6} \text{ dyne-sec}$ which is approximately 14 dB below $1 \times 10^{-5} \text{ dyne-sec}$.

C. Dynamic Range

The dynamic range of the system is given by the difference in the noise floor and the maximum system output.

Converting the previously obtained broadband noise voltage and the maximum input voltage into dBv;

$$\text{Noise floor: } e_{on} = -100 \text{ dBv}$$

Maximum output (Re: input): $e_{\text{omax}} \approx -20 \text{ dBv}$

$$e_{\text{omax}} - e_{\text{on}} \approx 80 \text{ dB}$$

D. Transient Response

Reference 2* discusses the non-ideal response of the EBP amplifier to the sensor's output signal.

Figure 5 in Reference 2 is a plot of % amplitude error in the first peak vs. f_0/f_1 where f_0 is the sensor resonant frequency and f_1 is the EBP amplifier's lower frequency cutoff frequency.

From Figure 2, the amplifier's nominal lower cutoff frequency is 65 Hz. For a sensor resonant frequency of 200 Hz or a ratio of $f_0/f_1 \approx 3.0$, a 21% error is obtained.

E. Stress Considerations

1) Semiconductors:

All semiconductors are rated for at least 175°C. Since total power consumed by the entire circuit is less than 4.8 mw and the maximum temperature is 125°C power ratings are not exceeded.

Voltage and current ratings of all semiconductors are substantially higher than those present in the circuit; hence, the semiconductors are not overstressed.

* Report No. 0-71200/7M-25, "EBP Amplifiers Response Characteristics," dated 8 February 1967.

2) Resistors:

All 1/8 watt carbon resistors used are rated at 10 mw at 125°C. Since total circuit power is only 4.8 mw no resistor is overstressed.

3) Capacitors:

The four (4) ceramic capacitors are rated at 200 VDC @ 125°C. These parts are used in 350 VDC applications where two (2) are placed in series.

The solid tantalum capacitors are rated at 2/3 of their normal operating voltage at 125°C.

Using this criteria the following list presents the approximate operating stresses.

<u>Component</u>	<u>125°C Rating</u>	<u>Circuit Stress Value</u>
C ₅	10V	<1V
C ₆	6V	<1V
C ₇	6V	<2V
C ₈	13V	<8V
C ₉	10V	<6V
C ₁₀	13V	<12V

Hence, no capacitor is electrically over stressed.

PART 3

T E M P E R A T U R E

	<u>25°C</u>	<u>125°C</u>	<u>-55°C</u>
Voltage Gain	22.4 dB	21.7 dB	22.5 dB
3 dB Freq. Response	83-1850 Hz	95-1200 Hz	88-2100 Hz
Output Impedance	—— Typically 500 Ω @ 400 Hz ——		
Maximum Output Voltage	1.04V rms	1.1V rms	1.0V rms
Power Supply Current	.36 ma	.39 ma	410 ma
Broadband Noise (Re: input)	-105 dBv	-99 dBv	-99 dBv
Transient Response: % 1st peak error	—— 20% Typical @ 400 Hz ——		

TABLE 2

Table 2 consists of data taken on a breadboard model of the EBP amplifier.

Figure 3 is the measured gain vs. frequency characteristics of the breadboard.

Figure 4 is the measured spot noise of the breadboard.

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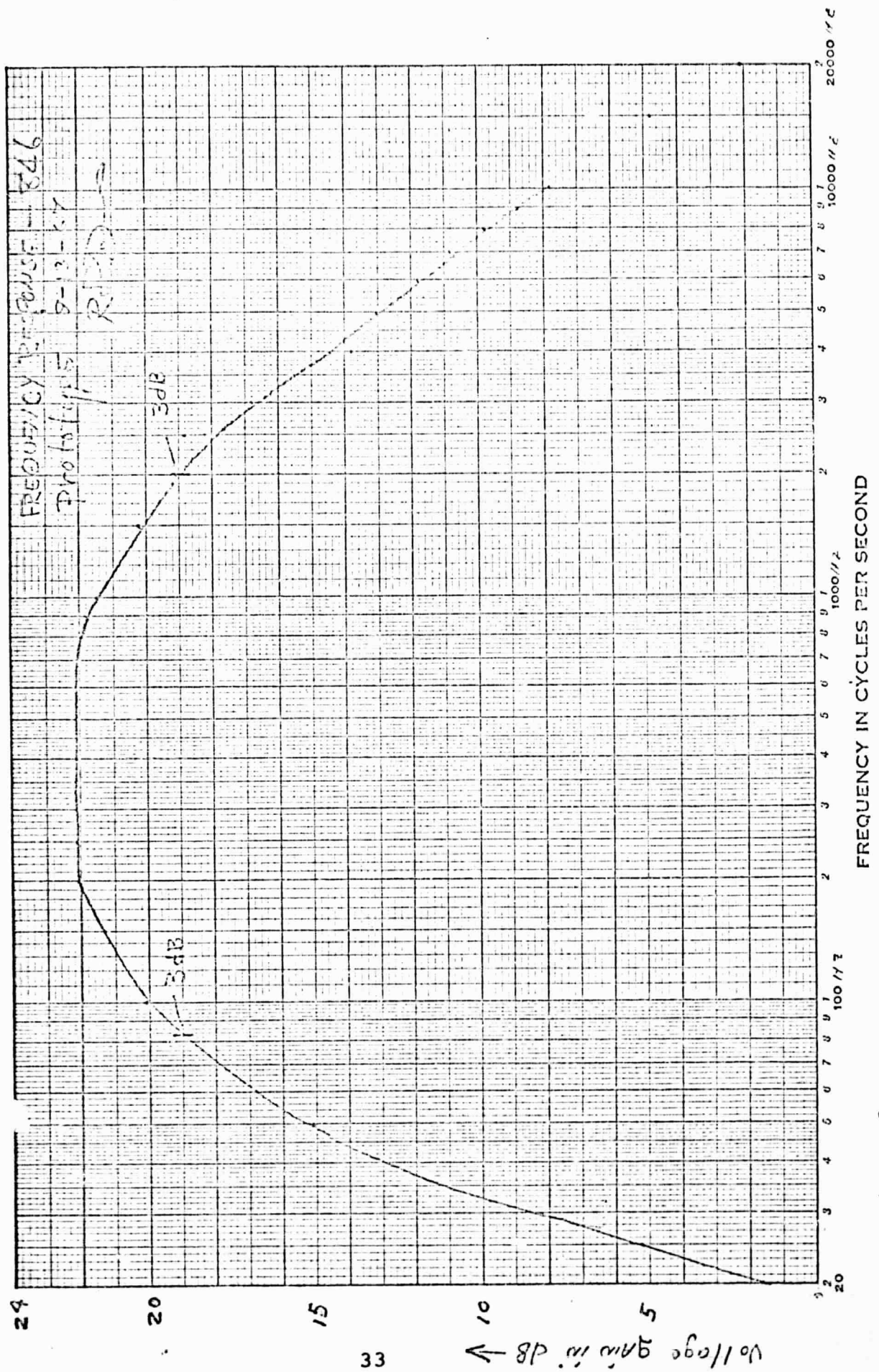


Figure 3.

