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National Aeronautics and Space Administration

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Manned Spacecraft Center

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DEVELOPMENT OF A DIRECT-CIRCUIT AMPLIFIER FOR SPACECRAFT INSTRUMENTATION SYSTEMS

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PART 1 - INTRODUCTION

The purpose of this document is to present a discussion on the development of the Direct-Current Amplifier and Transducer Power Supply, Engineered Magnetics Model EM2000D4, and to describe the unit and its operation. Using readily available components, this amplifier combines small size, light weight, and low power consumption with excellent stability, linearity, and low noise under extreme environmental conditions. This unit is presently being used in the Apollo-lunar module spacecraft instrumentation systems.

1. DESCRIPTION

The chopper-type amplifier and transducer power supply (10 VDC, 60 MA) is a conventional-component of welded-module construction contained in a 6.5-cubic-inch case. It was developed under NASA supervision by Gulton Industries, Engineered Magnetics Division, under NASA contract number NAS 9-2524. The unit has been evaluated by the Instrumentation and Electronic Systems Division of the Manned Spacecraft Center and has met all of the performance specifications listed in Table 1 and the environmental specifications contained in Appendix A (based on Environmental Specification IESD 19-1B developed by MSC). Terminal board connections are contained in Appendix B.

2. GENERAL

It is necessary to make many measurements of system functions and physical conditions such as temperature, strain, pressure, and acceleration in order to evaluate the performance of a spacecraft under actual flight conditions. These data must be transmitted to ground stations for evaluation. The telemetry systems generally used to accomplish this transmission require that all measurement signals be processed so that zero signal is represented by zero-volts and full-scale signal is represented by 5-volts. The majority of measurements are made in terms of DC voltages (in the millivolt region) or by slowly varying signals from DC to 1 KC. These signals can be conditioned from 0 to 5 V by means of a DC amplifier.

The Development Flight Instrumentation Systems for the LM program was allotted a minimum of weight, power and volume when compared to the numbers and characteristics of the measurements required to be transmitted.

Many components used on previous programs did not meet the requirements of the LM program because of their size, weight, power and environmental limitations. The DC amplifier fell into this category thus making it necessary to completely redesign this component.

TABLE 1. PERFORMANCE SPECIFICATIONS

Function	Value
Input supply voltage	28 V dc nominal (24 to 32 V dc)
Input supply ripple	4V p-p maximum (dc to 2 kc square wave)
Input supply transient	±15 V, 20 msec base width, 8 msec rise time
Feedback to input supply	30 mV p-p maximum with source impedance 1 ohm
Input supply polarity reversal	Unit internally protected
Input supply undervoltage	To 22 V dc with 10 percent maximum degraded unit performance
Input impedance	50,000 ohms or greater, dc to 1000 cps
Output signal	0 to +5 V with output bias set at either 0 or 2.5 V
Output bias	0 or 2.5 V, ±5 mV (selected by jumper). Stable with ±37 mV
Output impedance	1000 ohms or less, dc to 1000 cps
Voltage gain	Adjustable from 10 to 1000
Frequency response	Gain within ±1 percent of the dc value from dc to 1000 cps
Output signal ripple	25 mV p-p, dc to 15 Mc
Warmup time	15 minutes maximum
Linearity	±12.5 mV of a straight line between 0 and +5 volts for any gain setting

TABLE 1. PERFORMANCE SPECIFICATIONS (CONCLUDED)

Function	Value
Gain stability	0.75 percent
Power consumption	100 mA maximum
Transducer power supply: • Output voltage • Output voltage ripple • Output voltage regulation	 10 V dc ±50 mV, 10 to 60 mA loads 25 mV p-p, dc to 15 Mc ±10 mV for a change of ±4 V dc in the 28 V dc supply
Weight	10 ounces maximum
Volume	6.5 cubic inches
Common-mode rejection	100 dB or more for balance or unbalanced input lines (400 ohms maximum resistance) for voltages of +10 to -10 volts from 0 to 30 cps. 6 dB per octave decrease from 30 cps to 1 kc.

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PART 2 - DIRECT-CURRENT AMPLIFIER EVOLUTION

This part of the document describes four generations of DC amplifiers and their evolutionary progress toward smaller size and increased efficiency while maintaining an adequate degree of flexibility in application.

1. GENERAL

The functions of the DC amplifier under discussion are to provide:

(1) DC transducer excitation

(2) Space and circuitry f "dummy" bridge arms

(3) "Fine" bridge-balancing provision

(4) Stable DC amplification at selectable gains

(5) Bias to properly match the range of the transducer to that of a standard 0-to-5-VDC output

(6) Selectable frequency response

(7) "Calibrate" relays and circuitry for redundant check of channel operation.

Applications for these DC amplifiers include strain-gage bridges, thermistor bridges, thermocouples (with compensator power supplied by the amplifier), and voltage and current monitors.

The DC amplifiers designed by Engineered Magnetics are designated as Models EM2000D1, EM2000D2, EM20002A, and EM2000D4. The first of the group, EM2000D1, was a modified version of an amplifier produced originally for NASA at Huntsville, Alabama. The Huntsville amplifier was conceived as a general-purpose instrument capable of adaptation to almost any situation by virtue of a plug-in board which was field-replaceable and easily redesigned. In practice, the amplifier was supplied without the plug-in board. The user designed and manufactured these boards to suit individual requirements. This amplifier utilized welded-module construction and was solidly encapsulated in a thick aluminum casting. External features included four test jacks and two pushbutton switches to provide a local check on amplifier operation.

The EM2000D1 amplifier was identical to the amplifier originally designed for NASA at Huntsville except for the following two features:

(1) A 2.5-VDC bias voltage was provided to permit matching between a "plus or minus" input and a 0-to-5-VDC output range, and

(2) A modification to the output filter was designed for installation on the plug-in board to permit reduction of frequency response to values lower than the nominal 2.6 KC.

The next model, EM2000D2, was built to provide an increased-capacity (60 MA instead of 35 MA) transducer power supply of smaller physical size. This was made possible by the use of improved circuitry and the omission of the plug-in board. Provisions for "calibrate" and "dummy bridge" resistors, capacitors for reducing frequency response, and test points with pushbuttons were made on a terminal board which was accessible by removing a cover on one side of the case. All other features of the previous design were retained except for the wide versatility of the plug-in board. By using appropriate jumpers on the terminal board, bridge sources and voltage sources are accommodated. With the new circuitry, it was also feasible to raise the amplifier input impedance to a 50K-ohm minimum.

