NASA TECHNICAL NOTE

NASA TN D-4584

c. 1

TECH LIBRARY KAFB, NM

0131177

NASA TN D-4584

LOAN COPY: RETURN TO
AFWL (WLIL-2)
KIRTLAND AFB, N MEX

AN INTEGRATED-CIRCUIT DIRECT-COUPLED AMPLIFIER FOR SPACECRAFT USE

by Guss E. Wenzel

Manned Spacecraft Center
Houston, Texas

RECEIVED
31 MAY 1968

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MAY 1968

TECH LIBRARY KAFB, NM

0131177

AN INTEGRATED-CIRCUIT DIRECT-COUPLED AMPLIFIER FOR SPACECRAFT USE

By Guss E. Wenzel

Manned Spacecraft Center
Houston, Texas

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

ABSTRACT

The integrated-circuit direct-coupled differential-amplifier design described in this paper is based on a previous phase of development and has advanced the state of the art of direct-coupled amplifiers to the extent that the stability and drift characteristics are equal to, or superior to, the conventional high-performance chopper direct current amplifier. The circuit diagrams and the physical layout of the various components are presented. The amplifier performance, when powered from a typical flight battery, is described by various tables and plots of test data.

CONTENTS

Section	Page
SUMMARY	1
INTRODUCTION	1
CIRCUIT DESCRIPTION AND LAYOUT	3
TEST RESULTS	6
CONCLUSIONS AND RECOMMENDATIONS	9
APPENDIX A — CHOPPER AMPLIFIERS AND CHOPPER-STABILIZED AMPLIFIERS	50
APPENDIX B — AMPLIFIER SPECIFICATION	52
APPENDIX C — LABORATORY TEST DATA	58
APPENDIX D — SPECIFYING ZERO DRIFT	65
REFERENCES	66

TABLES

Table		Page
C-I	AMPLIFIER GAIN CHANGE WITH A VARIABLE TEMPERATURE	59
C-II	AMPLIFIER PERCENTAGE GAIN CHANGE WITH A VARIABLE TEMPERATURE	59
C-III	AMPLIFIER OUTPUT OFFSET VOLTAGE WITH A VARIABLE TEMPERATURE	60
C-IV	ERROR IN AMPLIFIER LINEARITY AT VARIABLE OUTPUT VOLTAGES	60
C-V	LOSS IN AMPLIFIER GAIN WITH AN INCREASE IN SIGNAL FREQUENCY	61
C-VI	AMPLIFIER COMMON-MODE SIGNAL REJECTION	61
C-VII	PEAK-TO-PEAK RIPPLE ON THE AMPLIFIER OUTPUT WITH A VARIABLE TEMPERATURE	62
C-VIII	AMPLIFIER INPUT AND OUTPUT RESISTANCES AND CHANGES IN OFFSET VOLTAGE WITH LARGE VARIATIONS IN THE SUPPLY VOLTAGES	62
C-IX	ERROR OF POWER-SUPPLY VOLTAGES WITH A CHANGE IN INPUT VOLTAGE AND TEMPERATURE	63
C-X	PEAK-TO-PEAK RIPPLE ON THE 10-VOLT TRANSDUCER SUPPLY WITH A VARIABLE TEMPERATURE	64

FIGURES

Figure		Page
1	Interconnections between the power supply and the amplifier	10
2	Schematic diagram of the complete amplifier	11
3	Connections of the basic amplifier module (SCA4-1)	12
4	Layout of the basic amplifier (SCA4-1) die	13
5	Connections of the drift-offset compensation-control circuitry (SCA4-2)	14
6	Layout of the drift-offset compensation-control circuitry (SCA4-2) die	15
7	Schematic diagram of the capacitor module (CA-02)	16
8	Capacitor module (CA-02)	17
9	Layout of the capacitor (CA-02) die	18
10	Schematic diagram of a 3-watt converter	19
11	Component subassembly of a 3-watt converter	20
12	Internal photograph of a 3-watt converter	21
13	Mechanical assembly of a 3-watt converter	22
14	Flat-pack assembly of a 3-watt converter	23
15	Flat-pack assembly photograph of a 3-watt converter	24
16	Schematic diagram of the capacitor module (CA-01)	25
17	Layout of the capacitor (CA-01) die	26
18	Converter switch (CS-01A) schematic	27
19	Layout of the converter switch (CS-01A) die	28
20	Converter voltage regulator (VR-03) schematic	29
21	Layout of the converter voltage regulator (VR-03) die	30
22	Converter voltage regulator (VR3-4) schematic, 10-volt	31

Figure		Page
23	Converter voltage regulator (VR3-4), 10-volt	32
24	Layout of the converter voltage regulator (VR3-4) die	33
25	Converter voltage regulator (VR3-5) schematic, 15-volt	34
26	Converter voltage regulator (VR3-5), 15-volt	35
27	Layout of the converter voltage regulator (VR3-5) die	36
28	Multicircuit die (MDC-1)	37
29	Multicircuit die (MCD-3)	38
30	Multicircuit die (MCD-4)	39
31	Printed-circuit test-board assembly	40
32	Offset stability with temperature (gain = 50)	41
33	Offset stability with temperature (gain = 1000)	42
34	Gain stability with temperature (gain = 50)	43
35	Gain stability with temperature (gain = 1000)	44
36	Common-mode input-signal rejection (gain = 50)	45
37	Common-mode input-signal rejection (gain = 1000)	46
38	Frequency response (gain = 50)	47
39	Frequency response (gain = 1000)	48
40	Transducer power-supply error with temperature	49
A-1	Chopper amplifier	50
A-2	Chopper-stabilized amplifier	51

AN INTEGRATED-CIRCUIT DIRECT-COUPLED AMPLIFIER FOR SPACECRAFT USE

By Guss E. Wenzel
Manned Spacecraft Center

SUMMARY

This paper describes an integrated-circuit direct-coupled differential amplifier which has been developed for spacecraft signal-conditioning use. The circuit diagrams and the physical layout of the various components are presented. The amplifier performance, when powered from a typical flight battery, is described by various tables and plots of test data. The data are obtained from two variations of the amplifier. One type of the amplifier has a voltage gain of 1000, and the other type of the amplifier has a voltage gain of 50. These voltage gains are considered to be the voltage-gain extremes of spacecraft signal-conditioning use.

The amplifier design, which is based on a previous phase of development, has advanced the state of the art of direct-coupled amplifiers to the extent that the stability and drift characteristics are equal to, or superior to, the conventional high-performance chopper direct current amplifier.

Although the amplifier design is considered to be complete and meets the requirements of use criteria, comments are made, where applicable, to point out areas where additional efforts could be applied to improve the performance, power, weight, and volume requirements and where effort must be applied before the amplifier is available for flight use.

INTRODUCTION

Signal-conditioning amplifiers built with discrete components have undergone a logical sequence of improvements within the past decade. For low-frequency applications, the chopper amplifier has become the most stable circuit for use with a high gain and a wide temperature range. The chopper amplifier is not to be confused with the chopper-stabilized amplifier (appendix A). The inherent use of transformers in most chopper designs has severely limited a further reduction in the volume and weight of this type of amplifier. The companion circuit, a direct-coupled amplifier, has been limited to low-gain use and a narrow temperature range because of the drift characteristics associated with the inherent difference in temperature coefficients and gradients. Although these design limitations are present, each generation of discrete-component amplifiers and signal-modifying circuits has made some contribution to an improved product. However, the point has been reached where the improvement in each generation has become negligible. This has been particularly true in the volume, weight, and power.

Since the volume, weight, and power are very important parameters in spaceflight use, the development of a state-of-the-art signal-conditioning amplifier was initiated in 1964 by the Manned Spacecraft Center. The basis of this development program was to investigate the feasibility of using silicon monolithic circuitry in a direct-coupled amplifier.

The first development phase verified that the microelectronic approach of using integrated silicon monolithic circuitry was feasible. The potential of producing linear amplifiers suitable for flight-signal conditioning was evident. The superiority of the linear amplifiers to the best qualities of the chopper amplifier and the discrete-component direct-coupled amplifier was also disclosed. The discrete-component direct-coupled amplifier is noted for its drift in output voltage, and a potentiometer is usually provided for last-minute adjustments before use. An analysis of this drift indicated that the reason for the drift was because complementary components, which have drift canceling effects, do not have identical characteristics and cannot be maintained at the same temperature. The integrated-circuit direct-coupled amplifier is much more desirable in this respect because complementary components have nearly identical characteristics. The components are manufactured simultaneously and in proximity to each other and can be maintained at approximately the same temperature. (The physical spacing between these components is only a few thousandths of an inch.) The net result is that a zero-setting potentiometer is neither required nor desired in an integrated-circuit direct-coupled amplifier, and the addition of the potentiometer would probably upset the inherent stability and introduce a zero drift. Test hardware from the first development phase substantiated these conclusions (refs. 1 and 2). In addition, the hardware demonstrated the quick warmup characteristics of integrated circuits and thereby opened the door to a new concept of signal-conditioning operation, that of sequencing amplifier operating power.

The test hardware of the first development phase demonstrated that an integrated-circuit amplifier, having a voltage gain of 1000, was stable within 1 percent in less than 50 microseconds after the application of the operating voltages. This is in marked contrast to the usual warmup time of 5 minutes for a discrete-component amplifier. Also, the latter amplifier must be powered continuously, even though it may supply a signal from a particular measurement for only a small fraction of the time (that is, one segment of a time-shared wave train, such as a pulse-amplitude modulation (PAM) signal). Since the "off" time for each channel slot of a 90×10 inter-range instrumentation group (IRIG) commutated signal is approximately 555 microseconds, a signal-conditioning system can be designed to operate from a time-shared power supply by using such microelectronic circuitry as given in reference 3. In addition to the obvious power savings, this mode of operation will eliminate some undesirable characteristics such as channel crosstalk and generated heat.

Although the first-phase amplifier design produced test hardware that was generally acceptable for flight signal-conditioning use, the manufacturing yield was lower than desired. It was concluded that a redesign would increase the manufacturing-yield rate and would significantly increase the circuit performance.

This report describes the results associated with the amplifier redesign. The detailed design and fabrication portion of the amplifier was performed by a contractor (ref. 4). This second-generation microminiature direct-coupled amplifier has fulfilled all the design goals to produce the circuitry for a state-of-the-art signal-conditioning amplifier. This amplifier may be used in many additional applications since, as the test data indicate, it is sufficiently stable over a wide temperature range. Although not described in this report, a complete signal-conditioning system with signal modifiers and dc amplifiers is being developed to incorporate power savings by time sharing of a common power supply. With this technique perfected, a typical signal-conditioning system will exhibit the same relative order of magnitude in power savings as it does in weight and volume when it is compared to a typical discrete-component system.

CIRCUIT DESCRIPTION AND LAYOUT

The microminiature integrated-circuit signal-conditioning amplifier, in its present packaging configuration, is divided into the following three main parts.

1. The transformer-coupled converter

2. The voltage regulators

3. The direct-coupled amplifier

Each part is subdivided into several specific circuits. The interconnections of the various circuits are shown in figure 1.

In a flight signal-conditioning system, the packaging would be condensed, and the specific circuits would be selected for proper system performance. However, in the development phase, the separate packaging concept was selected because of the versatility of use and the ease of evaluation of each type of circuit. Although the single-channel arrangement (transducer and amplifier), shown in figure 1, is being powered from one converter, there is sufficient power-supply capacity to power two signal channels. A second example of versatility is that the voltage regulators (VR3-4 and VR3-5) can be connected so that the power through the voltage regulators is turned on and off by a remote-control signal, such as a signal from a programing device. An additional example of versatility is that the voltage gain and the frequency response of the direct-coupled amplifier can be changed with a relatively small amount of effort.