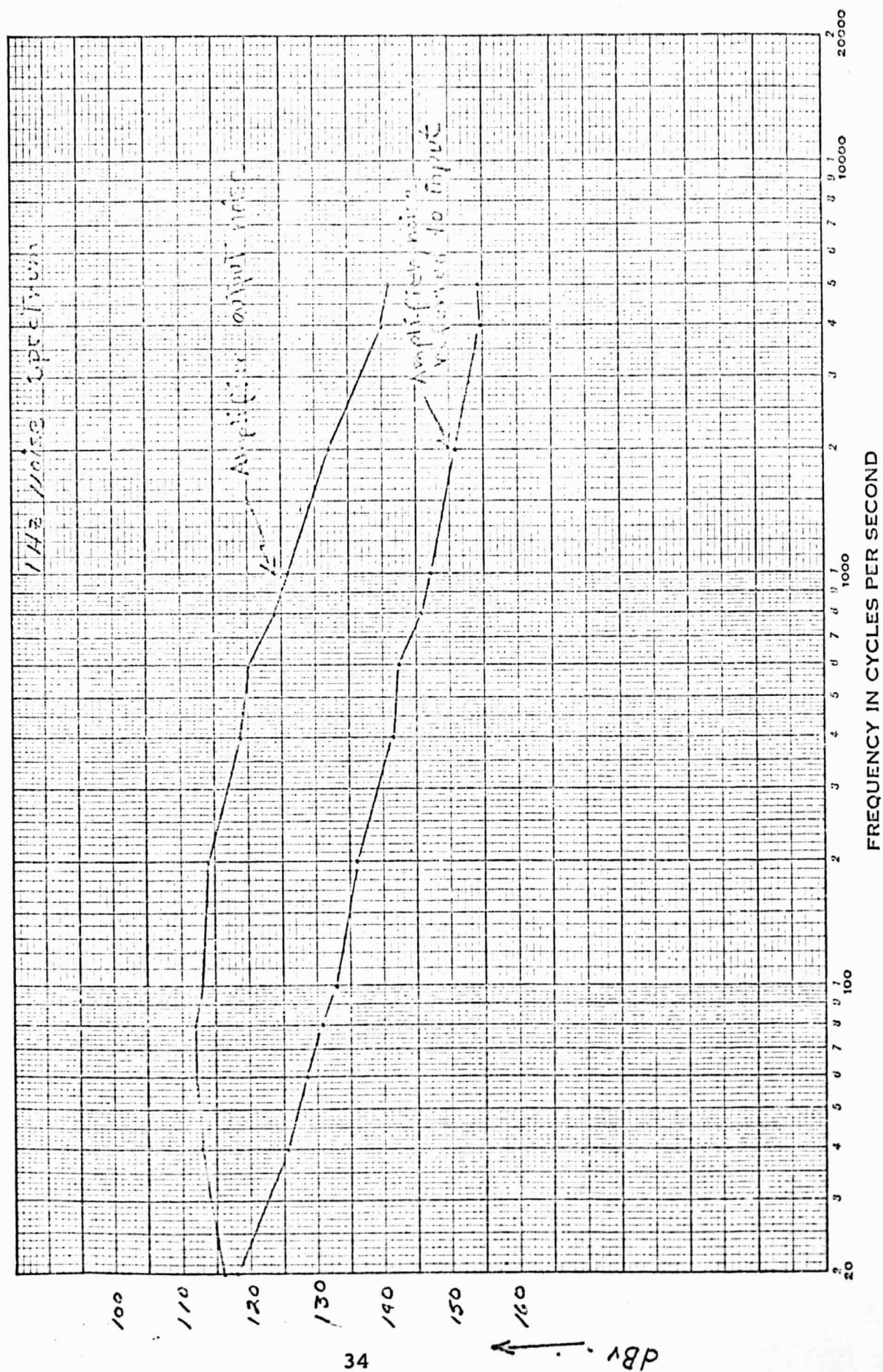


Figure 4.

PART 4

DISCUSSION AND CONCLUSIONS

The nominal calculated response (Figure 2) is in close agreement with the empirical response (Figure 3) except for amplitude scaling. This is due, as can be seen upon inspection of the circuit equations, to the value of the FET's g_m . The apparent wide range in worse case gain of Figure 2 is therefore misleading, since the primary source of g_m variations are initial device tolerances.

Typical g_m changes over the temperature range have been measured at less than 10%. Additionally, R_{11} is selected to set the initial system gain.

The low end frequency response of all calculated cases is sufficient for a sensor resonant frequency as low as 200 Hz. The high end frequency response variation is such that no noise or gain problems should be experienced during system operation.

The dynamic range margin is 20 dB with the output signal range approximately centered between the amplifier's dynamic limits.

The results of the analysis show that the EBP amplifier will be capable, under worse case conditions, of meeting the required system performance demands.

APPENDIX C

APPENDIX C

I. INTRODUCTION

A quality control program conforming to the requirements of NASA Quality Publication NPC 200-3 was instituted to guarantee performance of the EBP sensors.

The project flow diagram shown in Drawing B-10940 gives the inspection stations from receipt of vendor fabricated parts through assembly to the final end item tests. The entire quality program was performed in accordance with LTVR/WD Quality Control. Manual 63-000 December 1963.

Six quality control bulletins were issued and are shown in their respective positions in Drawing B-10940. These bulletins are listed below in chronological order together with changes that were made.