Packaging of the new unit was based on the concept of improving reliability and reducing costs by utilizing the case as the welding and wiring jig during all phases of construction and test A "Swiss cheese" casting of diallyl-phthalate served as the base for component mounting and also as the frame for the attachment of an external metal covering for ruggedness and shielding. After assembly, the voids were filled with a lightweight glass bead and silicone rubber encapsulating compound.

Model EM2000D2A was a modification of EM2000D2 with test points and pushbuttons deleted. The change permitted the use of the thermocouple compensation bridge with no additional external components other than the compensation bridge.

The last model, EM2000D4, is a smaller version of the EM2000D2. with tighter stability specifications, a more dense packaging concept, and improved circuitry. This unit is a return to the conventional module-type construction (welded) to attain higher packaging density. A terminal board for accessory resistors and capacitors is provided, and the finished unit is encapsulated for ruggedness and moisture protection. Circuit changes were made to improve the stability of the gain-potentiometer adjustment circuit, to incorporate a transistor demodulator, and to increase the power oscillator efficiency. A new and tighter chopper-transistor matching specification is also in use to more closely match transistors. These changes yielded a smaller assembly with greater flexibility in which both the amplifier gain and the zero instabilities were reduced by 25 percent resulting in a 25 percent reduction of power. With the use of module-type construction, it is feasible to test each type individually. Following testing and final adjustment, interconnecting wire is installed, and the operating assembly is placed in its metal case. When a unit has been fabricated and tested, the final encapsulation is injected through special openings in the case. In this way, it is possible to encapsulate a working unit without further risk of damage resulting from handling. The specifications for the four amplifiers are shown in Table 2.

2. DETAILED DESCRIPTION

The block diagram of the DC amplifier final design is shown in Figure 1. An important circuit of the amplifier is the low-level chopper which functions to convert the DC signal input to a proportional AC signal. In this way, the unavoidable instability of a direct-coupled amplifier does not contribute to the error of the composite amplification. In addition, the conversion to AC permits the use of transformer coupling at the input stage which greatly enhances common-mode capability. Instead of the limitation of direct-coupled amplifier instability, this arrangement is limited in zero stability by the performance of the chopper transistors which operate in the "inverted" mode. This mode of operation results in a reduction, by a large factor, of the "offset" instability which is unavoidably associated with switching transistors. An equivalent simplified circuit of the chopper is shown in Figure 2A.

Each of the four chopping transistors can be represented in its two quasi-steady states by the circuit shown in Figure 2B. In the "open" state, the ideal switch (S) is open, and the terminals are connected by means of a very high resistance (diode leakage) in series with a voltage (E). The Voltage (E) is dependent upon the back-bias conditions

TABLE 2. SPECIFICATIONS OF AMPLIFIERS

Constituents	EM2000D1	EM2000D2	EM2000D2A	EM2000D4
Volume, in^3	18.7	9.9	9.9	6.5
Weight, oz	20	12	12	6-1/2
Performance:				
• Gain stability, percent	1	1	1	.75
• Zero stability, percent of full scale	1	1	1	.75
• Transducer power supply capacity, mA	35	60	60	60
• Input impedance, kΩ	10	50	50	50
• Power consumption, mA	125	134	134	98
Test jacks, incorporated	Yes	Yes	No	No
Plug-in board, incorporated	Yes	No	No	No

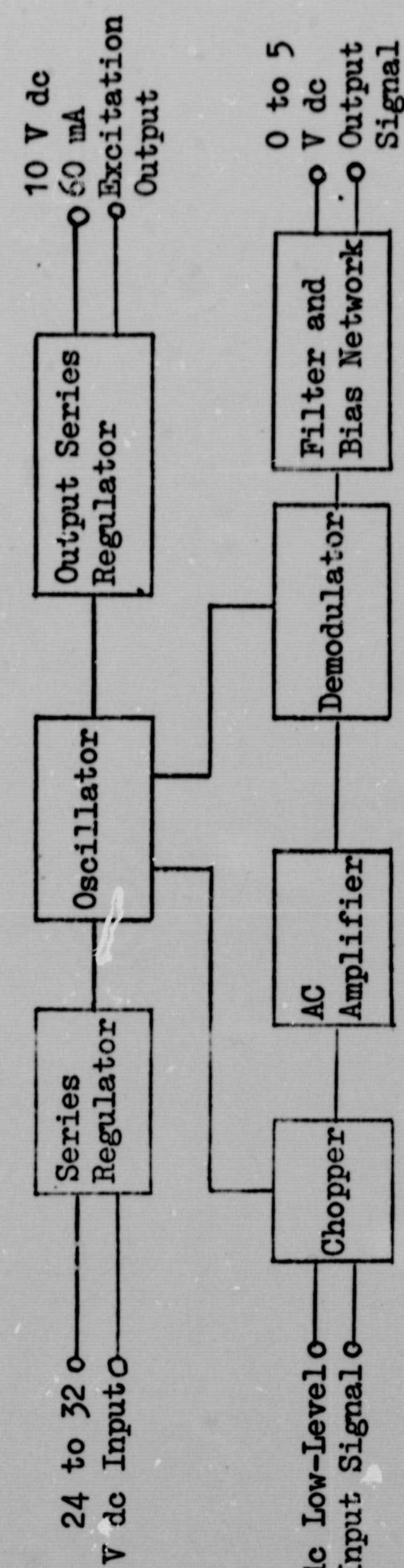
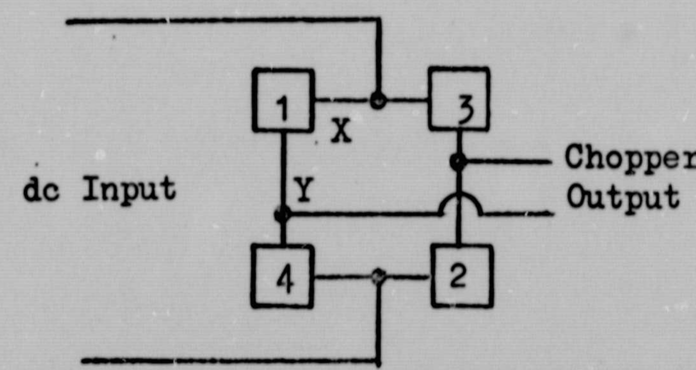


Figure 1. Block Diagram of the DC Amplifier



Blocks 1,2,3, and 4 are chopping transistors.