The balanced-type of circuit design of the direct-coupled amplifier was selected because of its inherent ability to cancel drift and to maintain stability. This type of circuit is particularly effective in integrated-circuit form because the corresponding components in each half of the circuit will be nearly identical since the components are manufactured at the same time. Because of their small size, these matched components can be maintained at the same temperature. The open-loop voltage gain of the amplifier is between 200 000 and 300 000. At a closed-loop voltage gain of 1000 maximum, the feedback ratio of 200 to 1 minimum is sufficient to obtain the required gain stability by force alone. Since zero drift cannot be eliminated solely by feedback, drift-offset compensation-control circuitry (SCA4-2) is required to obtain the proper performance within the required temperature range.

The amplifier presently consists of the following three separate modules (fig. 2).

1. The basic amplifier (SCA4-1)

2. The drift-offset compensation-control circuitry (SCA4-2)

3. The upper-limit frequency rolloff capacitors (CA-02)

Each module is 0.25 by 0.375 by 0.070 inch. However, the dice from these three modules can be mounted in a single module (0.375 by 0.375 by 0.070 inch) for flight use if a compact amplifier is desired. The connections and the layout of the dice within the module cases are shown in figures 3 and 4 for the basic amplifier (SCA4-1) and in figures 5 and 6 for the drift-offset compensation-control circuitry (SCA4-2). The capacitor die (CA-02) has the capability of selecting several sizes of capacitors (fig. 7) to accommodate a wide variety of uses. Three of the capacitor dice (CA-02) are mounted in a signel module for amplifier use (fig. 8). The layout of the capacitor die is shown in figure 9. The circuitry for the basic amplifier (SCA4-1) and the capacitors (CA-02) does not contribute new information to design technology and, therefore, is not discussed in detail. However, the drift-offset compensation-control circuitry (SCA4-2) is unusual; thus, the circuitry warrants further discussion.

The drift-offset compensation-control module (SCA4-2) contains the following circuitry.

1. A voltage to cancel the amplifier zero offset which is caused by minute differences in the two halves of the amplifier

2. A temperature-controlled voltage to keep the zero setting within the specifications over the temperature range

3. A resistor to obtain the proper voltage gain of the amplifier

4. A resistor to obtain the optimum common-mode signal rejection for a specific voltage gain

The critical resistors and capacitors can be factory adjusted for optimum circuit performance by evaporating fuse links associated with small increments of the particular component involved. The fuse links are evaporated by high-current pulses during the test and assembly phase of manufacture. A previous effort to supply the drift-offset compensation-control voltages with simple resistance-bridge networks and a temperature-sensitive diode was not as satisfactory as desired (refs. 1 and 2) because not all of the amplifiers could be properly compensated to an acceptable value. This difficulty was caused by the nonlinearity characteristics of the bridge networks when relatively large amounts of compensation were required. The drift-offset compensation-control circuitry (SCA4-2) overcomes this difficulty by generating the compensation voltages with transistor arrangements rather than resistor bridges.

The transformer-coupled dc-to-dc converter, which operates at an efficiency of approximately 70 percent between the battery input and the filtered dc output, provides 2.4 watts of output power to the regulators for operation of various transducer bridges, signal modifiers, and voltage reference V_{ref} sources. The input circuit consists of the following.

1. A radio frequency interference (RFI) filter with a series diode for reverse-voltage polarity protection

2. A pulse-width voltage regulator with a timing oscillator

3. A transistor switch in series with the primary winding of the power transformer

The frequency of operation of the switch is approximately 200 kHz, and the symmetry of the waveform is a function of the amplitude of the input voltage. The transformer secondary voltages are rectified and filtered. A schematic diagram of the circuits is given in figure 10.

The converter is packaged in a single container. Within the container is a flat-pack module with integrated circuits, a module containing a transformer and diode subassembly, and the remaining discrete components (fig. 11). The components are mounted on a printed-circuit board (figs. 12 and 13) and encapsulated with an epoxy resin. The flat pack (figs. 14 and 15) contains the following four integrated circuit dice.

1. A capacitor (CA-01)

2. A converter switch (CS-01A)

3. A voltage regulator (VR-03)

4. A power transistor (2N2851)

The capacitor (CA-01) die is shown in figures 16 and 17. The converter switch (CS-01A) (figs. 18 and 19) is the oscillator-control circuitry, with the capacitors and the transformer (T_2), that turns the power transistor (2N2851) on and off. This transistor is a commercial unit that has been removed from its conventional case. The voltage regulator (VR-03) (figs. 20 and 21) supplies a stable voltage to operate the converter-switch circuitry.

The transformer secondary voltages are half-wave rectified and filtered. Regulation is sufficient so that the regulator modules will provide the degree of regulation required to power the transducer bridges and the signal modifiers within specifications. An additional output winding from the converter provides 7 volts at a maximum of

60 milliamperes. This auxiliary output is available to generate reference voltages V_{ref} or for other usage that requires dc isolation from the other output voltages.

The voltage regulator (VR3-4) (figs. 22, 23, and 24) supplies 10-volt power for a 350-ohm transducer bridge. Two of these regulators for two 350-ohm transducer bridges can be powered from the converter output winding, or the regulator circuitry can be modified so that one 160-ohm transducer bridge can be powered from the winding.

The direct-coupled amplifier, which requires 200 milliwatts of operating power, and future signal modifiers are powered from a +15-volt power supply and from a -15-volt power supply. The voltage regulator (VR3-5) (figs. 25, 26, and 27) supplies 15 volts, and two modules are used to provide the positive and negative voltages. Two sets of voltage regulator (VR3-5) modules can be powered from the converter output windings for those situations where two signal modifiers are required.

As stated previously, the dc-to-dc converter, with the associated voltage regulators (VR3-4 and VR3-5), is designed to be versatile. Either one or two signal modifiers and their transducer bridges can be powered simultaneously for continuous operation, or the power transmission of the regulators can be operated by a control signal so that a number of signal channels can be sequentially powered to provide a low-power drain system with a serial output, such as a PAM wave train (ref. 3).

Common usage of microminiature substrates was applied, where possible, throughout the power supply, the regulators, and the amplifier designs. These substrates are referred to as a multicircuit die (MCD). The multicircuit die (MCD-1) (fig. 28) is used with the converter switch (CS-01A) and the voltage regulator (VR-03); the multicircuit die (MCD-3) (fig. 29) is used with the voltage regulators (VR3-4 and VR3-5); and the multicircuit die (MCD-4) (fig. 30) is used with the basic amplifier (SCA4-1) and the drift-offset compensation-control circuitry (SCA4-2).

A detailed description of the manufacturing techniques of this hardware can be found in the final report of the contractor (ref. 4), and amplifier specifications are given in appendix B. These specifications were the design goal of the prototype amplifiers and are not necessarily representative of future procurement specifications.

TEST RESULTS

To verify the performance characteristics of the direct-coupled amplifier and its related transformer-coupled power supply, five samples of each of the following components were tested in the Signal Conditioning Laboratory of the Instrumentation and Electronic Systems Division at the Manned Spacecraft Center.

1. A dc amplifier with a voltage gain of 50

2. A dc amplifier with a voltage gain of 1000

3. A dc-to-dc converter with voltage regulators to provide positive and negative voltage (15 volts) for amplifier operation and positive voltage (10 volts) for transducer operation

A graphic analysis of the test data is presented, and the actual test data are tabulated in appendix C.

For test purposes, a printed-circuit board has been designed to accommodate the various modules and components, such as bridge-completion resistors and a bridge-balance potentiometer (fig. 31). The dimensions of the card and the circuit board wiring were designed so that a signal channel could be operated independently on one board, or several channels could be operated on several boards with interconnections through the wiring of a card-holding rack. With the various modules interconnected in this manner, testing and evaluation can be made complete because of the accessibility of test points.

Probably the parameter of most interest to the user of dc amplifiers is the initial setting of the amplifier output voltage when the signal input voltage is zero and the behavior of this output setting (or zero drift) with time and temperature.

The zero drifts of the 10 samples are well within the specification requirements of 0 ± 50 millivolts at the amplifier output as shown in figures 32 and 33. In fact, most of the amplifiers had zero drifts within 0 ± 25 millivolts which may be expressed as $\pm 0.2\ \mu V/^{\circ}C$ referred to the input for amplifiers with a voltage gain of 1000 (appendix D). In addition, the test data obtained at the Manned Spacecraft Center correlated well with the test data obtained at the factory, which indicates that stability with time under storage conditions is satisfactory. It should be noted that only the drift components that are linear with temperature can be compensated for to the point of elimination. In addition, it is inherent in the circuitry of a high-performance dc amplifier that each amplifier performs slightly different when exposed to a variable ambient temperature. The shapes of the curves in figures 32 and 33 exhibit these characteristics. Therefore, test data should be obtained during manufacturing, before applying compensation, to select dice that can be properly compensated to an acceptable value for the desired voltage gain and the temperature range. For example, all 10 amplifiers met the zero-drift specification of 0 ± 50 millivolts at the amplifier output. However, since the amount of zero drift is affected by the amplifier gain, the amplifiers with a voltage gain of 1000 were selected and compensated more carefully than those amplifiers with a voltage gain of 50.

The accuracy of the voltage gain (that is, initial setting plus drift) is within ± 0.5 percent between -30° and $+200^{\circ}$ F. The characteristics of the 10 amplifiers that were tested are shown in figures 34 and 35. One amplifier gain (serial number 304) was improperly set at the factory because of a faulty resistor in the precision voltage-divider signal source. The faulty resistor was discovered and corrected before the remaining amplifiers were adjusted. The improperly set amplifier was not rejected because it was considered to be satisfactory for evaluation purposes.

The amplifier gain and zero setting (table C-VIII) are relatively insensitive to changes in the operating supply voltages. A 1-percent change in amplifier operating voltages will change the output signal by approximately 0.1 percent. In actual usage, the dc-to-dc converter and its voltage regulators will maintain the amplifier operating voltages stable within ± 0.25 percent over a temperature range of -30° to $+200^\circ$ F and a battery-voltage change of 22 to 32 volts. This variation will cause a change of less than 2 millivolts in the amplifier output.

The common-mode input-signal rejection (figs. 36 and 37) is increased to some extent with an increase in the amplifier-voltage gain. The worst case, 75 dB (at the limit of the amplifier pass band of 1 kHz), is sufficient for spacecraft use and should be sufficient for most other types of applications.

The input impedance to the amplifier (base to base of the input transistors) is greater than several megohms and is a function of the closed-loop voltage gain. However, when the base-biasing network is included, the input impedance to the package becomes a function of this resistive-biasing network, and the input impedance becomes independent of voltage gain. The input impedance for each of the 10 amplifier packages tested was measured to be between 100 and 200 kilohms. The output impedance of the amplifier is a function of the closed-loop voltage gain and was measured to be approximately 10 ohms for the amplifiers with a voltage gain of 1000 and approximately 1 ohm for the amplifiers with a voltage gain of 50 (table C-VIII).

Although the intended use of the amplifier is to provide an output signal between 0 and +5 volts, there is negligible linearity error between -3 and +6 volts. Beyond this range, the linearity deteriorates rather rapidly as the circuitry goes into saturation or cut-off conditions (table C-IV). If other applications require a bidirectional output signal or a greater voltage swing, adjustments can be made to increase the signal range capabilities. As the test data indicate, a small amount of instrumentation error was present which prevented all data points from forming a smooth curve.

With a minimum amount of added capacitance to insure the dynamic stability of the amplifier, the frequency response is essentially flat from dc to a minimum of 200 kHz. Under this condition, the peak-to-peak noise on the amplifier output will be approximately 50 millivolts, and the warmup time requirements will be less than 20 microseconds. As additional capacitance is added to the circuitry, the pass band and the output noise will be reduced, and the warmup time will be increased. With a pass band of approximately 10 kHz (± 1 percent), the noise will be approximately 25 millivolts, and the warmup time will be approximately 25 microseconds. The typical response curves, when sufficient capacitance is added to the circuitry so that the response is flat (within ± 1 percent) to 1 kHz, are shown in figures 38 and 39. The output noise with this frequency response is approximately 10 millivolts.