Quality Control Bulletins Prepared for Project 08460

1. QC846-1 December 1967

Establishes QC parameters and procedures for EBP spring and weldment assembly.

a. Revision A December 1967

Para 5.1 Inserts traceability to NBS.

b. Revision B July 1968

1. Para. 3.1.1 - Changes resonant frequency of spring-impact plate assembly from "250 Hz" to "200 to 250 Hz."

2. Para 6.2.2 - Changes frequency upper limit from "370 to 380 Hz" to "300 to 310 Hz."

2. QC 846-2 December 1967
Establishes QC procedures for electronic components
 - a. Revision A - December 1967
Para. 2.1 - Inserts traceability to NBS.
3. QC 846-3 December 1967
Establishes receiving procedures.
4. QC 846-4 January 1968
Establishes environmental test procedures.
 - a. Revision A - July 1968
 1. Para. 1.0 - Changes "Each EBP to be tested" to "One EBP to be tested."
 2. Para. 3.2.1 to 3.2.13 - Changes rate of change in temperatures to maximum rate possible.
 - b. Revision (Letter to T. F. Krenek) 18 June 1968
 1. Page 2 - Changes time at each temperature extreme.
 2. Para. 7.10, 7.17, 7.20 - Changes procedures to conform to Page 2.
5. QC 846-5 January 1968
Establishes calibration procedures.
 - a. Revision A- July 1968
Para. 3.2 - Delectes measurements at various temperatures.
6. QC 846-6 February 1968
Establishes end item test plan.
Note: Revision to QC 846-6 contained in letter to T. F. Krenek 18 June 1968 was in error. No revision is necessary.

In addition to these bulletins, a number of Inspection Procedure Checklists were prepared for the other inspection stations. Process control documents were also issued. These are also keyed in Drawing B-10940.

II. QUALITY CONTROL PROGRAM

Examples of the inspection procedure checklists used in the quality control program are given below.

The inspection procedure numbers are keyed to the project flow diagram Drawing -10940.

The final tests have been specified by LTVR documents QC 846-1, -4, -5, -6. Results of these tests have been recorded in appropriate laboratory notebooks and are available for inspection.

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PAGE 1 OF 1

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WESTERN DIVISION
LING-TEMCO-VOUGHT, INC.
1859 S. MANCHESTER AVE. ANAHEIM, CALIF. 92803

INSPECTION
PROCEDURE
CHECKLIST

PART NO. C-10947	PART NAME Module Assembly		DATE	
TYPE OF MATERIAL	QUANTITY 4	P.O. OR MFG. ORDER NO.	PURCHASED PART ☒ LTVR FABR. PART ☐	
INSP. PROC. NO. QC 846-E3	CONTRACT NO.	VENDOR Epi-VosTron Industries		
DRAWING NO. C-10947	LOT NO.	SERIAL NO.	REC. INSP. ☒	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.0	Manufacturers Certification (per NASA NPC 271)					✓
2.0	Verify correct position and value of each part	20x Binocular Microscope				✓
3.0	0.937 $\pm$ 0.010 Inspect top and bottom disk 2 places each	Dial Caliper				✓
3.1	Visually inspect alignment of top and bottom disks					✓
3.2	0.312 $\pm$ 0.010 spacing of top and bottom discs. Inspect 4 places around circumference					✓
3.3	Total module thickness wire included <0.460					✓
3.4	0.12 min R11 lead wires					✓
3.5	0.312 hole top and bottom $\pm$ 0.010					✓
3.6	0.007 $\pm$ 0.002					✓

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INSPECTION
PROCEDURE
CHECKLIST

PART NO. C-10947	PART NAME EBP Electronics Module Assembly	DATE 24 May 1968	
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☒ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-E4	CONTRACT NO. NAS 9-7290	VENDOR	
DRAWING NO. C-10902	LOT NO.	SERIAL NO. 2	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.0	Resistance Point 6 to "B" ≥ 1 G ohm.	GR Megohmmeter 100V Bias			1GΩ	
1.1	Resistance - Point 6 - gnd. ≥ 10 G ohm.				≈200 GΩ	
1.2	Resistance - Point "B" to gnd. ≥ 10 G ohm.				≈50 GΩ	
2.0	<u>Ambient Temperature Test</u> 1. Apply + 350 ± 15 VDC between 6 and gnd. 2. Apply + 12 ± .10V between 5 and gnd. 3. Ground 2. 4. Connect 10k ± 5% resistor from 4 to gnd. 5. Attach 50 ± 2.5pf dummy sensor to B and gnd. 6. Measure power supply current. Must be <0.45 ma.	1. +350VDC power supply 2. +12VDC power supply 3. Voltmeter HP 412A 4. Ammeter 5. 10k 5% resistor 6. 50pf dummy sensor with series driving capability			0.415 ma .39 ma .42 ma	RM -65 +250
PREPARED BY:		DATE	INSPECTOR <i>[Signature]</i>	COMPL. DATE		

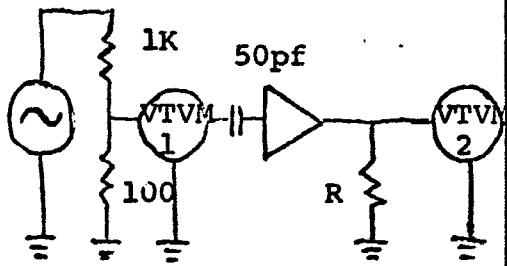
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**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE	
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☒ LTVR FABR. PART ☐	
INSP. PROC. NO. QC 846-E4	CONTRACT NO. NAS 9-7290	VENDOR		
DRAWING NO. C-10902	LOT NO.	SERIAL NO. 2	REC. INSP. ☐	IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
3.0	1. Apply 24.5 mV r.m.s. 400Hz sine wave to dummy sensor through divider network as shown below. This level = 0dB on VTVM #1	1. See 2.0 2. Hewlett Packard Audio Signal Generator Model 200CD 3. 2-HP AC-VTVM Model 4000 4. 1K resistor 5. 100 ohm resistor				
3.1	Record power supply input current.				0.415 <u>ma</u> 0.390 <u>ma</u>	RM -65
3.2	Record VTVM #2 level in dB relative to VTVM #1 Gain - 21 ± 2 dB				20.8 DB (3300) (260 <u>mv</u>) 21.0 DB 20.2 DB	RM -65 +250
						