Figure 2A.

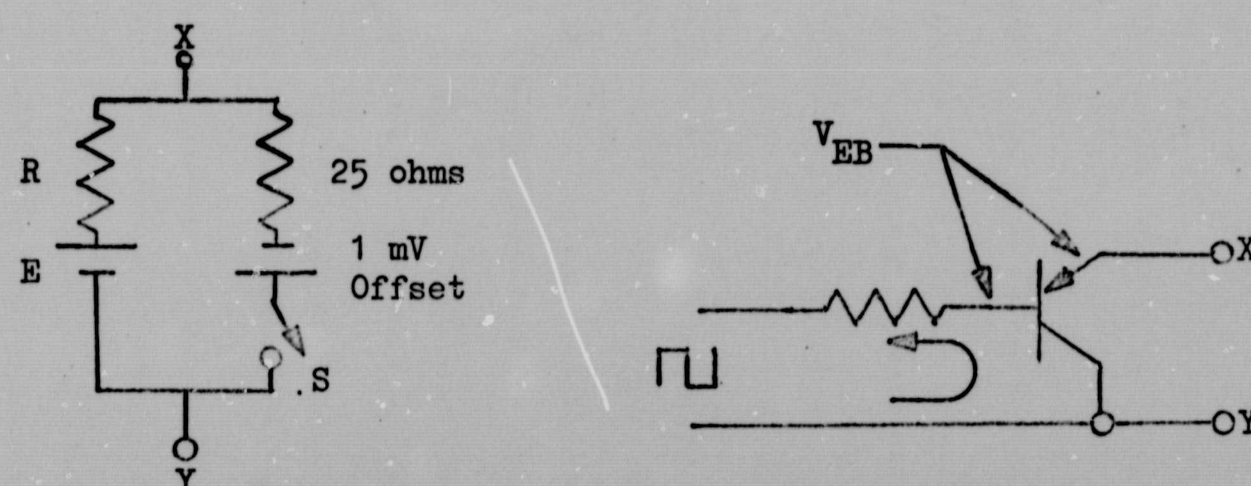


Figure 2B.

Figure 2. Simplified Circuit of the Chopper

of the base-emitter diode. The resultant of (E) and (R) in this design (by Engineered Magnetics) is a few nanoamperes (maximum) of current and causes negligible effect on performance. With the switch (S) closed, the switch is "on" and impresses its series voltage (shown as 1 MV) on whatever is across it. Presence of base current causes "on" conditions. For low voltages and currents, the switch is capable of bipolar switching. During the switching interval, presence of capacitances and the stored charge causes additional transient effects. In application, transistors 1 and 2 are paired, as are 3 and 4. These are connected so that offsets of each pair of transistors are opposing and only the difference is of consequence. The matching procedure is designed to optimize the chopper set in this regard. In order to realize input isolation, it is necessary to drive the chopper transistors from a transformer-isolated source.

The AC amplifier conditions the signal to the appropriate output level. Stable amplification is assured through the use of negative feedback so that any dependence on transistor parameters is virtually eliminated. Temperature stability of the AC amplifier is essentially determined by the temperature coefficient of the feedback resistance and the compensation circuitry. "Fine" gain adjustment is achieved by utilizing a potentiometer as one element of the feedback network; "coarse" gain adjustment is achieved by switching taps on the secondary of the input transformer. Compensation for gain instabilities resulting from temperature effects is achieved by the use of a temperature-sensitive wire-wound resistor in the feedback network. Compensation for zero instability is applied as AC at the input of the amplifier.

From the amplifier, the AC signal is transformer-coupled to the demodulator. At this point, another pair of transistors, performing similar switching as in the chopper, converts the signal to DC. This demodulation, also called "synchronous rectification," must be used to preserve linearity through zero. After demodulation, the output signal contains an appreciable AC component which must be filtered. A bias voltage is also available to match a "plus or minus" input to a 0-to-5-VDC output range. When the input signal is zero, the output signal is 2.5 volts. The bias voltage and demodulator drive are transformer-coupled from the power oscillator so that the output circuit is completely DC-isolated from all other circuits.

The bias and drive power for the chopper blocks previously mentioned are supplied from the 28-VDC supply through a series regulator and a power oscillator. The series regulator eliminates dependence on supply voltage by providing a stable drive voltage to the oscillator. The oscillator is of the resistance-capacitance (R-C) type with transformer output and provides a stable frequency with isolation through the use of secondary windings. Two oscillator transistors are utilized in the (noninverted) switching mode One of the oscillator secondary windings is used to provide isolated power for the DC excitation supply. The excitation supply is stabilized by means of an output series regulator incorporating a differential sensing amplifier.

3. AUXILIARY CIRCUITS

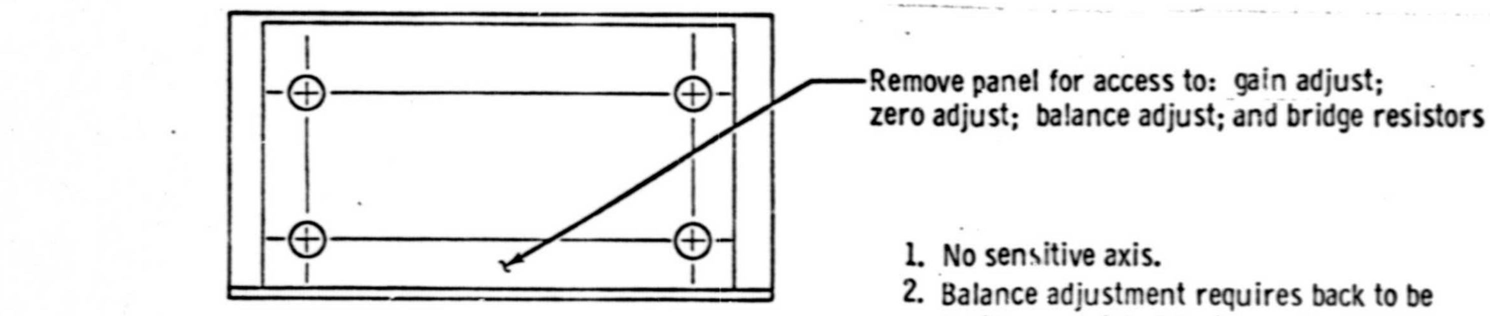
Certain auxiliary functions are provided by relays and by a field-accessible terminal board. In addition to the gain and zero controls, the terminal-board area provides space for three dummy bridge resistors, a bridge-balance network, calibration resistors, an input attenuator, and capacitors to reduce frequency response.