Since a transducer-excitation voltage is often required in conjunction with a signal-conditioning amplifier, the power supply was designed to have an isolated output of 10 volts at approximately 30 milliamperes. Different voltages and currents can be obtained with minor modifications. All five power supplies drifted less than half of the allowable ± 50 millivolts when exposed to a temperature variation of -30° to $+200^\circ$ F and a battery voltage variation of 22 to 32 volts. Figure 40 shows a plot of the individual response curves.

CONCLUSIONS AND RECOMMENDATIONS

The integrated-circuit direct-coupled amplifier, which was designed under this development program, is an outstanding success. In addition to the obvious reduction in volume and weight and the improvement in reliability that is inherent with integrated circuitry, the performance of this amplifier was improved from the usual ±1-percent gain and zero stability between temperature variations of 0° to +160° F to less than ±0.5-percent gain and zero stability between temperature variations of -30° to +200° F. Also, this amplifier exhibits an improved common-mode signal rejection and a broader frequency-response capability over the conventional discrete-component amplifier. The warmup time requirement is a function of the capacitance that determines the frequency response. If this capacitance is small, so that the amplifier response is greater than 10 kHz (±1-percent gain value), the amplifier will warm up in less than 25 microseconds (within 1 percent of its ideal zero drift and gain settings) after the application of its supply voltages. This unique characteristic will allow a new dimension in system design which will result in a reduction of system operating power.

Although the development of the circuitry has been completed, additional effort must be expended before flight hardware is available. This effort consists of adding flight quality control and reliability requirements to the specifications, the acquisition of a container to withstand the environments, and formal qualification testing. During development, only a minimum of flight quality control and reliability requirements were enforced because of the many circuit changes that are associated with design and because the development cost was held to a minimum. Except for insuring proper operation within the required temperature range, no environmental testing has been performed. These kinds of tests should not cause problems, because many designs of containers that can withstand the various environments and the normal levels of shock and vibration are available. In addition, the microcircuits are conformal coated within the sealed flat packs to prevent movement of the connecting wires.

Effort could be expended to better the amplifier, but this effort is not required. For example, extensive life tests could be conducted. One amplifier was successfully operated for 15 000 hours before the test was stopped because of project managerial reasons. Some circuit simplification may be possible, but the amount of improvement may not justify the additional cost of further development. Effort could be applied to improving the process to increase the manufacturing yield of the dice. This yield is presently between 2 and 5 percent. One area that appears feasible for investigation is the development of an improved method for adjusting the values of resistors. It would be most desirable to be able to increase or decrease the value of a resistor in very small increments while the circuit is operating during final adjustments.

It is strongly recommended that amplifiers of a design similar to the design described in this paper be considered for use in applications where performance, weight, and volume are critical design parameters.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, March 6, 1968
904-02-13-09-72

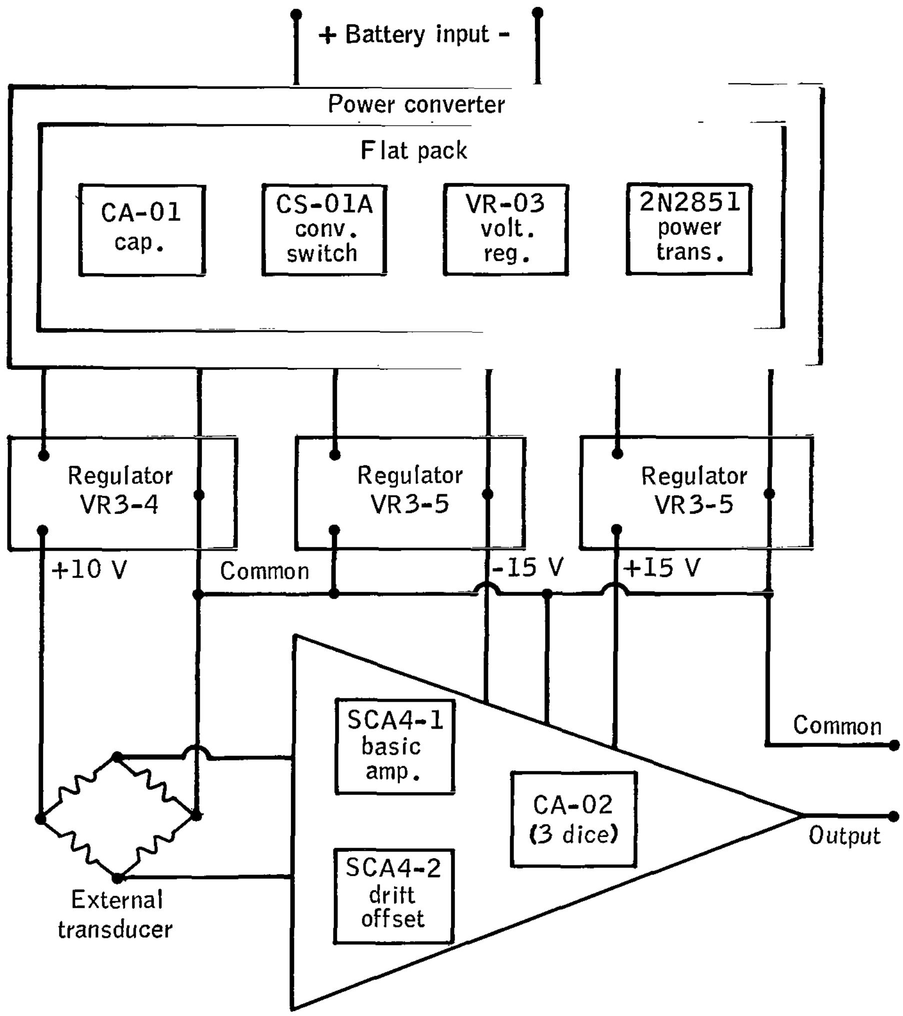


Figure 1. - Interconnections between the power supply and the amplifier.

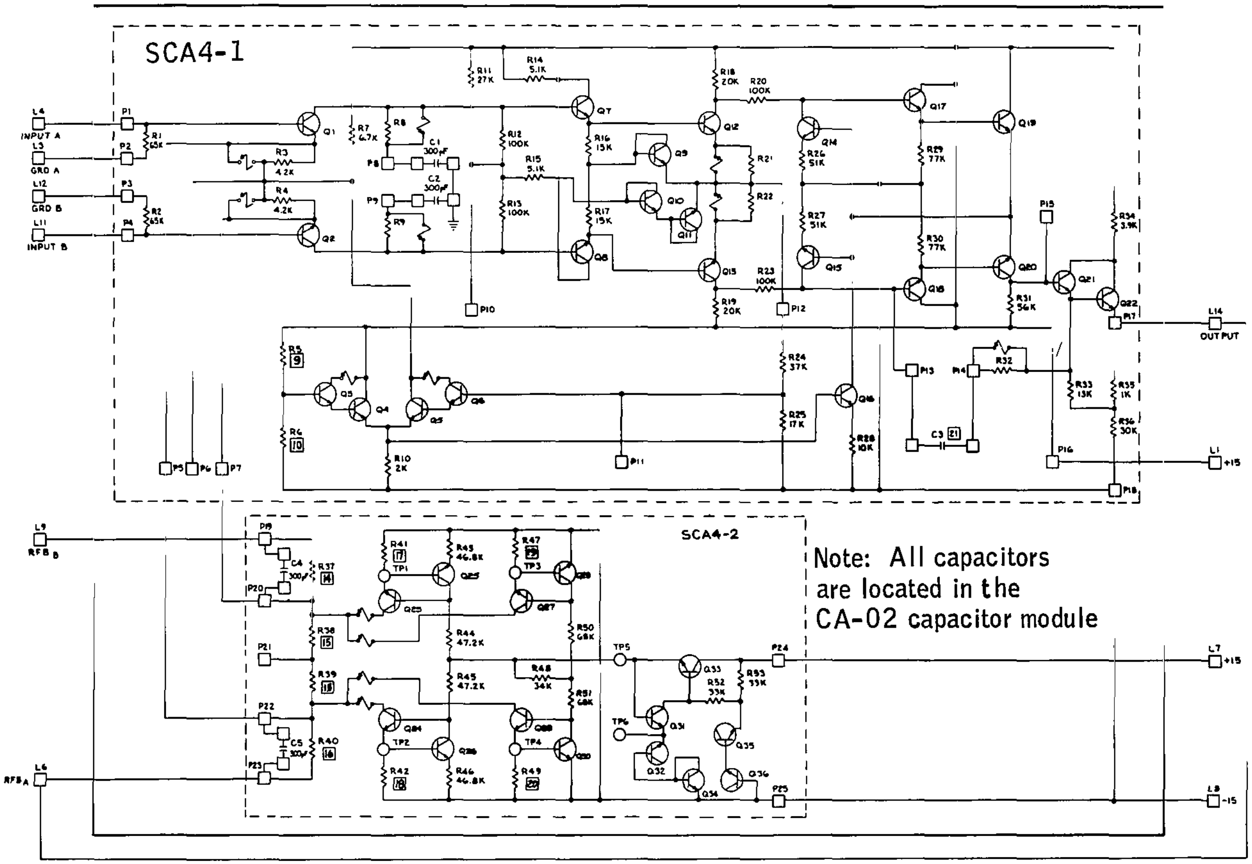


Figure 2. - Schematic diagram of the complete amplifier.

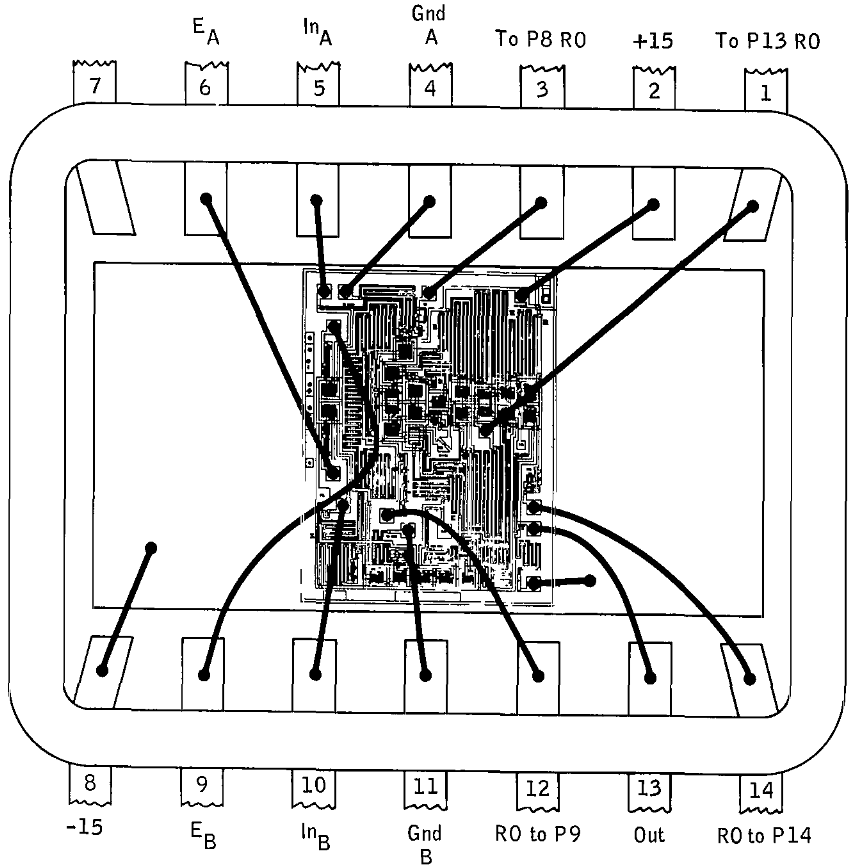


Figure 3. - Connections of the basic amplifier module (SCA4-1).