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WESTERN DIVISION
LING-TENG CO. VOUCHER, INC.
1859 S. MANCHESTER AVE., ANAHEIM, CALIF. 92603

INSPECTION PROCEDURE CHECKLIST

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☒ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-E4	CONTRACT NO. NAS 9-7290	VENDOR	
DRAWING NO. C-10902	LOT NO.	SERIAL NO. 2	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
4.0	Remove resistor R (10k)	1. See step 3.0				
4.1	Record VTVM#2 level - V ₁				270 <u>mv</u>	RM
4.2	Connect 9.5k <u>±</u> 1% resistor in place of R					
4.3	Record new level of VTVM#2 -V ₂				255 <u>mv</u>	RM
4.4	$Z_o = \left(\frac{V_1 - V_2}{V_2} \right) 9500 \text{ ohms}$ Where Z_o = output z V₁ = no load resistor reading V₂ = 9.5k load resistor reading Z_o must be <8 k ohms.				<u>≈560Ω</u> 791Ω 400Ω	RM -65 +250
5.0	Reconnect 10k resistor					
5.1	Check generator level (OdB - .0245V)				24.5 <u>mv</u>	input
5.2	Record VTVM #2 level.				255 <u>mv</u>	out
5.3	Decrease generator frequency until VTVM #2 shows a -3dB change from 5.2				85 <u>Hz</u>	RM
	Note: VTVM #1 level must be held constant					
5.4	Record generator frequency				72 <u>Hz</u> 77 <u>Hz</u>	-65 +250
	Must be 80 <u>±</u> 15Hz					
6.0	Repeat section 5 increasing the generator frequency					
	- 3dB point must be 1800 <u>±</u> 250Hz				1900 <u>Hz</u> 2500 <u>Hz</u> 1500 <u>Hz</u>	RM -65 +250
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INSPECTION
PROCEDURE
CHECKLIST

PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.	PURCHASED PART ☒ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-E4	CONTRACT NO. NAS 9-7290	VENDOR	
DRAWING NO. C-10902	LOT NO.	SERIAL NO. 2	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book.

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
7.0	Connect oscilloscope to point 4	Oscilloscope				
7.1	Set generator to 250 Hz					
7.2	Increase generator level until negative portion of output waveform observed on scope begins to distort or clip					
7.3	Record VFVM #2 level (Eng. Info. Only)				≈ 1.05 RMS ≈ 1.05 - 65 ≈ 1.05 +250	

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INSPECTION
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PART NO. C-10947	PART NAME EBP Electronics Module Assembly		DATE	
TYPE OF MATERIAL	QUANTITY	P.O. OR MFG. ORDER NO.		PURCHASED PART LTVR FABR. PART ☒
INSP. PROC. NO. OC 846-E4	CONTRACT NO. NAS 9-7290	VENDOR		
DRAWING NO. C-10902	LOT NO.	SERIAL NO. 2	REC. INSP. ☐	IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

Proper shielding to minimize 60Hz pickup will be used throughout. Record all data in laboratory note book.

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
8.0	Short input					
8.1	Record VTVM #2 level. Must be $<100\mu\text{V}$ R.M.S. (broadband noise)				$< 65 \mu\text{V}$	
9.0	Connect pulse generator to point 2.	1. General Radio Pulse Generator Model 1217C				
9.1	Connect oscilloscope to point 2.	2. Tektronix Oscilloscope Plug In Type W				
9.2	Apply $10 \pm 1\mu$ sec wide, 0 to $+10 \pm 1\text{V}$ square pulse. Measure pulse amplitude.	$2\mu\text{sec/cm}$ 20mV/cm Attenuator $\times 100$			$+10.0$	
9.3	Connect oscilloscope to point A.					
9.4	Negative going ($+11$ to 0V) pulse shall appear					
9.5	Measure rise and fall times. (Change sweep speed to 0.1μ sec/cm) Must be $<0.25\mu\text{sec}$ 10% to 90%				$5.0 \mu\text{s (rise)}$ $0.05\mu\text{s (fall)}$	
9.6	Measure and record amplitude. Must be $11.00 \pm .5\text{V}$ to $0.0 + 0.1\text{V}$ - 0.1				$.05\mu\text{s fill}$ RM $5.5\mu\text{s fuse}$ +250 $+11.0$ RM -65 $+10.3$ +250	

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INSPECTION
PROCEDURE
CHECKLIST

PART NO. C10946	PART NAME Electronics Assembly		DATE OCT. 2-1968
TYPE OF MATERIAL	QUANTITY 6	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☒
INSP. PROC. NO. QC 846-E5	CONTRACT NO.	VENDOR	
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Visually examine assembly for: a. conformal coating b. foam potting.					✓
2.	Inspect solder connection, black wire to cover.					✓

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INSPECTION PROCEDURE CHECKLIST

PART NO. B-10933	PART NAME Washer-Diaphragm Mounting		DATE FEB 6 1968	
TYPE OF MATERIAL 2024-OCertified Al	QUANTITY 16	P.O. OR MFG. ORDER NO.		PURCHASED PART ☒ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-11A	CONTRACT NO. NAS9-7290	VENDOR Advanced Precision Tooling		
DRAWING NO. B-10933	LOT NO.	SERIAL NO.	REC. INSP. ☒	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.0	Check material certification	Dial Caliper				✓
2.0	2.240 $\pm$ 0.010	Dial Caliper				✓
2.1	1.630 $\pm$ 0.010	Dial Caliper				✓
3.0	0.010 $\pm$ 0.001	Micrometer				✓
4.0	6 holes to fit welding fixture	Welding Fixture				✓
5.0	Visually inspect 1.630 100% for burrs on two sides.	20x Binocular Microscope				✓

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**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. B10895	PART NAME Ring, Dia. Mtg.		DATE JUN 10 1966	
TYPE OF MATERIAL	QUANTITY 5	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐	
INSP. PROC. NO. QC 846-IIB	CONTRACT NO.	VENDOR		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect edges and threads for nicks or burrs.					
2.	Measure 1.740 $\begin{smallmatrix} +.000 \\ -.001 \end{smallmatrix}$ Dia. Dem. (Measure mounted on C10921 housing)					
3.	Check 1.630-48 thread using C10921 housing					
4.	Measure .015 Dia. hole. Go - No - Go Go - #78 Drill blank No Go - #76 Drill blank					
5.	Check .016 $\begin{smallmatrix} +.002 \\ -.000 \end{smallmatrix}$ R grooves using SK505 wrench.					
6.	Measure .080 $\pm$.005 dem.					