The calibrate-checking relays are actuated remotely and permit a check on amplifier operation even after installation and connection to the intended source. These circuits remove the connections from the measurand and substitute a known input signal that is developed by divider resistors which are powered from the 10 VDC excitation supply.

4. PACKAGING AND MECHANICAL CONSIDERATIONS

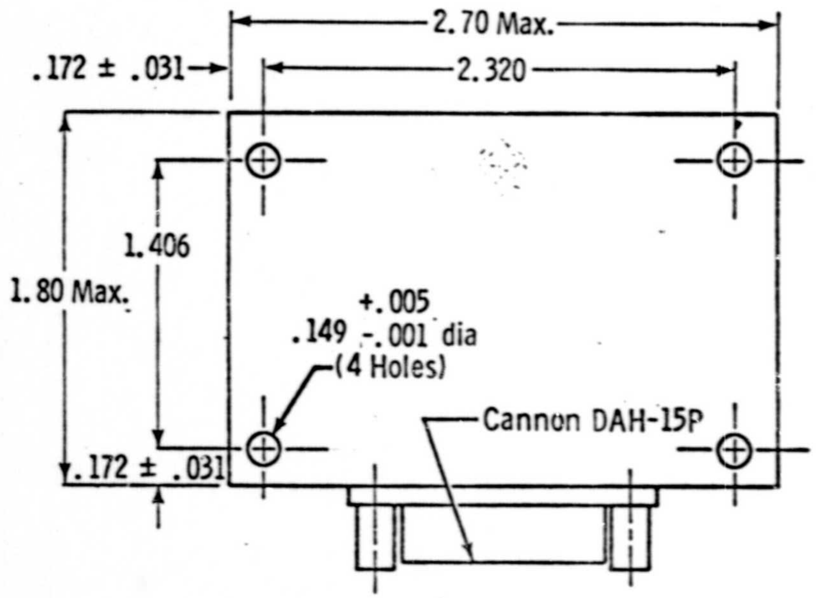
Internal wiring is primarily resistance-welded with certain interconnections of stranded copper wire. Solid encapsulation of the finished unit ensures preservation of desired subassembly configuration under severe environmental conditions. The glass bead and silicone rubber encapsulating material provides a number of desirable properties including light weight, moisture resistance, and excellent freedom from component-part stress during thermal-shock conditions.

Welded-module construction (see Figure 3) was chosen because of attainable component density, ease of manufacture, and convenience in testing. The requirement of high-density packaging played a major role in the selection of the materials which would provide adequate moisture sealing.



1. No sensitive axis.
2. Balance adjustment requires back to be easily accessible (strain ampl only).
3. Ground strap to be provided at time of installation.
4. Refer to dwg SC550072 for wiring and hookup configurations.
5. Surface flatness tir = .025 (top and bottom).
6. Finish - Flat black paint per engineered magnetics div. procedure EMP 77644.
7. Material - aluminum.
8. Power consumption -110 milliamperes at nominal 28 Vdc.
9. The back panel shall not extend more than 0.033 inches above the case surface when installed on the case.
10. Rubber stamp 1/8 high white characters use ink (epoxy base, non-conductive) Wornow ink, series M, as manufactured by Wornow Process Paint Co., Los Angeles, Calif., or equiv.

This dwg. taken from engineered magnetic div of Gulton Industries, Hawthorne, Calif. - Dwg. No. 48654C.



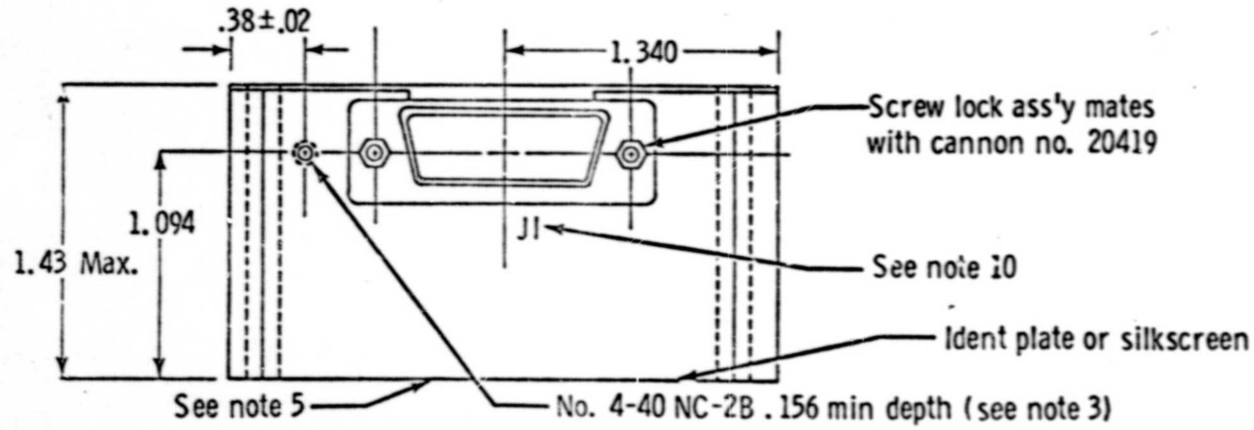


Figure 3. The Welded-Module Construction

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PART 3 - AMPLIFIER DESIGN

The design of the EM2000D4 follows the general pattern of the chopper amplifiers which have been produced for several years by Gulton Industries, Engineered Magnetics Division. The specification requiring improvement for this unit are as follows:

(1) Improved zero stability,

(2) Improved gain stability,

(3) Reduced power consumption,

(4) Reduced size and weight

1. PROBLEMS

Electromagnetic interference (EMI) problems are not appreciably more severe than usually encountered. The basic approach was to reduce noise generation to a feasible minimum and to filter the remaining noise.