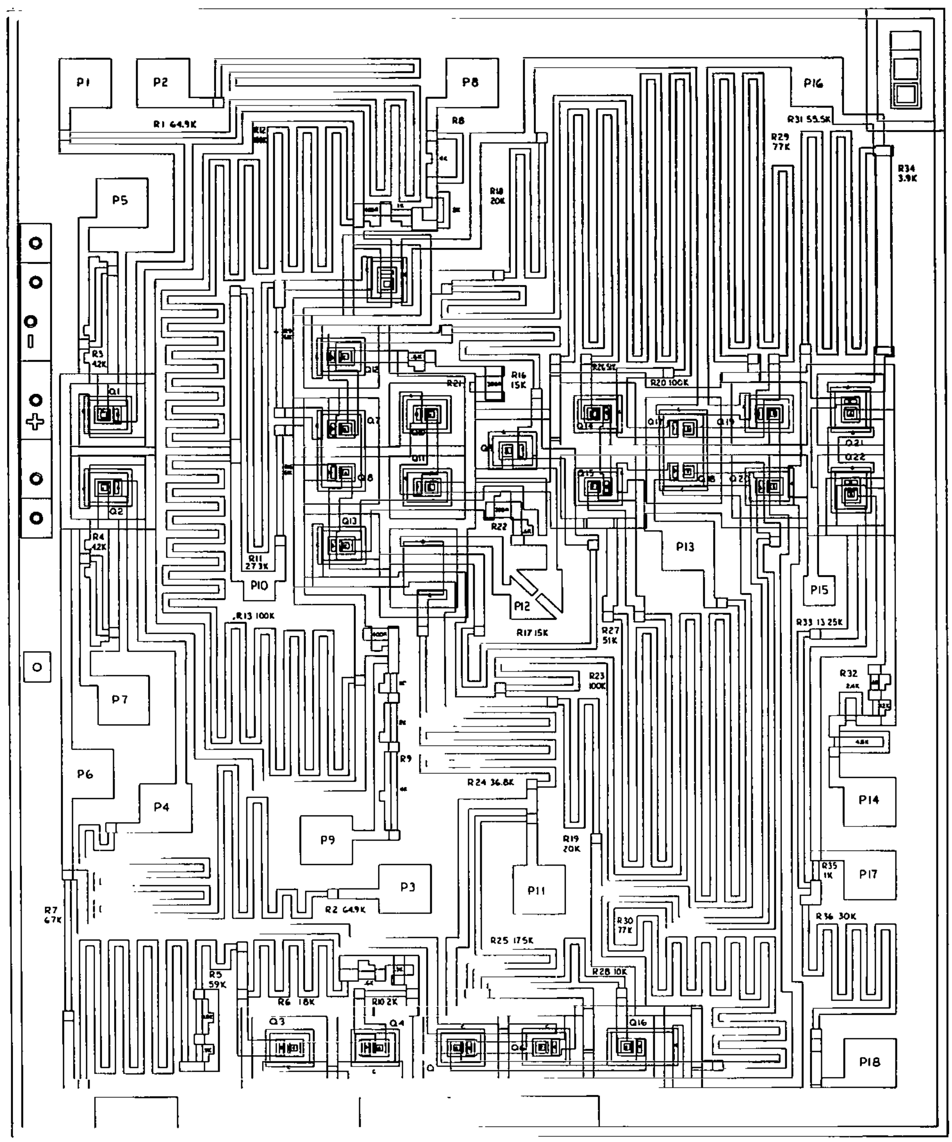


Figure 4. - Layout of the basic amplifier (SCA4-1) die.

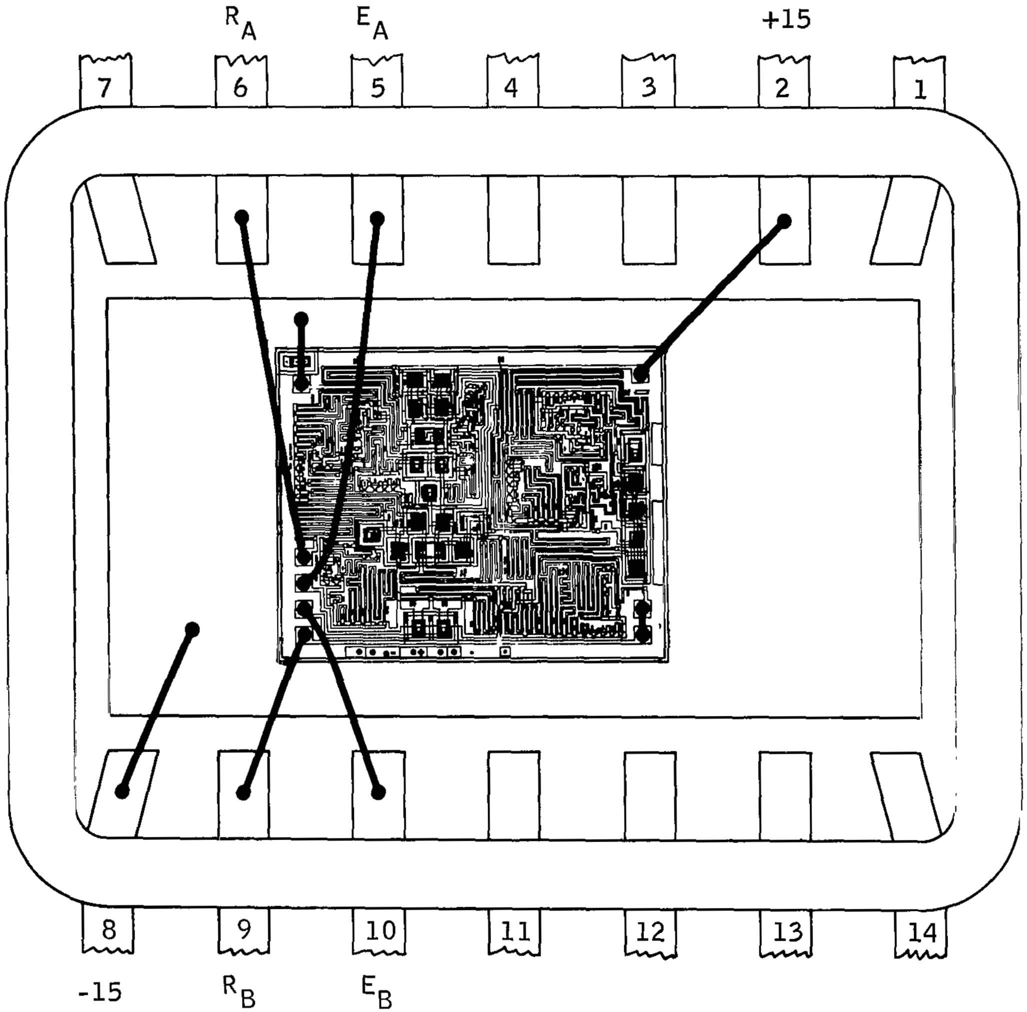


Figure 5. - Connections of the drift-offset compensation-control circuitry (SCA4-2).

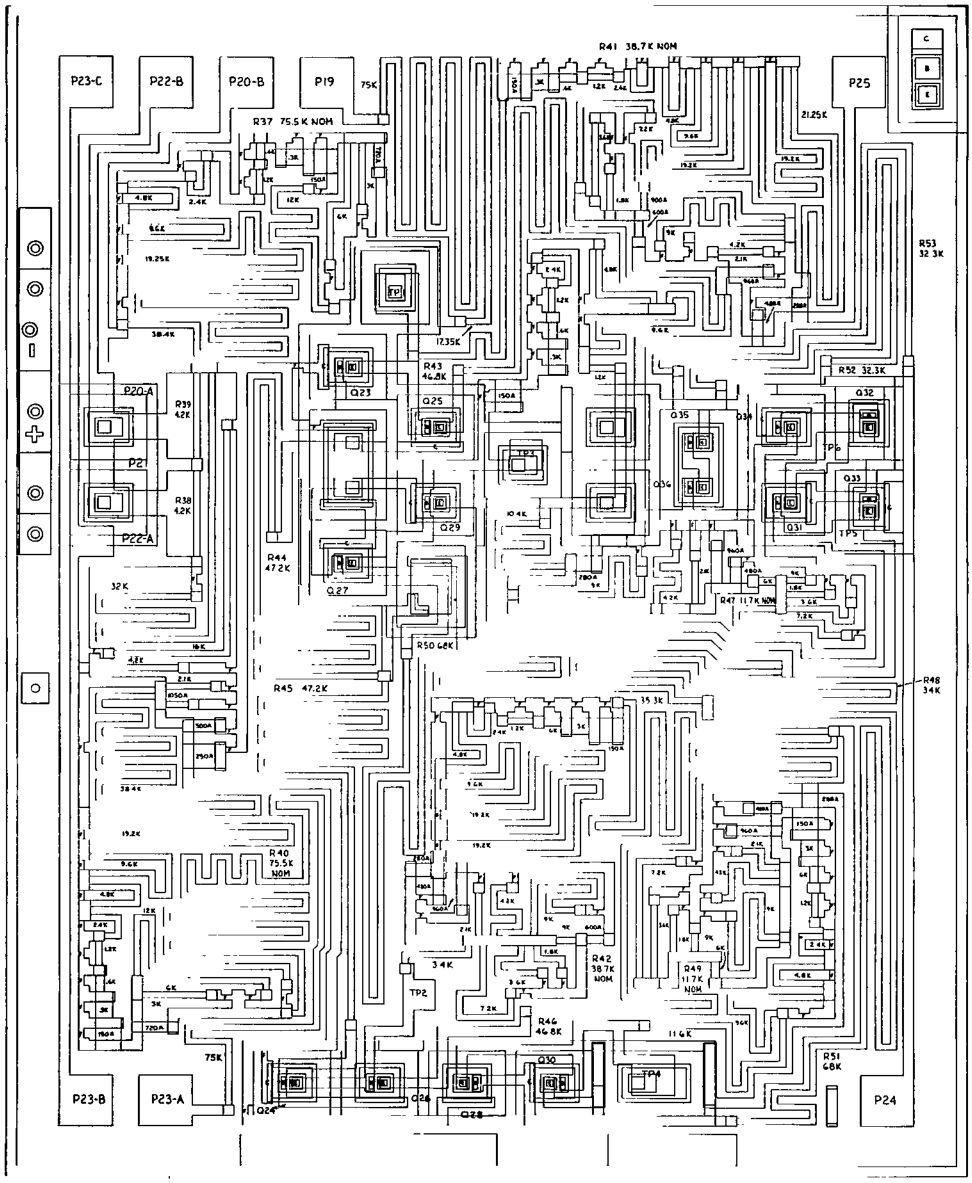


Figure 6. - Layout of the drift-offset compensation-control circuitry (SCA4-2) die.

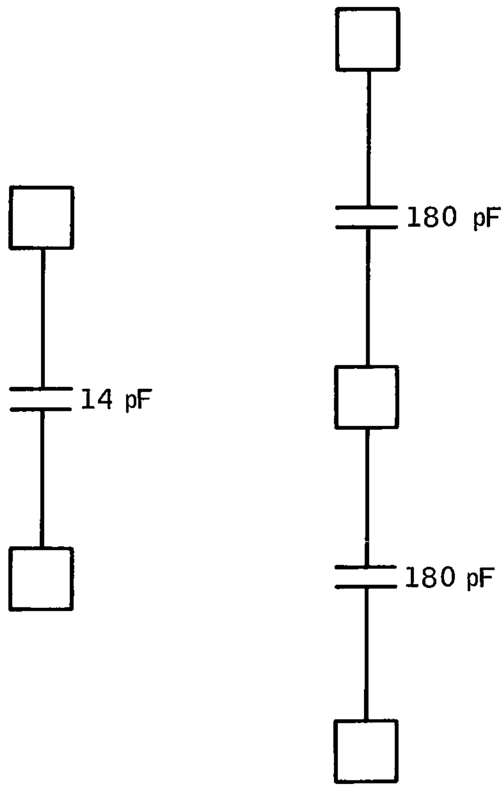


Figure 7. - Schematic diagram of the capacitor module (CA-02).