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**INSPECTION
PROCEDURE
CHECKLIST**

PART NO. C-10917	PART NAME Impact Plate		DATE 7/1/64-66
MATERIAL 2024-T4	QUANTITY 6	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐
INSP. PROC. NO. OC 846-I3	CONTRACT NO. NAS9-7290	VENDOR Advanced Precision Tooling	
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☒ IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.0	Material Certification					
2.0	1.945 $\pm$.005	1- 2 inch			1.944-1.946	
2.1	1.945 $\pm$.005	Micrometer				
3.0	0.46 $\pm$.002	Micrometer			.039-.043	
3.1	.125 x .030 deep to fit fixture	Welding fixture				
4.0	.036 + .000 - .006	Dial Indicator & Height Gauge			.035 - .035 5	
4.1	.026 $\pm$.0003	Dial Indicator & Height Gauge				
4.2	+ .007 TIR Parallelism Indicate .010 radius. Adjust levelling screws to make plane of radius parallel to surface plate Indicate circular rib Record typical variations around axis of plate	Surface Plate Dial Indicator Levelling Fixture			.001-.002 Max TIR	
5.0	.0203 +.0000 -.0008 3 point method	Measuring Microscope				
5.1	45° x .060 $\pm$.005	Measuring Microscope			.060 - .062	

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**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. B10943	PART NAME Diaphragm Assembly		DATE 7-10-68	
TYPE OF MATERIAL	QUANTITY 3	P.O. OR MFG. ORDER NO. 9394	PURCHASED PART ☒ LTVR FABR. PART ☐	
INSP. PROC. NO. QC 846-I4	CONTRACT NO. NAS9-7290	VENDOR K + D ELECTRON BEAM WELDING CO		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.0	Inspect for pinholes in diaphragm between weld and area to be punched out. Use substage illumination. Any pinholes are cause for rejection.	Measuring Microscope				X
2.0	Inspect weld 100% for burn-through and lack of weld. Any areas of burn-through and lack of weld are cause for rejection.					X
3.0	Any nonuniform areas appearing in the weld zone are to be noted.					X
4.0	Inspect for ripples in diaphragm. Note.					X
	<u>Procedure QC 846-I4A</u>					
1.0	Edge of trimmed washer and diaphragm to be within 1/64-inch of diaphragm mounting ring. Trimming tool should not have touched mounting ring.	20X Microscope				X
2.0	0.015 pin in place.	Visual				X
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INSPECTION PROCEDURE CHECKLIST

PART NO. C10944	PART NAME Impact Plate Assembly		DATE JUL 17 - 68
TYPE OF MATERIAL	QUANTITY 3	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-I6	CONTRACT NO.	VENDOR	
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Verify bonding materials, expiration dates.					✓
2.	Visually check bonded area for voids, cracks or chips.					✓

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**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. B10943		PART NAME Impact Plate Heat Treated		DATE 3-14-68		
TYPE OF MATERIAL		QUANTITY 5	P.O. OR MFG. ORDER NO.		PURCHASED PART ☐ LTVR FABR. PART ☐	
INSP. PROC. NO. QC 846-I7		CONTRACT NO.		VENDOR California Doran		
DRAWING NO.		LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐	
SPECIAL INSTRUCTIONS						
OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect .010 radius for nicks or gouges.					✓
2.	Check $\pm$.007 TIR Parallelism using 3 point levelling fixture. Indicate .010 radius. Indicate circular rib. Record typical variations.					✓
PREPARED BY:		DATE	INSPECTOR <i>Bob Morrison</i>		COMPL. DATE	

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INSPECTION
PROCEDURE
CHECKLIST

PART NO. B10935	PART NAME Contact Ring		DATE MAR 4-68
TYPE OF MATERIAL	QUANTITY 5	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846 B1	CONTRACT NO.	VENDOR	
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect nickel plating.					✓
2.	Inspect edges for nicks or burrs.					✓
3.	Measure 1.040 $\pm .002$ Dem.					✓
4.	Measure 1.115 $\pm .002$ Dem.					✓
5.	Measure .010 $\begin{matrix} +.001 \\ -.000 \end{matrix}$ thickness.					✓

PREPARED BY:	DATE	INSPECTOR <i>Hi / [Signature]</i>	COMPL. DATE
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**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. B10934	PART NAME Backplate		DATE MAR 4 - 65
TYPE OF MATERIAL 2024 T4 AL	QUANTITY 5	P.O. OR MFG. ORDER NO.	PURCHASED PART ☒ LTVR FABR. PART ☐
INSP. PROC. NO. OC 846 B2	CONTRACT NO.	VENDOR Advanced Precision Tooling	
DRAWING NO. B10934	LOT NO.	SERIAL NO.	REC. INSP. ☒ IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect edges for nicks and burrs 125 finish.					✓
2.	Measure 1.115 $\pm .002$ Dia.					✓
3.	Measure .948 $\pm .002$ Dia.					✓
4.	Measure .021 $\pm .000$ -.001 thickness.					✓
5.	Measure .030 $\pm .000$ -.002 thickness.					✓
6.	Measure .112 $\pm .001$ Dia.					✓
7.	Measure .225 thickness.					✓
8.	Check 4-48 NF-2A thread using B10936 nut.					✓
9.	Check 0-80 NF-2B thread using Go - No Go gages.					✓
10.	Check .0001 TIR using three point leveling fixture.					✓
11.	Check .062 slot.					✓