Several design problems with this type of amplifier are affected by the selection of the chopping frequency. Factors favoring a high frequency are the size of the magnetic components, the available signal frequency response, and the ease of power and signal filtering. Factors favoring a low chopping frequency are the gain stability due to unavoidable fixed-time delays and the power consumption due to iron loss and losses associated with oscillator transistor switching. A chopping frequency of 10 KC, a good compromise considering all factors, results in an amplifier with inherent gain stability in the order of 1 to 1-1/2 percent. The zero stability is less dependent on the chopping frequency and more dependent on the chopper-transistor characteristics and matching.

A key element in the solution to the electrical design problem is the use of an improved (though somewhat more complex) power oscillator. The decrease in frequency instability made it possible to attain improved inherent gain stability and also to appreciably reduce the magnitude of the "uncompensatable" component of the gain dependence on temperature.

The uncompensatable component of gain drift is that portion which cannot be removed with the use of gain compensation and which is a straight-line function of temperature. The frequency of the improved oscillator is determined by an R-C circuit and is almost totally independent of its DC supply voltage. Thus, frequency instability due to production tolerance on the regulated input DC voltage is virtually eliminated as compared to the previously designed oscillator where frequency and voltage were proportional. The R-C stabilizing components are chosen for a desirable (small and linear) temperature dependence. Reduced switching losses are also inherent in the improved oscillator which is one of the most significant reasons for power reduction. Switching-time stability is improved resulting in a small but significant improvement in zero stability.

Toward the realization of lower power consumption, shunt current drain in the input series regulator was reduced. Also, current drain of the AC amplifier was somewhat reduced. An additional important reduction in current drain was realized in the demodulator. This improvement was made possible through the use of a transistor rather than a diode demodulator. The low value of current gain is due to the demodulator transistors being used in the "inverted" mode (as are the chopper transistors), causing the inverted mode gains appreciably in zero offset and stability. Whereas previous amplifiers had utilized specially matched diodes to attain a 5-MV match, unmatched transistors now provide a 2-MV match. The penalty for this improvement is increased cost.

A final change in design to increase stability was to tighten grading requirements for the input chopper transistors. Under new specifications, the chopper contribution to zero shift averages better than 1 μV/°C without compensation. The specification requirement is approximately 0.7 μV/°C so that relatively little compensation is required.

A design difficulty was encountered in the attempt to achieve the packaging density necessary for the available package size. Even with the density possible by using welded interconnects in modular construction, it was necessary to utilize a thin-wall case. The case was thickened at the corners around the mounting holes for adequate rigidity. Two of these corners also served as a backing against which the gasket behind the removable cover plate was compressed. This compressible gasket sealed the terminal-board area against intrusion of moisture. The terminal board carries printed wiring to interconnect some of its pins. The printed wiring is double-sided for increased reliability.

With a thin-wall case it is not feasible to utilize an "O-ring" against humidity penetration into possible cracks at vulnerable points in the case. Instead, sealing is achieved by using a bonding-type silicone rubber. This compound is used to form a sealing gasket which actually conforms to the required space and, at the same time, it adheres permanently to the bulk encapsulant and to the case interfaces at the connector and at the corners and edges of the package.

The module subassemblies are welded and tested, and the test-selected parts are installed. A set of welded modules (no "matching" of modules is required), a pair of relays, an external connector, and a terminal board are then wired with insulated copper-stranded wire to make a working amplifier. Installed in its case, the assembly is then tested temperature-compensated, and encapsulated. The encapsulant used is Emerson & Cuming ECCO-SIL 4640 which is a lightweight silicone rubber material containing glass microballoons.

2. ELECTROMAGNETIC INTERFERENCE CONTROL PLAN

The Model EM2000D4 DC amplifier was designed to minimize effects of electromagnetic interference. The following considerations were incorporated into the design of the unit to assure compliance to all interference requirements.

a. Conducted (to generate the minimum):

(1) Avoid current spikes, due to transistor and diode switching, by component selection and design.

(2) Keep capacitance coupling from fast-switching voltages to a minimum by lead routing and length.

(3) No shielding is used.

(4) Utilize inductance-capacitance (L-C) networks for suppression of the remaining interference which is not tolerable.

b. Radiated: "Conducted" specification compliance almost invariably guarantees the meeting of "Radiated" specification for this type of unit.

c. Susceptibility (to keep capacity from output to power at a minimum):

(1) Audio susceptibility is reduced by series L and series regulator at power input.

(2) RF susceptibility is reduced by series L and shunt C to case, since RF on the power line can cause spurious output.

3. DISCUSSION OF PRODUCTION PROBLEMS

The expected production schedule was not being met at the start of the production run. Investigation into the reasons for delays uncovered the following problem areas:

a. The temperature stability of the gain potentiometer used was not adequate considering production tolerances; that is, while most units would perform adequately, there were many units in which the potentiometer wiper setting would shift by the amount of the resolution, either temporarily or permanently.

b. Wire routing was such that, under certain conditions, spurious oscillation would result.

c. Shielding of the input from the AC amplifier output transformer was marginal and resulted in occasional spurious oscillation.

d. Damage to wiring resulted from the removal of the assembly from its case.

These findings are now discussed in order.

3.1 Temperature Stability of the Gain Potentiometer

Investigation disclosed that an ambiguity in potentiometer specification, coupled with the fact that all trimming potentiometers actually perform many times better than their specification, resulted in the erroneous assumption that satisfactory temperature-stability performance could be expected. Further, the magnitude of the unexpected shift was too large to be absorbed in the gain-stability specification. Nothing short of potentiometer range reduction was found to be capable of eliminating this problem.

3.2 Wire-Routing

Wire-routing problems were fairly easy to overcome by means of more detailed drawings and photographs of models. A special thin shield, easily added to the AC amplifier output transformer, eliminated the marginal shielding condition which caused spurious oscillation. A slight redesign of the terminal board permitted easy removal of the assembly from the case without damage to wiring. These improvements were quickly implemented, and production was on a schedule more closely resembling expectations.