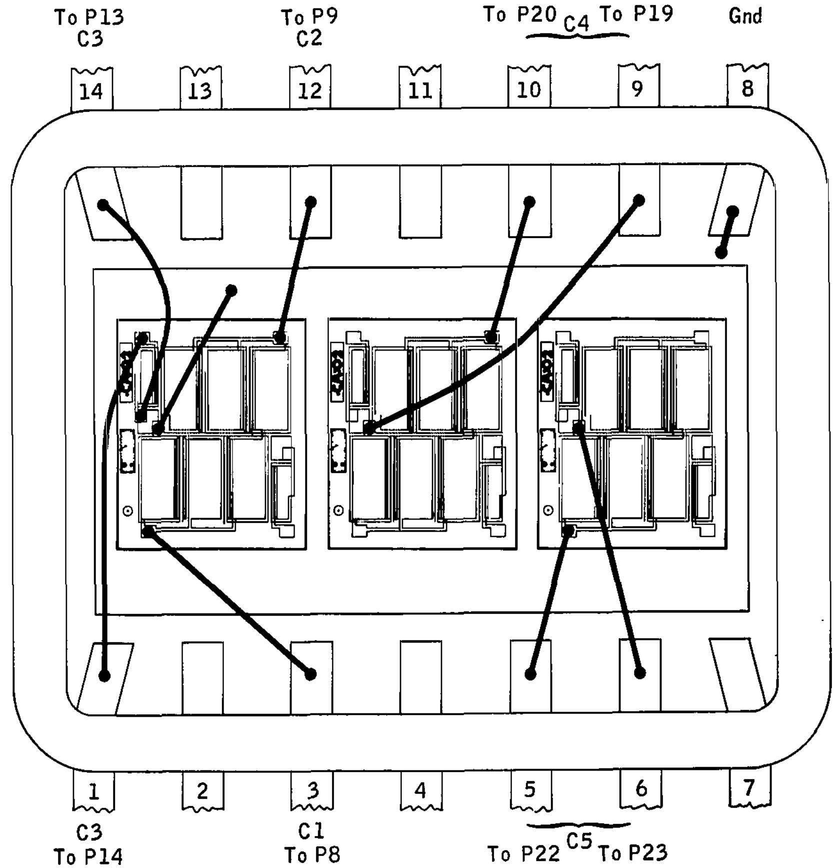


Figure 8. - Capacitor module (CA-02).

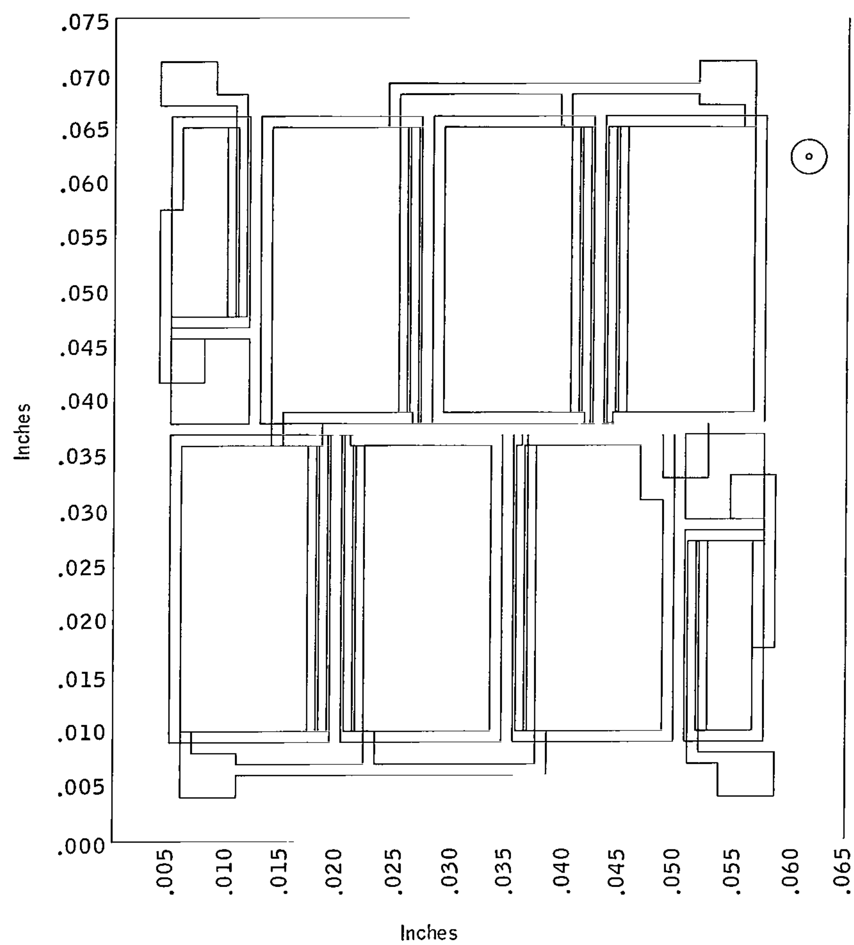


Figure 9. - Layout of the capacitor (CA-02) die.

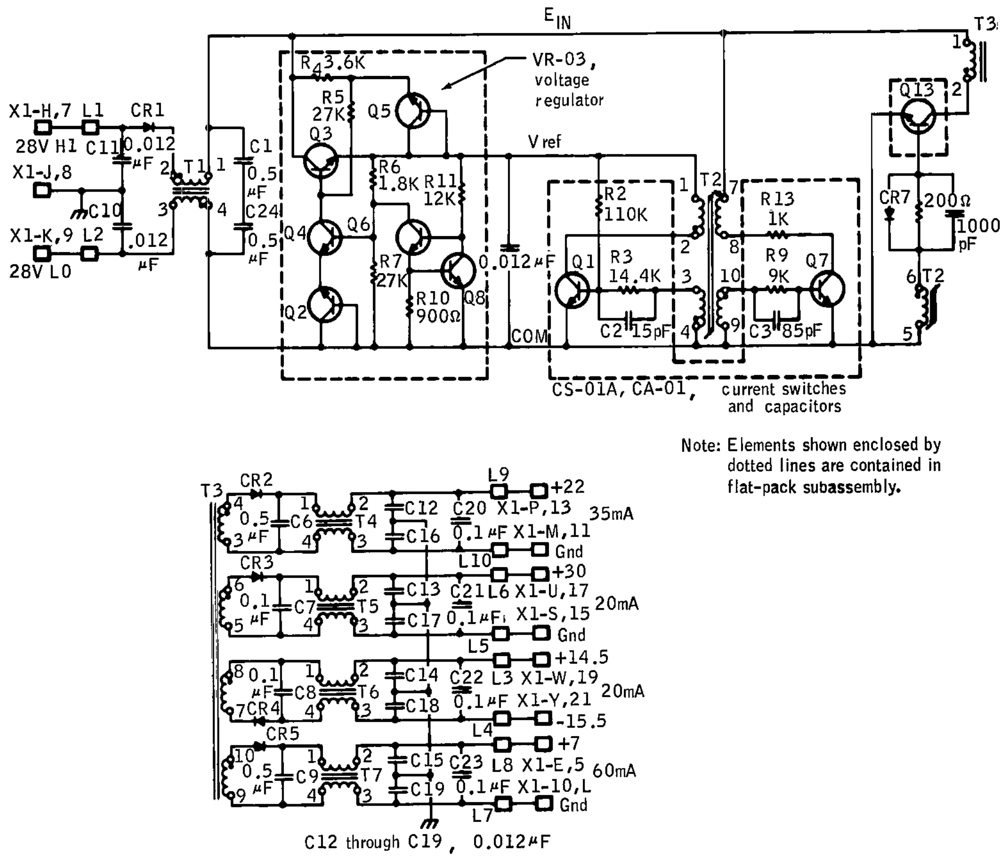


Figure 10. - Schematic diagram of a 3-watt converter.

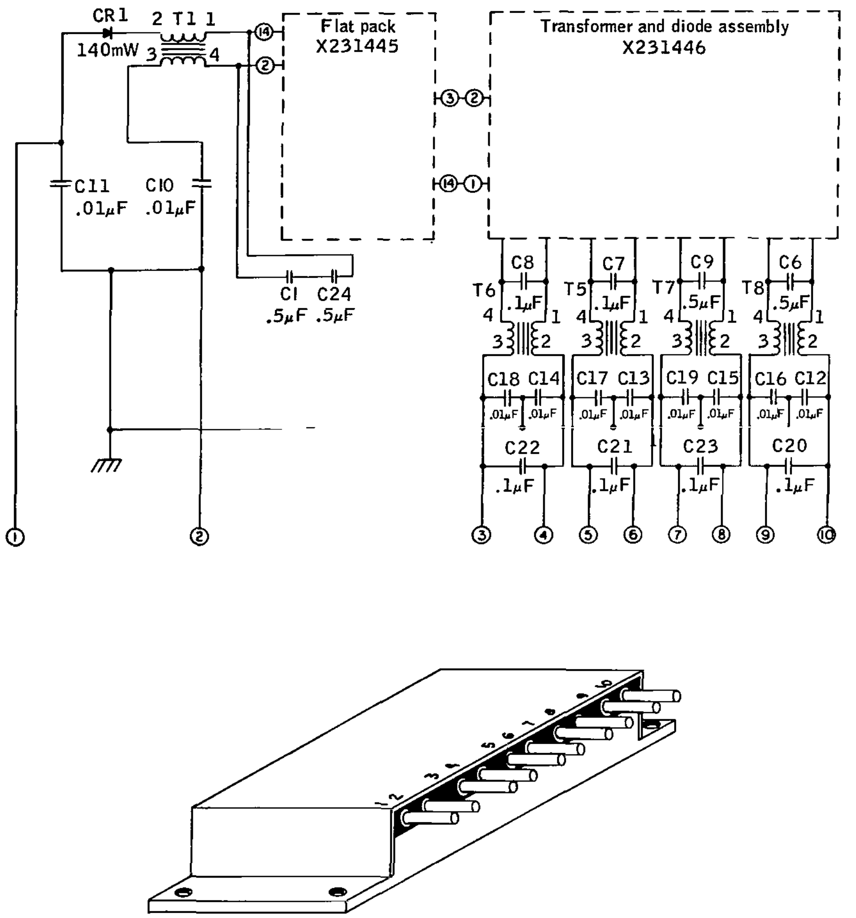


Figure 11. - Component subassembly of a 3-watt converter.

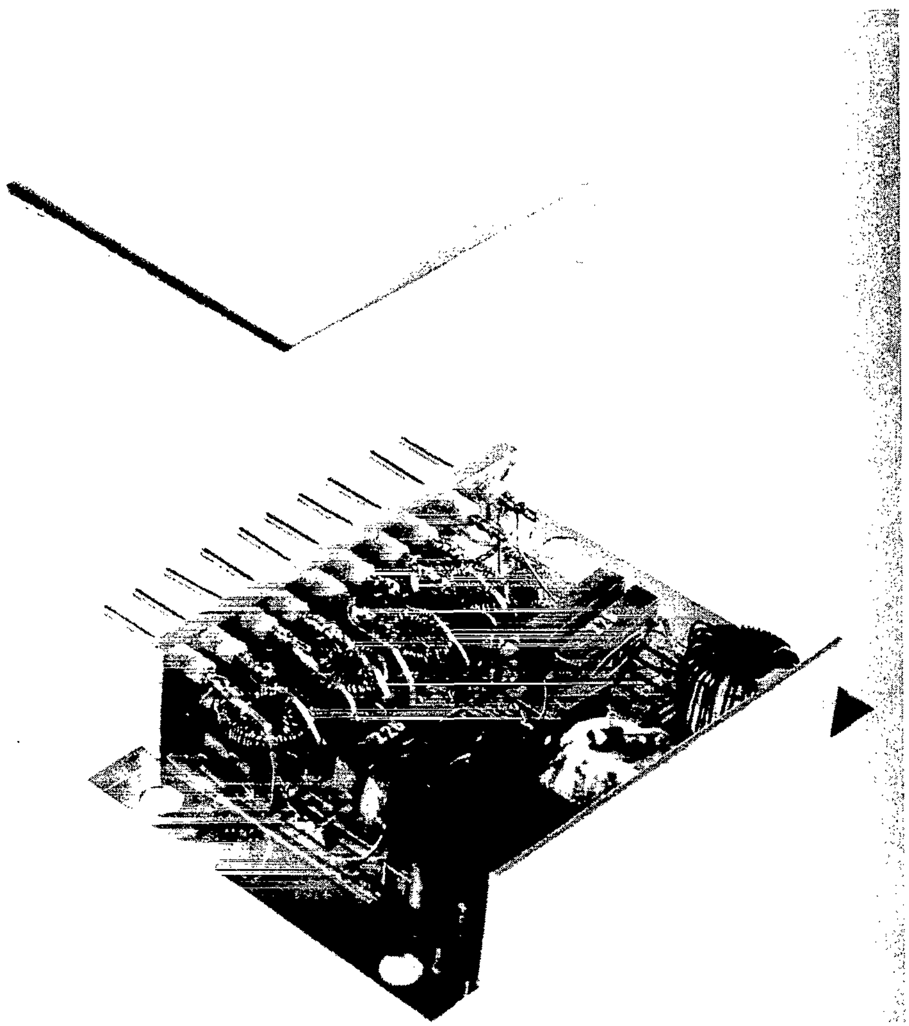


Figure 12. - Internal photograph of a 3-watt converter.