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**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. C10921		PART NAME Housing		DATE MAY 4 68		
TYPE OF MATERIAL		QUANTITY 5	P.O. OR MFG. ORDER NO.		PURCHASED PART ☐	
INSP. PROC. NO. QC 846 B3A		CONTRACT NO.	VENDOR		LTVR FABR. PART ☐	
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐	FINAL INSP. ☐	
SPECIAL INSTRUCTIONS						
OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect edges and threads for nicks and burrs.					✓
2.	Inspect .015 radius for nicks, burrs or any roughness of finish.					✓
3.	Measure 1.580 $\begin{smallmatrix} +.004 \\ -.000 \end{smallmatrix}$ Dia.					✓
4.	Measure 1.530 $\begin{smallmatrix} + \\ -.002 \end{smallmatrix}$ Dia.					✓
5.	Measure 1.500 $\begin{smallmatrix} +.000 \\ -.002 \end{smallmatrix}$ Dia.					✓
6.	Measure 1.144 $\begin{smallmatrix} + \\ -.001 \end{smallmatrix}$ Dia.					✓
7.	Check 1.630-48 thread using B10895 ring.					✓
8.	Check 1.500-48 thread using C10921.					✓
9.	Measure .270 $\begin{smallmatrix} + \\ -.005 \end{smallmatrix}$ Dem.					✓
10.	Measure .130 $\begin{smallmatrix} + \\ -.005 \end{smallmatrix}$ Dem.					✓
11.	Measure .005 $\begin{smallmatrix} + \\ -.002 \end{smallmatrix}$ Dem.					✓
12.	Measure .140 Dia. hole in center.					✓
PREPARED BY:		DATE	INSPECTOR <i>Al. L. L...</i>		COMPL. DATE	



LTV RESEARCH CENTER
WESTERN DIVISION
 LING-TRACHT VUGHT INC.
 1859 S. MANCHESTER AVE., ANAHEIM, CALIF. 92803

**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. B10922	PART NAME Nut Case Mtg.		DATE JUNE 6, 1966	
TYPE OF MATERIAL	QUANTITY 5	P.O. OR MFG. ORDER NO.		PURCHASED PART LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-B4	CONTRACT NO.	VENDOR		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect edges for nicks or burrs.					✓
2.	Check 1.580-48 thread using C10921 housing.					✓
3.	Check .067 dia. holes (2 places) using SK 618 wrench.					✓
4.	Measure .050 thickness dem.					✓
5.	Measure 1.640 $\pm$.002 Dia. Dem.					✓

PREPARED BY:	DATE	INSPECTOR <i>W. J. ...</i>	COMPL. DATE
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PAGE _____ OF _____

LTV RESEARCH CENTER
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1859 S. MANCHESTER AVE., ANAHEIM, CALIF. 92803

INSPECTION
PROCEDURE
CHECKLIST

PART NO. B10952	PART NAME Screw		DATE MAR. 12 - 68	
TYPE OF MATERIAL	QUANTITY 5	P.O. OR MFG. ORDER NO.		PURCHASED PART ☐
INSP. PROC. NO. QC 846 B4	CONTRACT NO.	VENDOR		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect nickel plating					✓
2.	Inspect edges and threads for nicks and burrs.					✓
3.	Check 0-80 NF-2A thread.					✓
4.	Measure .100 dem.					✓
5.	Measure .055 $\pm$.005 head dem.					✓
6.	Measure .034 $\pm$.005 slot depth.					✓
7.	Measure .030 $\pm$.005 slot width.					✓
8.	Measure .105 $\pm$.005 head diameter.					✓

PREPARED BY:

DATE

INSPECTOR

COMPL. DATE

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

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INSPECTION
PROCEDURE
CHECKLIST

PART NO. B10936	PART NAME Nut, Backplate Mtg.		DATE MAR 12 - 68	
TYPE OF MATERIAL	QUANTITY 5	P.O. OR MFG. ORDER NO.		PURCHASED PART ☐
INSP. PROC. NO. QC 846 B4	CONTRACT NO.	VENDOR		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INCP ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect nickel plating.					✓
2.	Inspect edges and threads for nicks and burrs.					✓
3.	Check 4-48 NF thread using Backplate #B10934					✓
4.	Measure .065 $\pm$.005 thickness.					✓
5.	Measure .210 Dia. Dem.					✓

PREPARED BY:	DATE	INSPECTOR <i>[Signature]</i>	COMPL. DATE
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INSPECTION
PROCEDURE
CHECKLIST

PART NO. B10923	PART NAME Nut, Elec. Ass'y. Mtg.		DATE 10-2-5-65	
TYPE OF MATERIAL	QUANTITY 5	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐	
INSP. PROC. NO. QC 846-B4	CONTRACT NO.	VENDOR		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect edges and threads for nicks or burrs.					✓
2.	Check 1.500 - 48 - 3A thread using C10921 housing					✓
3.	Check .032 dia. holes using 10931 wrench (4 places)					✓
4.	Measure .050 thickness dem.					✓
5.	Measure 1.400 dia. dem.					✓

PREPARED BY:	DATE	INSPECTOR <i>W. H. H. H.</i>	COMPL. DATE
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INSPECTION PROCEDURE CHECKLIST

PART NO. B10941	PART NAME Washer		DATE 11/12/4-68	
TYPE OF MATERIAL	QUANTITY 5	P.O. OR MFG. ORDER NO.		PURCHASED PART ☐ LTVR FABR. PART ☐
INSP. PROC. NO. QC 846-B4	CONTRACT NO.	VENDOR		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☐ FINAL INSP. ☐	

SPECIAL INSTRUCTIONS						
OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect edges for nicks or burrs.					✓
2.	Measure 1.141 $\pm .002$ Dia. Dem.					✓
3.	Measure .113 $\begin{smallmatrix} +.002 \\ -.000 \end{smallmatrix}$ Dia. Dem.					
PREPARED BY:		DATE	INSPECTOR <i>[Signature]</i>		COMPL. DATE	

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INSPECTION
PROCEDURE
CHECKLIST

PART NO. B10951	PART NAME Lug - Contact		DATE MAY 6 1966	
TYPE OF MATERIAL	QUANTITY 10	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐	
INSP. PROC. NO. QC 846-B4	CONTRACT NO.	VENDOR		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect nickel plating.					✓
2.	Inspect edges for nicks or burrs.					✓
3.	Measure .250 $\pm$.010 length dem.					✓
4.	Measure .067 $\pm$.004 - .000 hole diameter.					✓
5.	Measure .031 hole Dia.					✓
6.	Measure .100 $\pm$.010 width dem.					✓
7.	Check hole placement .050 and .040 dems.					✓
8.	Measure chambers. .030 45° Typ.					✓
9.	Measure material thickness .003					✓

PREPARED BY:	DATE	INSPECTOR <i>[Signature]</i>	COMPL. DATE
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INSPECTION
PROCEDURE
CHECKLIST