3.3 Shielding

At a later stage in production, tests at NASA/MSC indicated a small degree of out-of-limit performance in RF susceptibility. Tests at Engineered Magnetics, Hawthorne, California, substantiated this finding. The cause was an incorrect interpretation of the NASA specification which was incorporated in the electro-interference test procedure, inadvertently approved by NASA. Correction of the problem proved to be fairly easy with the addition of a section of L-C filtering.

3.4 Wire Damage

An inordinate number of failures in the demodulator module led to the correction of the final production problem. The reason for the demodulator failures was mechanical interference between welded circuitry and a toroidal inductor. This was caused by a slightly overtoleranced shield which was added earlier in the production run. Study of this problem revealed that no appreciable relaxation of tight tolerances could be realized without a new layout of the demodulator module. This was accomplished with certain circuit simplifications.

4. CONCLUDING REMARKS

The results of the electrical tests performed at NASA/MSC indicate that this unit has performed well within the required specifications. In 75 percent of the tests, the measured values were less than 50 percent of the maximum allowable deviation. Figure 4 is a graphic presentation of the average test values obtained from five units. Figure 5 is a typical linearity curve representative of this design.

Test results indicate that this unit is virtually insensitive to the mechanical environment levels (vibration, shock, acceleration) imposed by the specification. The drift characteristics measured during temperature, altitude, oxygen, and humidity environments were also within specification requirements.

Salt fog environmental tests on the early prototype and production units indicated that the unit was not adequately sealed. A small amount of moisture penetrated under the connector and produced partial shorting between pins. Improved potting and sealing techniques have subsequently solved this problem. EMI tests performed indicated that