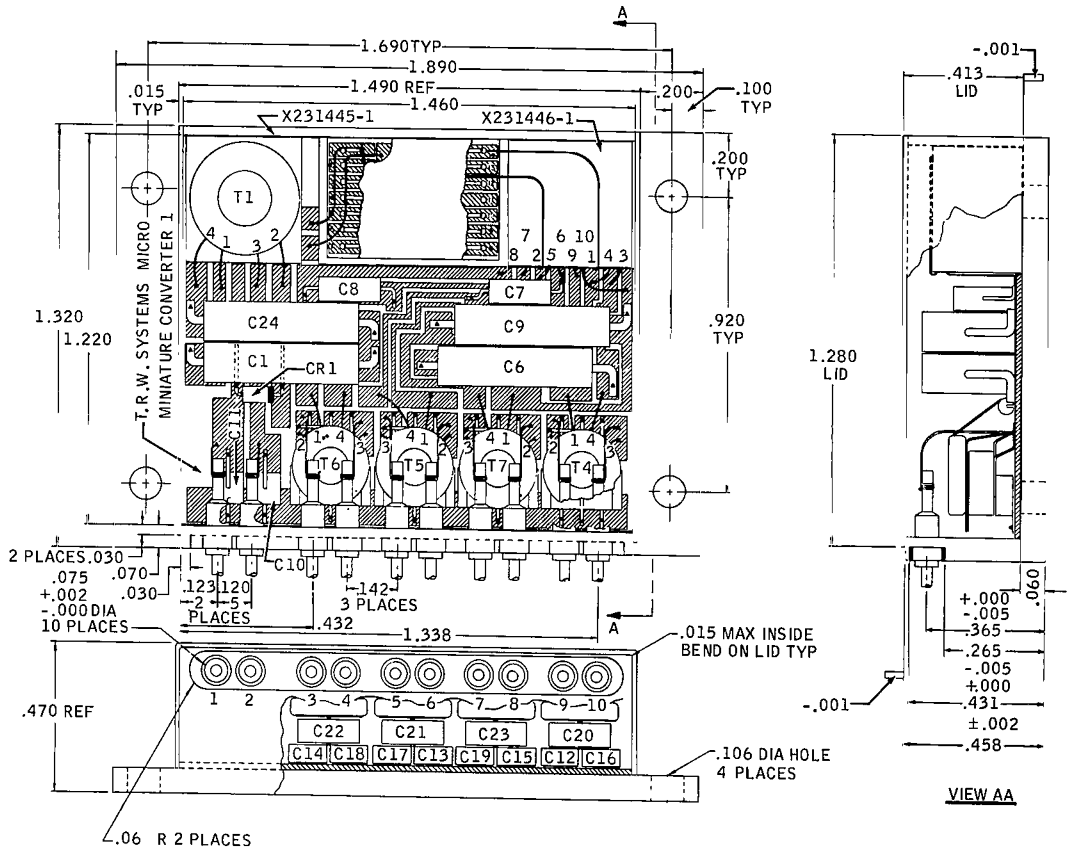


Figure 13. - Mechanical assembly of a 3-watt converter.

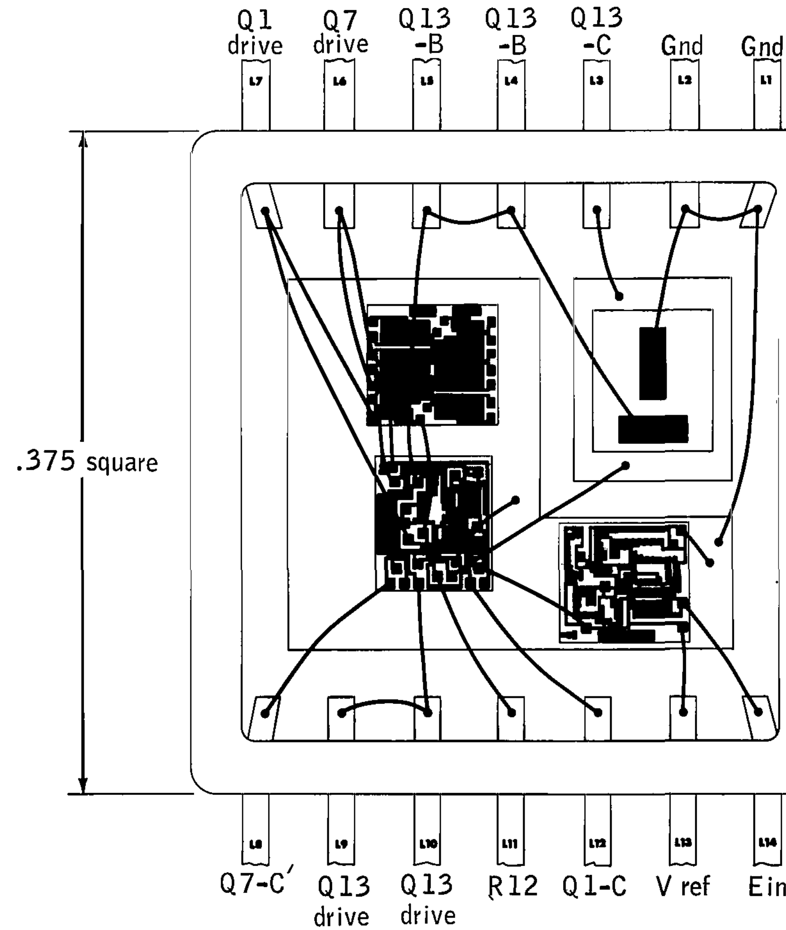


Figure 14. - Flat-pack assembly of a 3-watt converter.

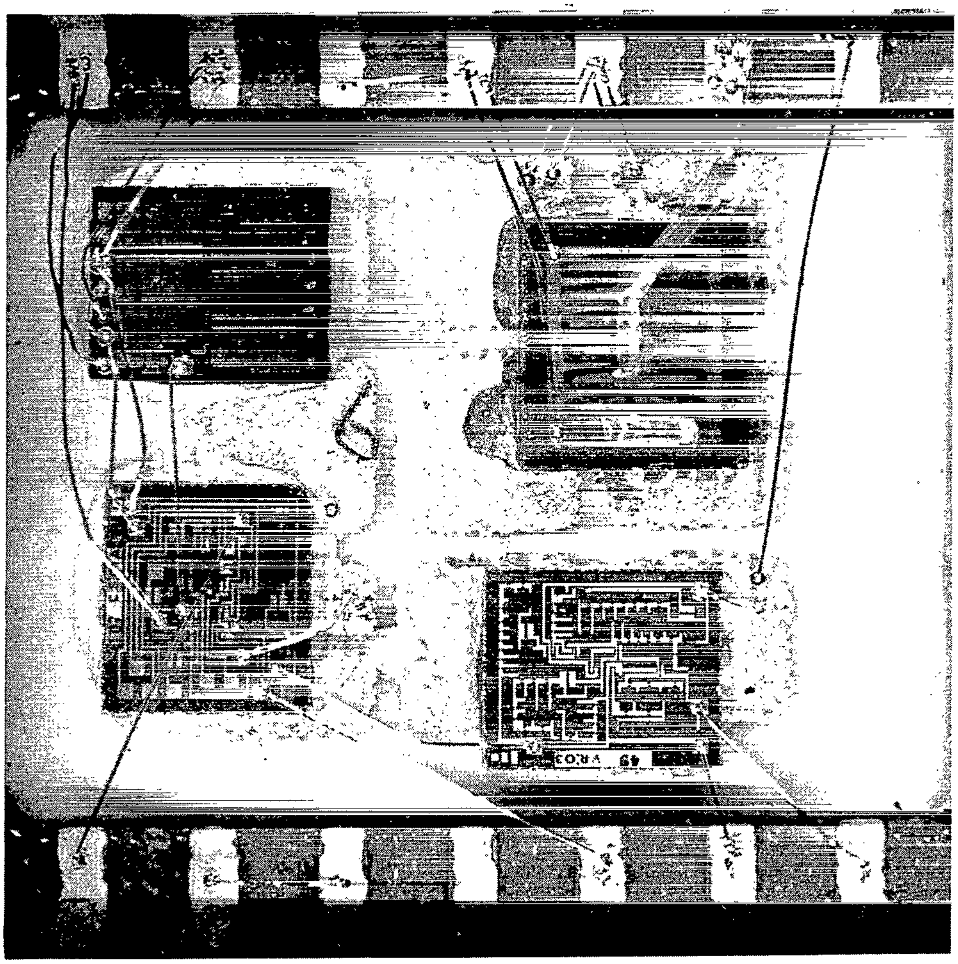


Figure 15. - Flat-pack assembly photograph of a 3-watt converter.

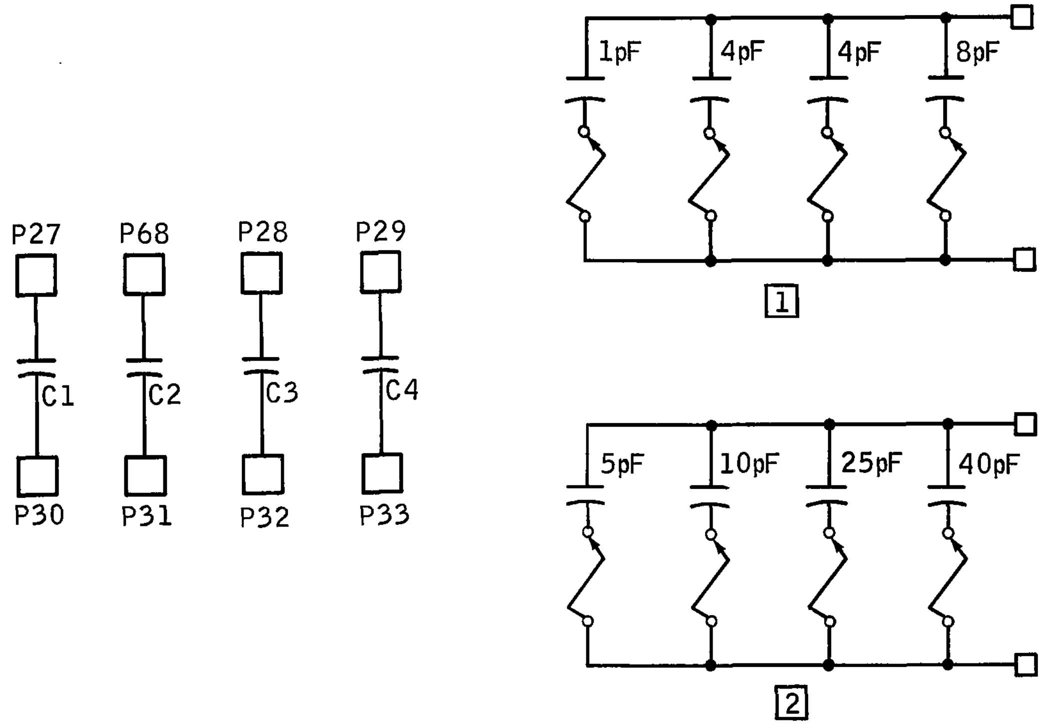


Figure 16. - Schematic diagram of the capacitor module (CA-01).