PART NO. B10937	PART NAME Backplate Assembly		DATE 11/15/76	
TYPE OF MATERIAL	QUANTITY 3	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☐	
INSP. PROC. NO. OC 846-B5	CONTRACT NO.	VENDOR		
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐	IN-PROCESS INSP. ☐ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	Inspect laminated area for nick, cuts or air bubbles.					
PREPARED BY: _____ DATE _____ INSPECTOR <i>Don Hinson</i> COMPL. DATE _____						

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**INSPECTION
 PROCEDURE
 CHECKLIST**

PART NO. C10945	PART NAME Back Plate to Housing Assembly		DATE 8-27-67
TYPE OF MATERIAL	QUANTITY 3	P.O. OR MFG. ORDER NO.	PURCHASED PART ☐ LTVR FABR. PART ☒
INSP. PROC. NO. QC 846-B7	CONTRACT NO.	VENDOR	
DRAWING NO.	LOT NO.	SERIAL NO.	REC. INSP. ☐ IN-PROCESS INSP. ☒ FINAL INSP. ☐

SPECIAL INSTRUCTIONS

OPER. NO.	CHARACTERISTIC AND/OR PROCEDURE	EQUIP. AND SCALE MULTIPLYING FACTORS	AQL	NO. OF REJECTS	ACTUAL VALUES OBTAINED	✓
1.	During assembly procedure QC 846-P6 verify dial indicator measurements QC 846-P6, Para. 5 and Para. 7. Record shim thickness and distance measurement.					✓
2.	Visually check assembly using D10945 for reference.					✓
PREPARED BY:		DATE	INSPECTOR <i>Bill Linn</i>		COMPL. DATE	

MATERIAL INSPECTION AND RECEIVING REPORT		1. PROC. INSTRUMENT IDENT. (CONTRACT) NAS 9-7290		6. INVOICE NO. NO.		7. PAGE 1 OF 1	
				DATE		8. ACCEPTANCE POINT D	
2. SHIPMENT NO. LTV0001Z		3. DATE SHIPPED 68Oct16		4. B/L Q		5. DISCOUNT TERMS	
9. PRIME CONTRACTOR CODE Ling-Temco-Vought Research Center Western Division 1859 South Manchester Anaheim, California 92803				10. ADMINISTERED BY CODE NASA Manned Spacecraft Center General Research Procurement Branch Houston, Texas 77058			
11. SHIPPED FROM (If other than 9) CODE FOD: D				12. PAYMENT WILL BE MADE BY CODE NASA Manned Spacecraft Center General Research Procurement Branch Houston, Texas 77058			
13. SHIPPED TO CODE Transportation Officer Building 420 NASA Manned Spacecraft Center Houston, Texas 77058				14. MARKED FOR CODE Mr. Paige B. Burbank Technical Monitor, Code TG Contract NAS 9-7290 Item No. 1			
15. ITEM NO.	16. STOCK PART NO. (Indicate number of shipping containers - type of container - container number.)	17. DESCRIPTION	18. QUANTITY SHIP/REC'D	19. UNIT	20. UNIT PRICE	21. AMOUNT	
1		Flight Prototype Sensor EBP 52 S/N 1 & 2	2	ea.			
2		EBP Interface Requirement Document	1	ea.			
3		EBP Drawings (Items 2 & 3 are included in the final report)	1	set			
		Final Report and Data Package	2	ea.			
		Mounting Nut Wrench	1	ea.			
22. PROCUREMENT QUALITY ASSURANCE ☒ PQA ☐ ACCEPTANCE of listed items has been made by me or under my supervision and they conform to contract, except as noted herein or on supporting documents. DATE _____ SIGNATURE OF AUTH GOVT REP A.E. Moore S0513A TYPED NAME AND OFFICE _____ ☐ PQA ☐ ACCEPTANCE of listed items has been made by me or under my supervision and they conform to contract, except as noted herein or on supporting documents. DATE _____ SIGNATURE OF AUTH GOVT REP _____ TYPED NAME AND TITLE _____ 23. RECEIVER'S USE Quantities shown in column 17 were received in apparent good condition except as noted. DATE _____ SIGNATURE OF AUTH GOVT REP _____ TYPED NAME AND OFFICE _____ * If quantity received by the Government is the same as quantity shipped, indicate by () mark, if d.f. () mark, enter actual quantity received below quantity shipped and encircle.							
23. CONTRACTOR USE ONLY							

CERTIFICATE OF PERFORMANCE

This certifies that the Electrostatic Ballistic Pendulums (EBP-52 S/N 1 & 2) delivered to the National Aeronautics and Space Administration under Contract Number NAS 9-7290 have been made in conformance with contractual requirements and have passed the required Quality Control Tests.

Copies of these tests will be maintained on file at LTV Research Center, Western Division and are available for inspection at any time.



John K. Hilliard
Director

END ITEM TEST REPORT

EBP-52 Serial No. 2

Contract NAS 9-7290

In accordance with LTV Research Center Quality Control Bulletin QC 846-6-End Item Test Plan bead dropping and excitation with the self-calibration circuitry were performed on EBP-52 Serial Number 2. A slight deviation from the end item plan was made for convenience. The bead dropping and excitation with the self-calibration circuitry were performed at different times and in different vacuum systems. This deviation should in no way alter the meaning or results of the end item test.

The results of the bead dropping are shown in Figures 1 - 3 which are oscilloscope photographs showing the initial impact of the first bounce of the bead. The drop height was 1.03 cm. Figure 4 is one of the three identical oscilloscope photographs of the response of sensor #1 to the self-calibration circuitry excitation.

These tests were performed 11 October 1968.