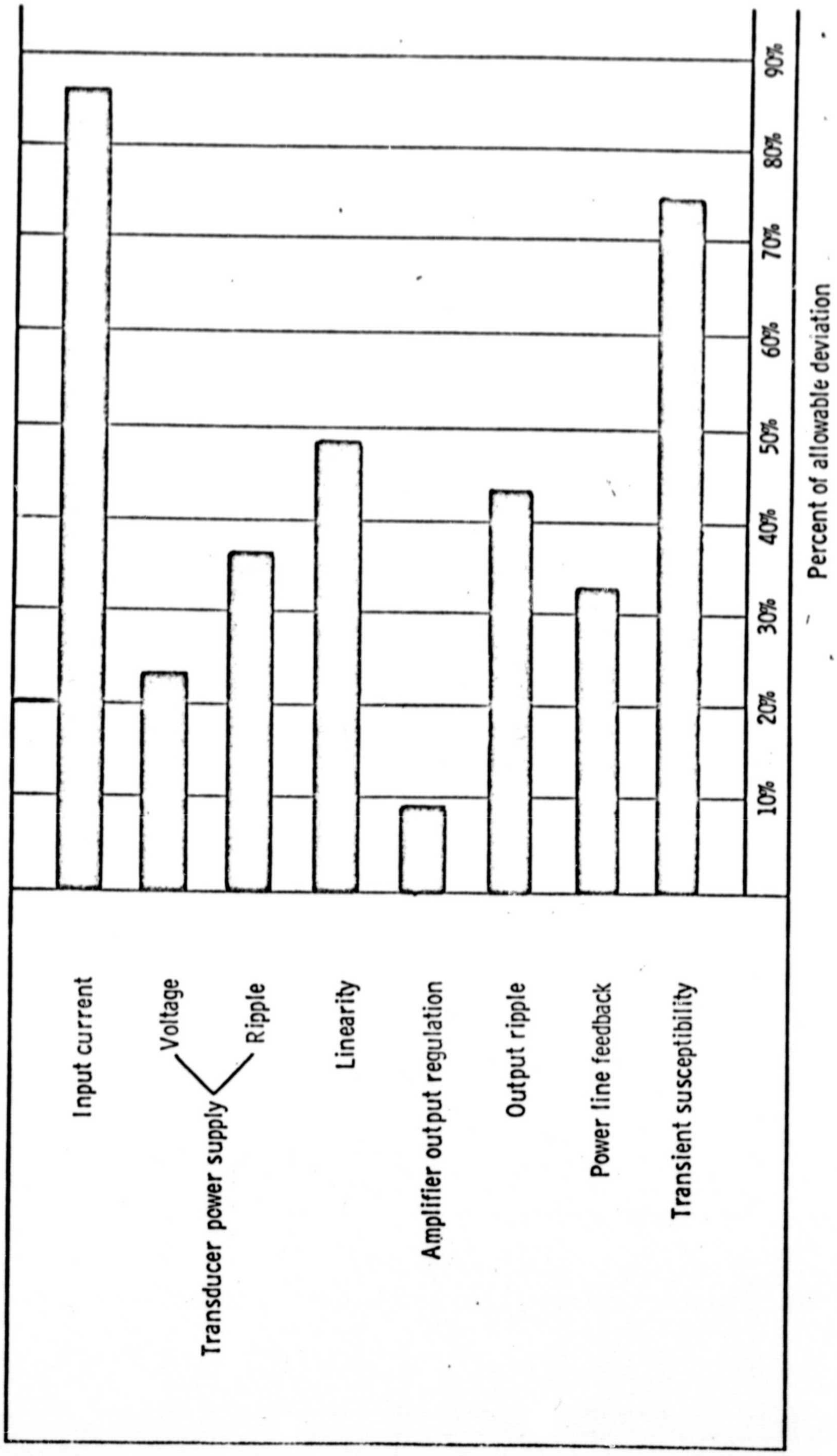

Figure 4. EM2000D4 Low-Level DC Amplifier

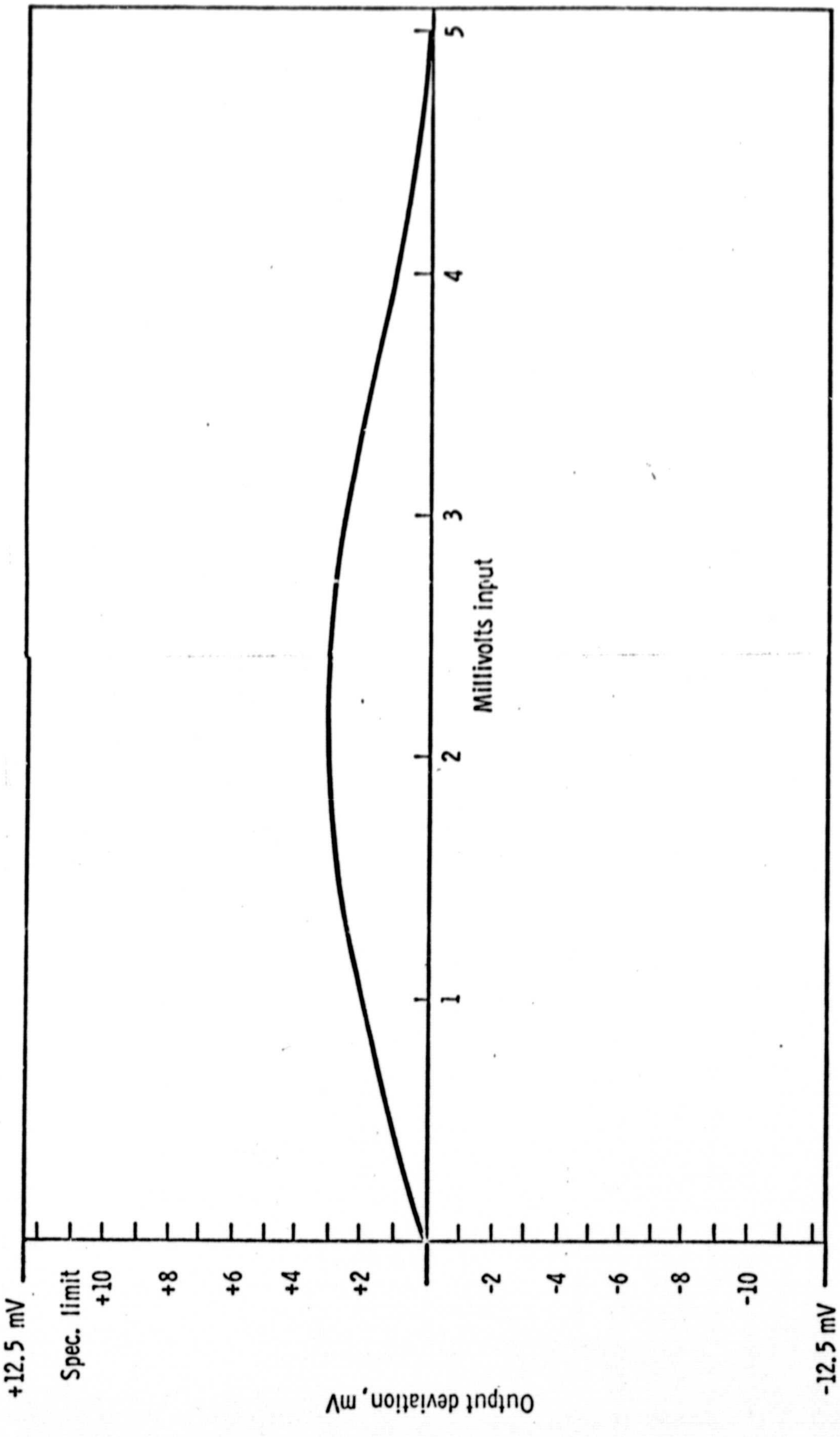

Figure 5. Typical Linearity, EM2000D4 Amplifier

the design complied fully with the requirements of MIL-I-2600, MSC-EMI-10A, and MSC/IESD 19-3

Significant improvements over the amplifiers available at the beginning of the LM program have been realized in the design of the EM2000D4 DC amplifier. These improvements include power consumption reduced 24 percent (by actual test, not specification limit), weight reduced 46 percent, and volume reduced 34 percent.

APPENDIX A - ENVIRONMENTAL SPECIFICATIONS

The information contained in this appendix is based on Environmental Specification MSC/IESD 19-1B (April 1, 1965), developed by MSC.

1. SCOPE

This specification covers:

- Vibration
- Acceleration
- Acoustics
- Temperature
- Humidity
- Vacuum
- Shock
- Salt Fog
- Oxygen
- Sand and Dust
- Fungus
- Hazardous Gases
- Electrical Requirements

Note

Conduct tests in sequence listed if facilities permit.

2. REQUIREMENTS

2.1 Vibration (random and sinusoidal to be used sequentially)

Random and sinusoidal motion shall be applied sequentially along each of three mutually perpendicular axes for 36 minutes. Random spectra are referenced to a log-log plot and held to a ±30 percent power spectral density. The component shall be operative and monitored throughout test.

12.3g root mean square (rms) for 5 minutes

10 cps, 0.01 g^2/cps

10-75 cps, linear increase to 0.14 g^2/cps

75-200 cps, constant 0.14 g^2/cps

200-2000 cps, linear decrease to 0.05 g^2/cps

5g rms for 25 minutes

10 cps, 0.0017 g^2/cps

10-75 cps, linear increase to 0.023 g^2/cps

75-200 cps, constant 0.023 g^2/cps

200-2000 cps, linear decrease 0.0082 g^2/cps

Sinusoidal motion shall be swept logarithmically from 5 cps to 2 kc to 5 cps in 6 minutes in each of the three mutually perpendicular axes. The component shall be operative and monitored thoughout the test.

5-10 cps, constant 0.20 in double amplitude (D.A.)

10-26 cps, constant ± 1g

26-56 cps, constant 0.03 in D.A.

56-2000 cps, constant ± 5g

2.2 Acceleration

The component shall be subjected to 20g for a time duration of 10 minutes minimum in each direction of three mutually perpendicular axes including whatever time is required to make a functional test. The component is not to be subjected to greater than 20g while increasing or decreasing to test level. The component shall be monitored at all times.

2.3 Acoustic Noise

Components shall be subjected to 165 ± 1 dB random noise referenced to 0.0002 dynes/cm^2 for a period of 15 minutes. Octave bands (center frequencies) will be held to ± 3 dB. Components shall be monitored at all times.