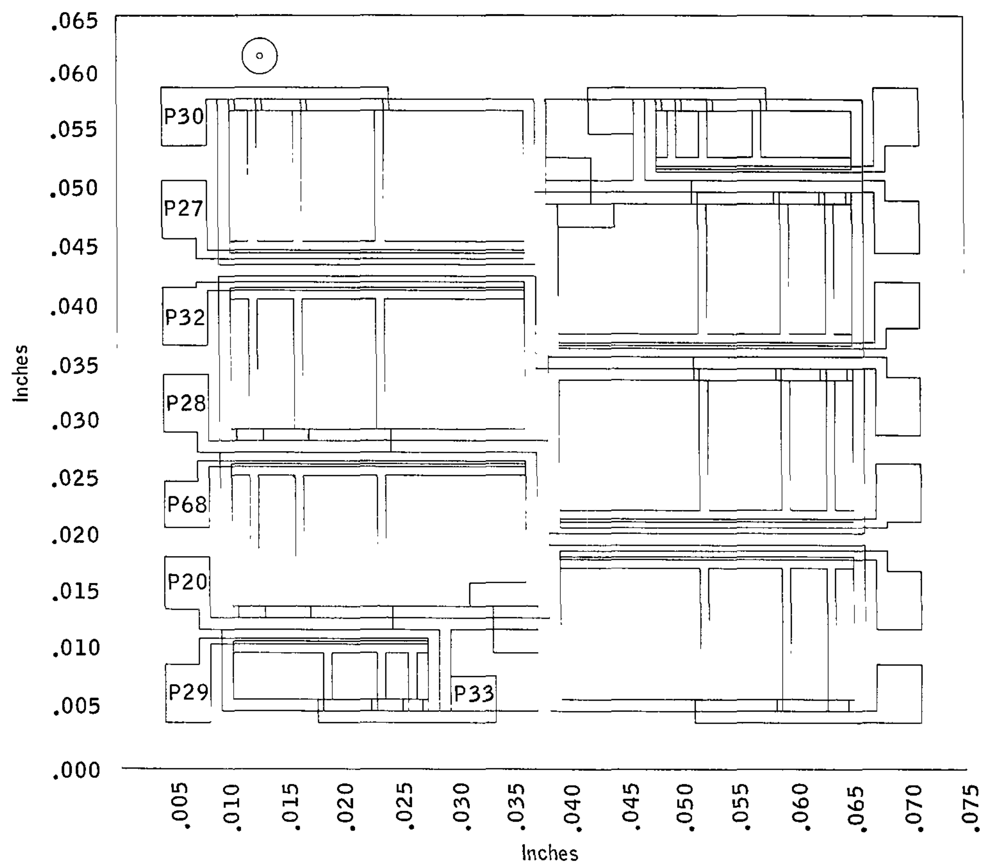


Figure 17. - Layout of the capacitor (CA-01) die.

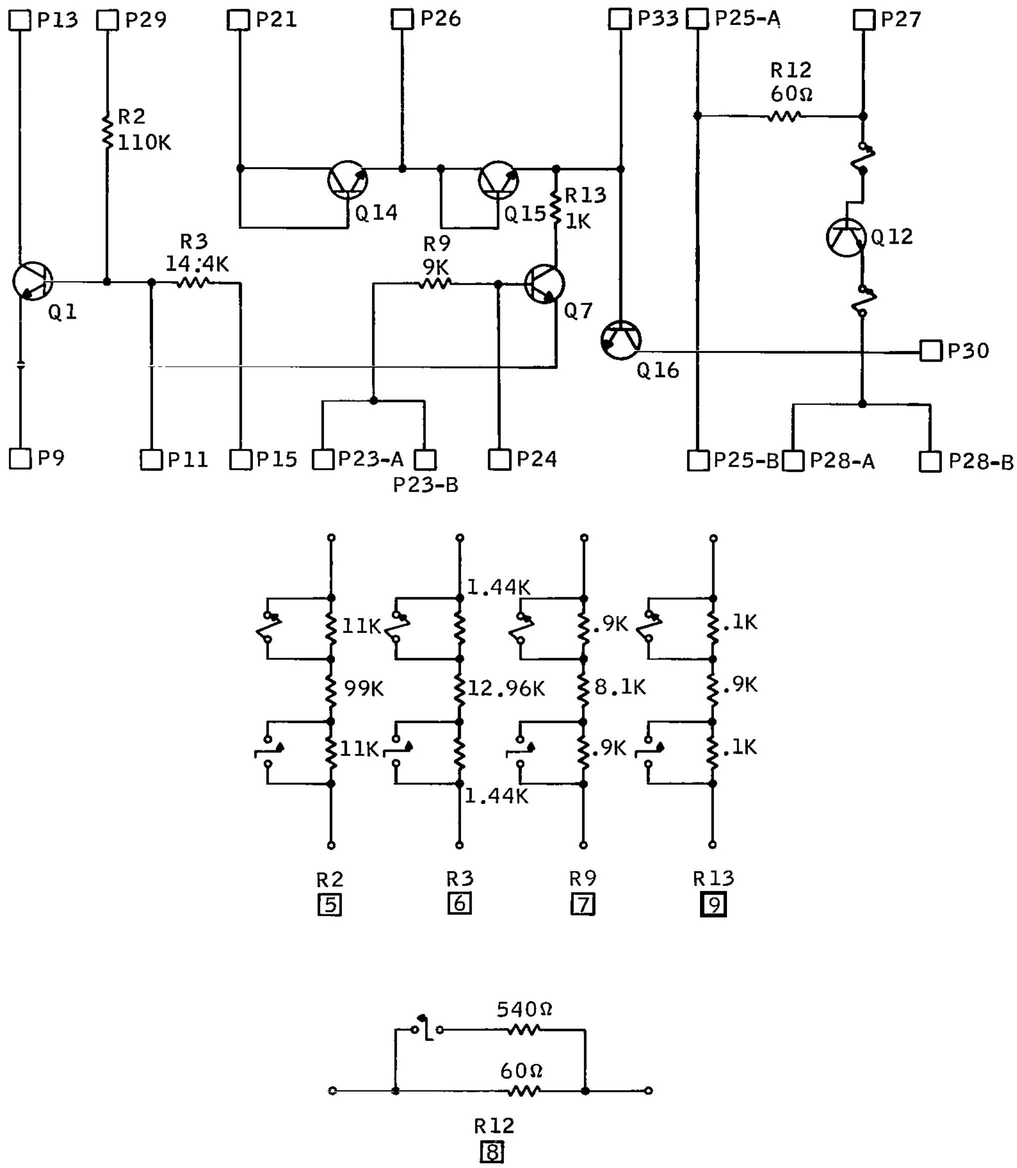


Figure 18. - Converter switch (CS-01A) schematic.

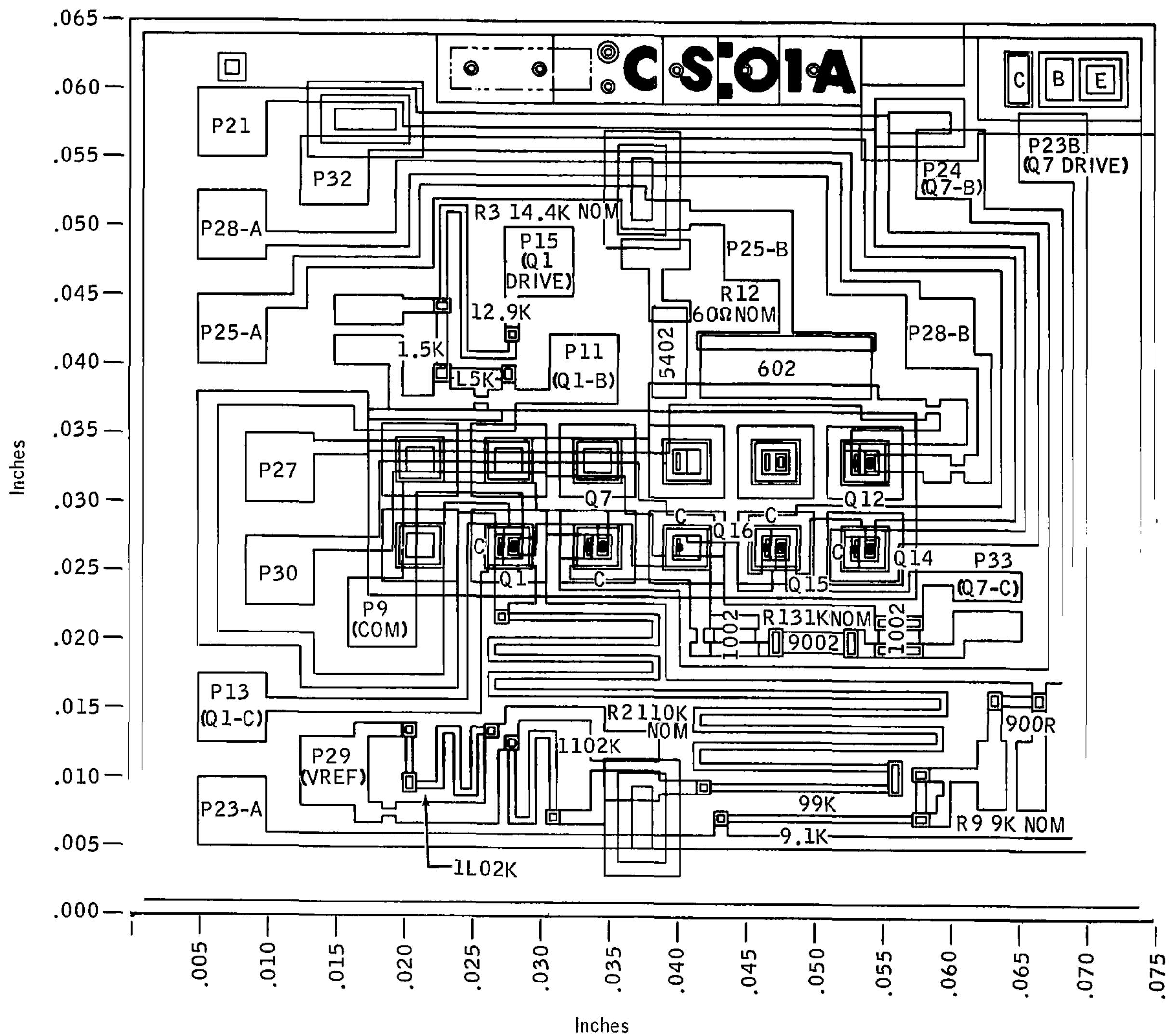
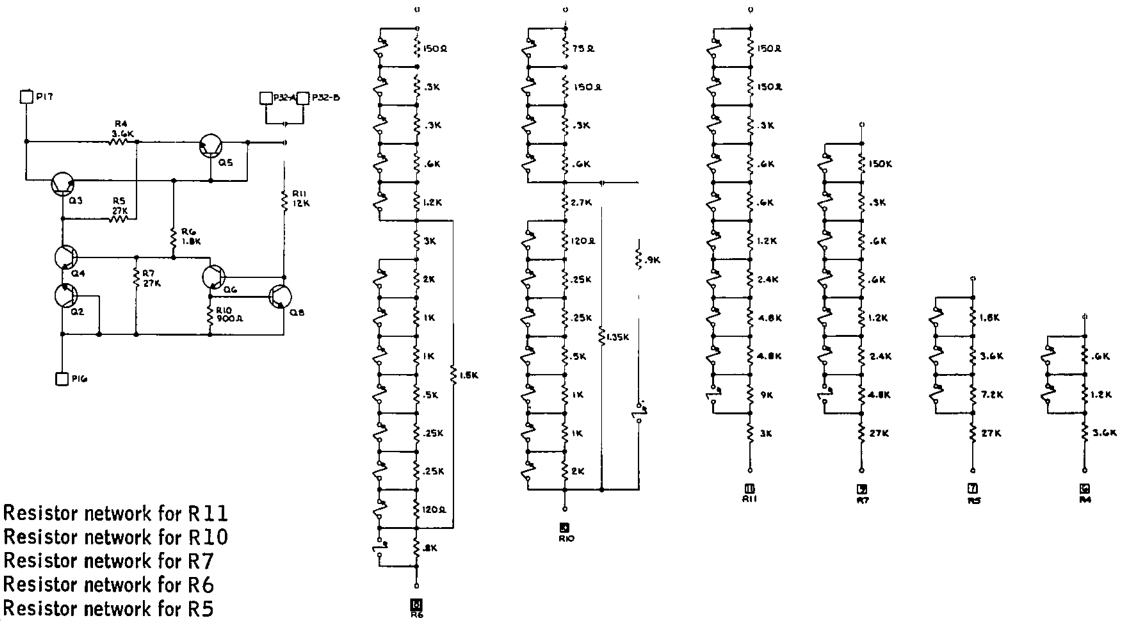


Figure 19. - Layout of the converter switch (CS-01A) die.