Kenneth Erikson

Kenneth Erikson
Quality Principal Investigator

A. E. Moore S0513A
Government Representative

DATA PACKAGE

EBP-52 Serial No. 1

The following items are included in this data package:

1. Waivers (none required)
2. Deviations (none required)
3. Operating Instructions
4. Calibration Instructions
5. Drawings and Specifications
6. Special Handling Instructions
7. End Item Test Report
8. DD Form 250 (MIRR)

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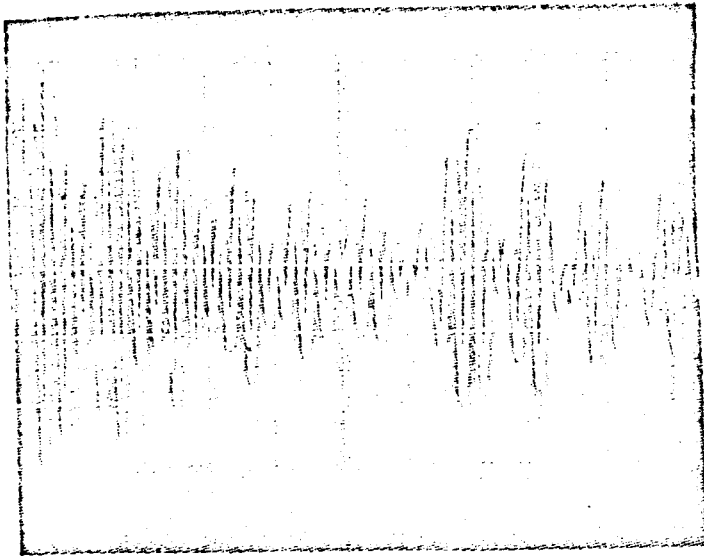


Fig. 1

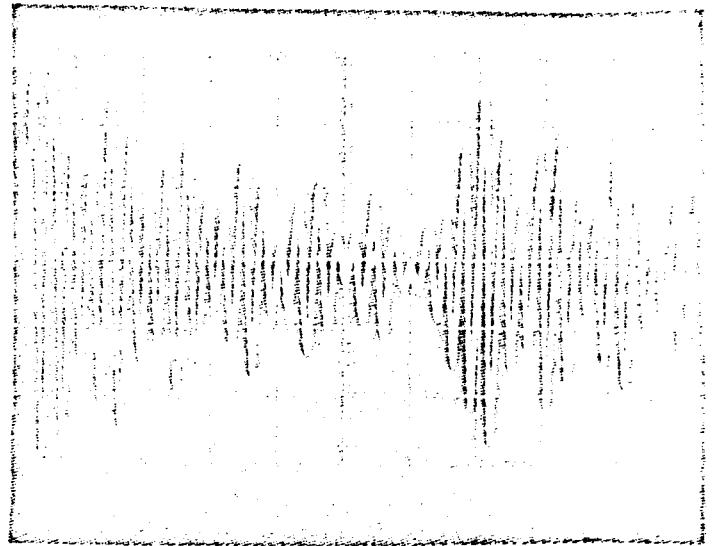


Fig. 2

Bead dropping - 0.1 v/cm - Vertical
10 ms/cm - Horizontal

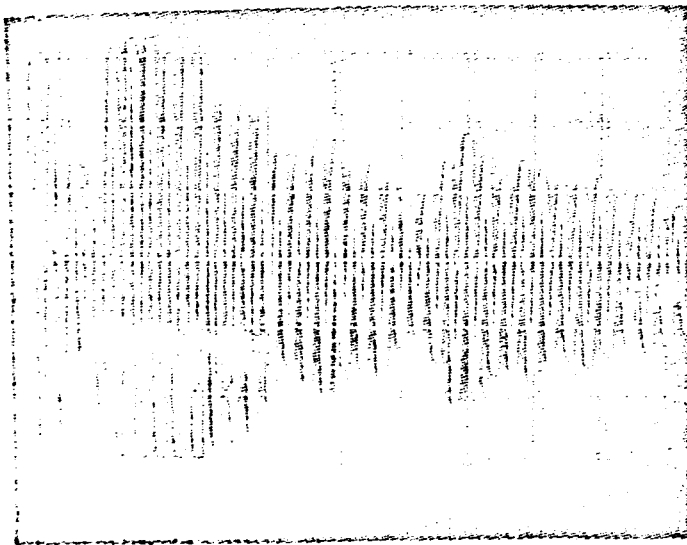


Fig. 3

Same as Figures 1 and 2.

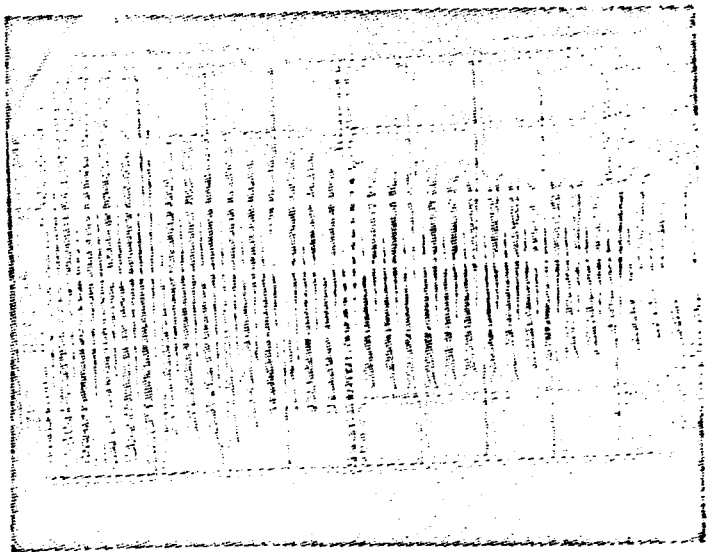


Fig. 4

Excitation by self-calibration
circuitry.

0.02 v/cm - Vertical
10 ms/cm - Horizontal
1 msec 10v Input pulse
20 msec delay

CALIBRATION DATA

EBP-52 Serial No. 1

The sensitivity is calculated from:

$$\text{momentum} = m \sqrt{2gh} + \frac{1}{2} mgt$$

where $m = 1.31 \times 10^{-4}$ gm, $h = 1.03$ cm, $g = 980$ cm/sec²

and t is taken from the photographs

Therefore

$$\text{momentum} = 5.9 \times 10^{-3} + 64.2 \times 10^{-3} \times t$$

From Figure 1: $t = 61$ msec; momentum = 9.82×10^{-3} dyne-sec

Output Voltage = .265 v Sensitivity = 27 v/dyne-sec

From Figure 2: $t = 63$ msec; momentum = 9.95×10^{-3} dyne-sec

Output Voltage = .28 v Sensitivity = 28.1 v/dyne-sec

From Figure 3: $t = 64$ msec; momentum = 10×10^{-3} dyne-sec

Output Voltage = .27 v Sensitivity = 27 v/dyne-sec

Sensitivity = 27.4 volts/dyne-sec (average value)

From Figure 4: internal calibrator output = 76 mv

Equivalent momentum of remote calibrator = 2.77×10^{-3} dyne-sec.