Octave Band, cps	Sound Pressure Level, dB
22.4 to 45	157
45 to 90	160
90 to 180	159
180 to 355	158
355 to 710	156

Octave Band, cps	Sound Pressure Level, dB
710 to 1400	151
1400 to 2800	145
2800 to 5600	139
5600 to 11200	133
Overall 165 dB	

2.4 Temperature (at atmospheric pressure, -65° to +160°F)

The following steps shall be followed during the 5-day temperature cycle. The component shall be mounted in the chamber in a manner which ensures adequate circulation around all surfaces.

a. Reduce temperature to -65°F and soak for 4 hours ±15 minutes. The component shall be in a deenergized condition. No operational check is required.

b. Increase temperature to 100 ±5°F in 30 ±10 minutes. Energize and soak for 4 hours Conduct an operational test. Record time, temperature, and data; deenergize equipment.

c. Increase temperature to 160 ±5°F in 15 ±5 minutes and soak for 24 ±1 hours. Energize components during the last 30 minutes; conduct an operational test. Record time, temperature, and data; deenergize component.

d. Decrease temperature to 0 ±5°F in 15 ±5 minutes and soak for 24 ±1 hours. Energize component during the last 30 minutes; conduct an operational test. Record time, temperature, and data; deenergize equipment.

e. Continue cycling as in steps c and d except with component energized during the last 36 hours. Conduct an operational check at room ambient temperature at conclusion. Record temperature, time, and data. The Time-Temperature table for energizing is as follows:

Hours	4	4	24	24	24	24	24
Temp, °F	-65	+100	+160	0	+160	0	+160
Energized	no	yes	30 min	30 min	30 min	12 hr	yes

2.5 Humidity

One hundred percent humidity including condensation for 5 days in a temperature range of 80 to 160°F. Temperature cycling shall be maintained as in MIL-STD-810 (USAF) Method 507. The component shall be operative during last 30 minutes.

2.6 Altitude

a. Stratosphere-ionosphere environments

Ambient pressure to 100,000 + 10,000 feet or -0 feet, equivalent pressure in 2.5 + 0 minutes or -0.5 minute; continue to 200,000 + 50,000 feet or -0 feet, and hold for 30 minutes. The component shall be operative.

b. Deep space environment

Nominal 5 days at 1 X 10^{-6} mm Hg pressure or less for 5 days. The components shall be operative 2 hours each 24-hour period.

2.7 Shock

Shock impulses at 30g for 11 ±1 msec. There shall be 3 shocks in each direction of three mutually perpendicular axes for a total of 18 shock impulses. Shock input will be a saw-toothed waveform with 10 ±1-msec rise and 1 ±1-msec decay time. The component shall be operating during test.

2.8 Salt Fog

As in MIL-STD-810 (USAF) Method 509 (equivalent to spray or 5-percent salt solution in water for 50 hours).

2.9 Oxygen Atmosphere

One hundred percent atmosphere at 5 PSIA for not less than 5 days. The component shall be operative 10 minutes each 24-hour period.

2.10 Sand and Dust

Sand and dust are such as encountered in desert and ocean beach areas (equivalent to 140-mesh silica flour with a particle velocity up to 500 feet per minute) and as described in MIL-STD-810 (USAF) Method 510.

2.11 Fungus

The fungus test will be conducted as specified in MIL-STD-810 (USAF) Method 508 on components containing nutrient materials. Whenever possible, fungus resistant materials as defined in MIL-E-5400 should be used.

2.12 Hazardous Gases

In the event of a short circuit, the nonmetallic materials shall not give off products that are deleterious to the astronaut at the temperature at which the material fuses.

At low pressure and/or high temperatures, there shall be no outgassing containing nauseous, toxic, or harmful components such as carbon dioxide, carbon monoxide, hydrogen sulfide, sulfur dioxide, methane, indole, skatole, mercaptans, ozone, and similar compounds which shall result in decreased performance capabilities of the astronaut.

2.13 Electrical Requirements

Operating voltage shall be 28 ± 4 VDC. No damage will occur to the component with a constant input voltage of 37 VDC for 10 minutes. The component output data shall not vary over ± 1 percent during application of four-volt peak-to-peak ripple (DC to 2 KC square wave), imposed on the 28-V bus. The component shall operate with less than 10-percent performance degradation with the input voltage between 22 and 24 VDC.

The transient susceptibility test shall be performed as described in this paragraph. The components shall survive a minimum of 10 negative 28-V pulses and 10 positive 15-V pulses with a rise time of

8 msec or less, a time base of 20 msec, and at a random pulse repetition frequency. This pulse will be applied to the input bus with the component operating at 28 VDC.

Feedback ripple shall be measured across a 1-ohm resistance inserted in series with the power source and will be less than the following values:

a. 30 mV peak-to-peak for any component drawing less than 1 ampere of current at 28 V

b. 100 mV peak-to-peak for a component drawing between 1 to 3.5 ampere of current at 28 V

c. 150 mV peak-to-peak for a component drawing between 3.5 to 8 ampere of current at 28 V

Reverse polarity of input power for 10 minutes shall not damage component. Isolation resistance between primary power input and signal output shall exceed 20 M-ohm at 100 VDC.

2.14 Design and Testing

Components shall be designed and tested in accordance with MIL-I-26600/MSC-EMI-10A.

APPENDIX B

TERMINAL BOARD CONNECTIONS AND COMPLETION NETWORK DIAGRAMS FOR THE EM2000D4 AMPLIFIER

Terminal	Function
32, 22, 33, 23, 27, 17	Calibrate circuitry
Between 32 and 22	Resistors for calibration
Between 33 and 23	Resistors for calibration
Between 27 and 17	Resistors for calibration
Between 31 and 21	Bridge completion resistors
Between 20 and 30	Bridge completion resistors
Between 29 and 19	Bridge completion resistors
Between 24 and 34	Resistance thermometer
Between J1-15 and J1-6	Resistance thermometer
Between 16 and 26	Terminals for input-series resistor (if used)
13	Spare wire
12	Spare terminal
Between 18 and 28	Bridge-balance padder resistor
Between 4 and 3 Between 11 and 10	Low-pass filter cutoff selection capacitors

TABLE B-1. TERMINAL BOARD CONNECTIONS

Terminal	Gain
Jumper 8-1	200 to 1000
Jumper 8-2	50 to 200
Jumper 8-9	10 to 50
Terminals 15 to 25	Appropriate resistor

TABLE B-2. COARSE GAIN ADJUSTMENT

Terminal	Volts
Jumper 6-7	0.0
Jumper 6-5	2.5

TABLE B-3. BIAS SETTING PROVISION