11 Resistor network for R11
10 Resistor network for R10
9 Resistor network for R7
8 Resistor network for R6
7 Resistor network for R5
6 Resistor network for R4

5 Symbol represents fusible conductor, normally open

4 Symbol represents fusible conductor, normally closed

Figure 20. - Converter voltage regulator (VR-03) schematic.

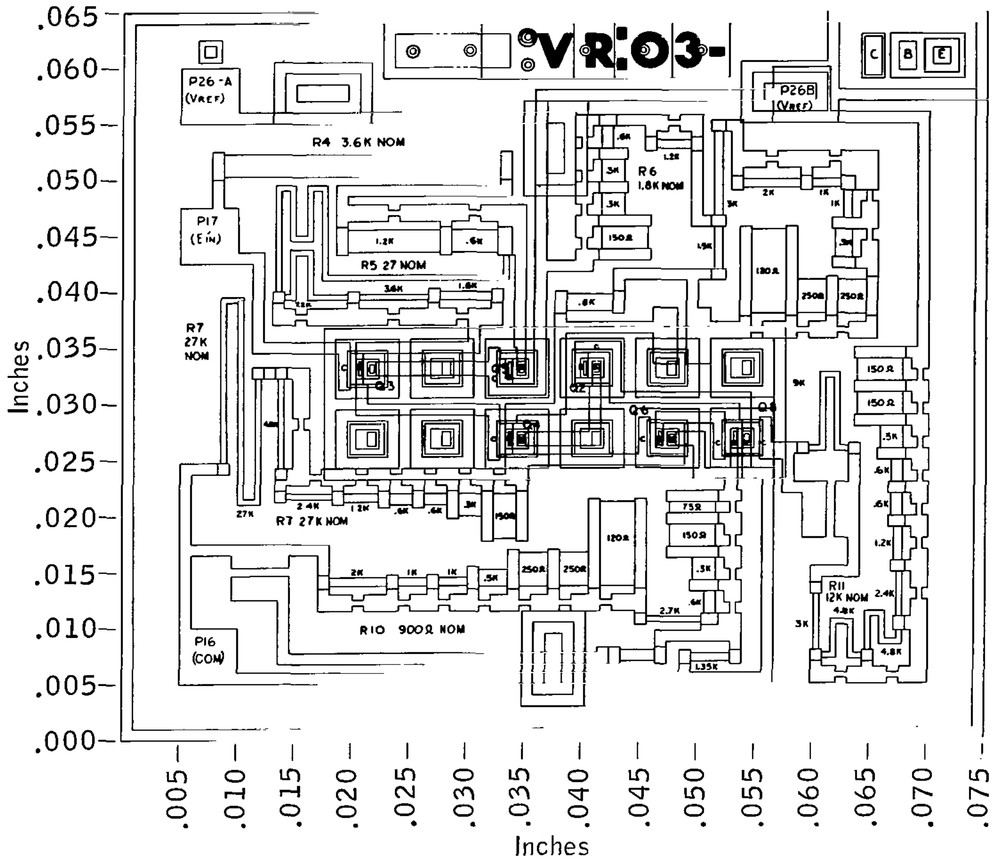


Figure 21. - Layout of the converter voltage regulator (VR-03) die.

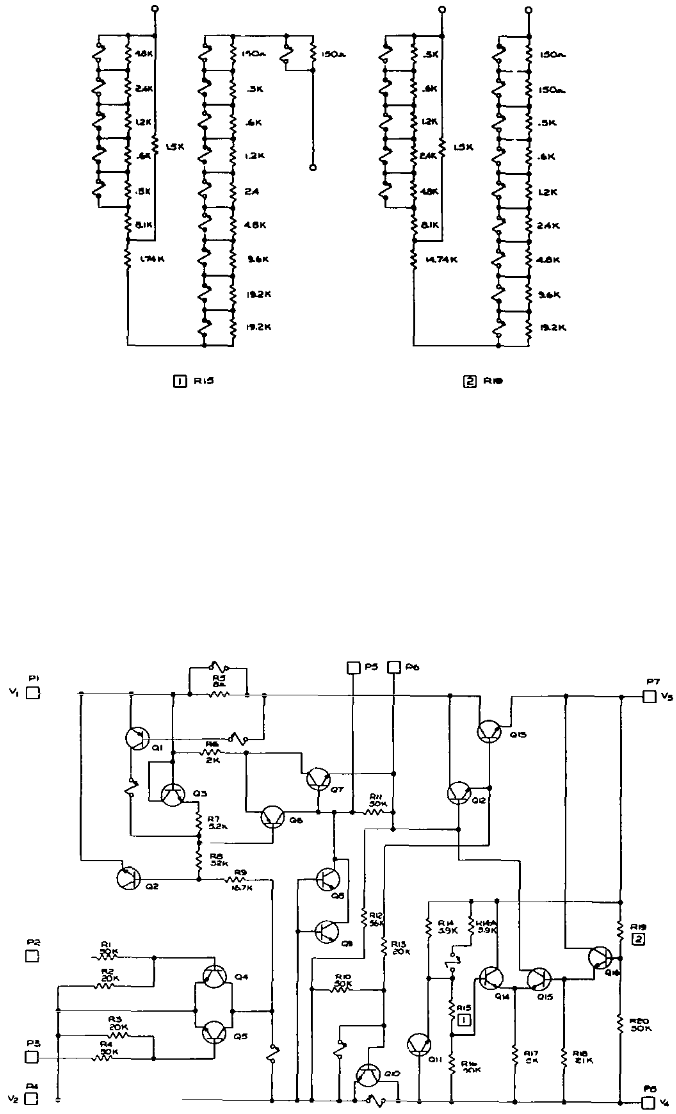


Figure 22. - Converter voltage regulator (VR3-4) schematic, 10-volt.

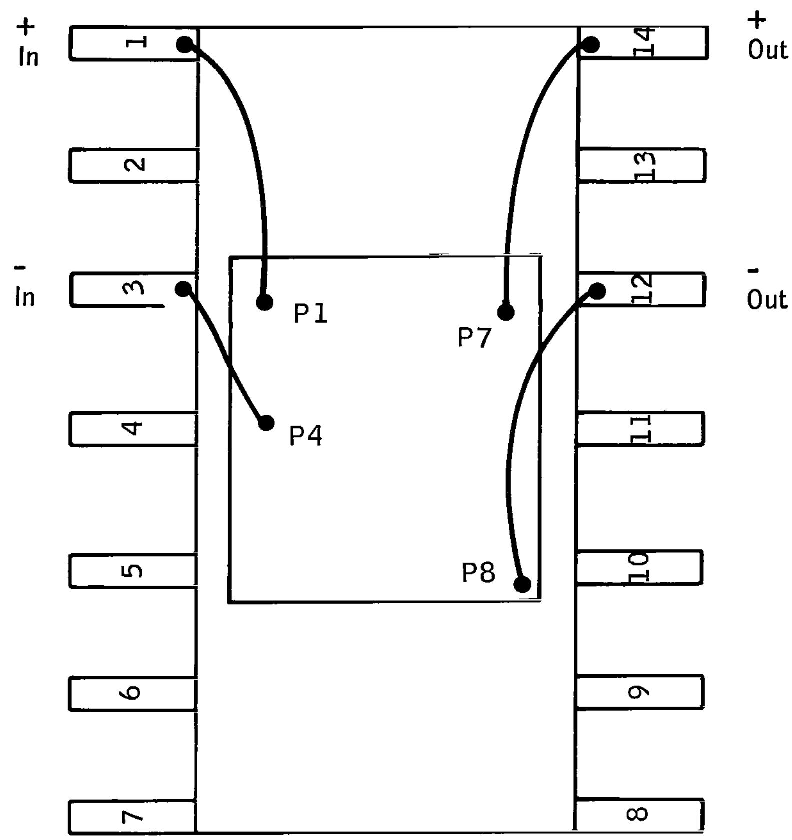


Figure 23. - Converter voltage regulator (VR3-4), 10-volt.

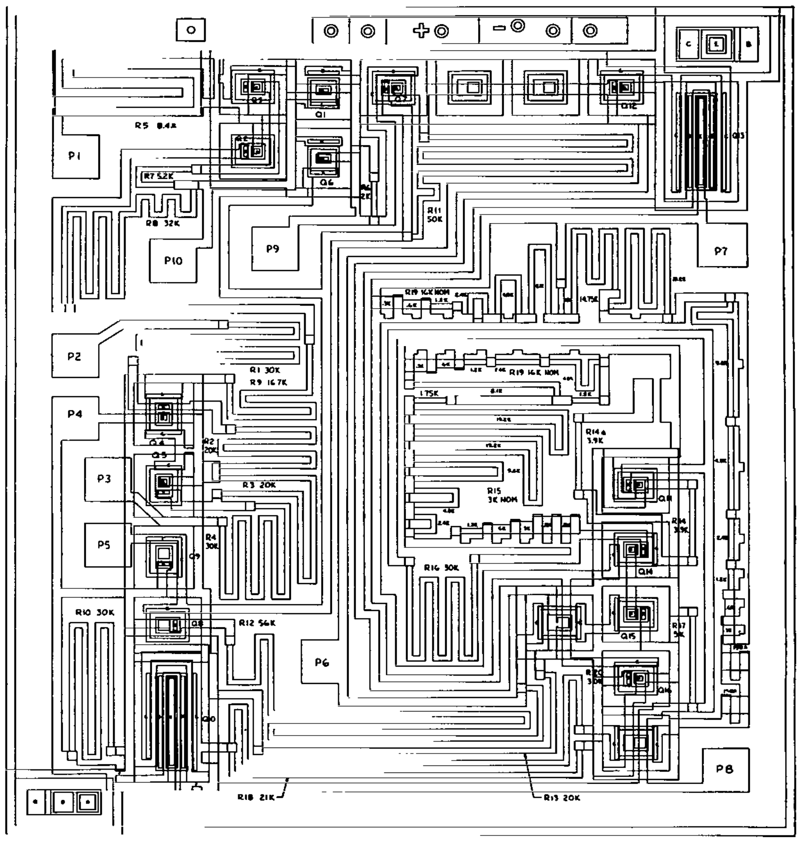


Figure 24. - Layout of the converter voltage regulator (VR3-4) die.

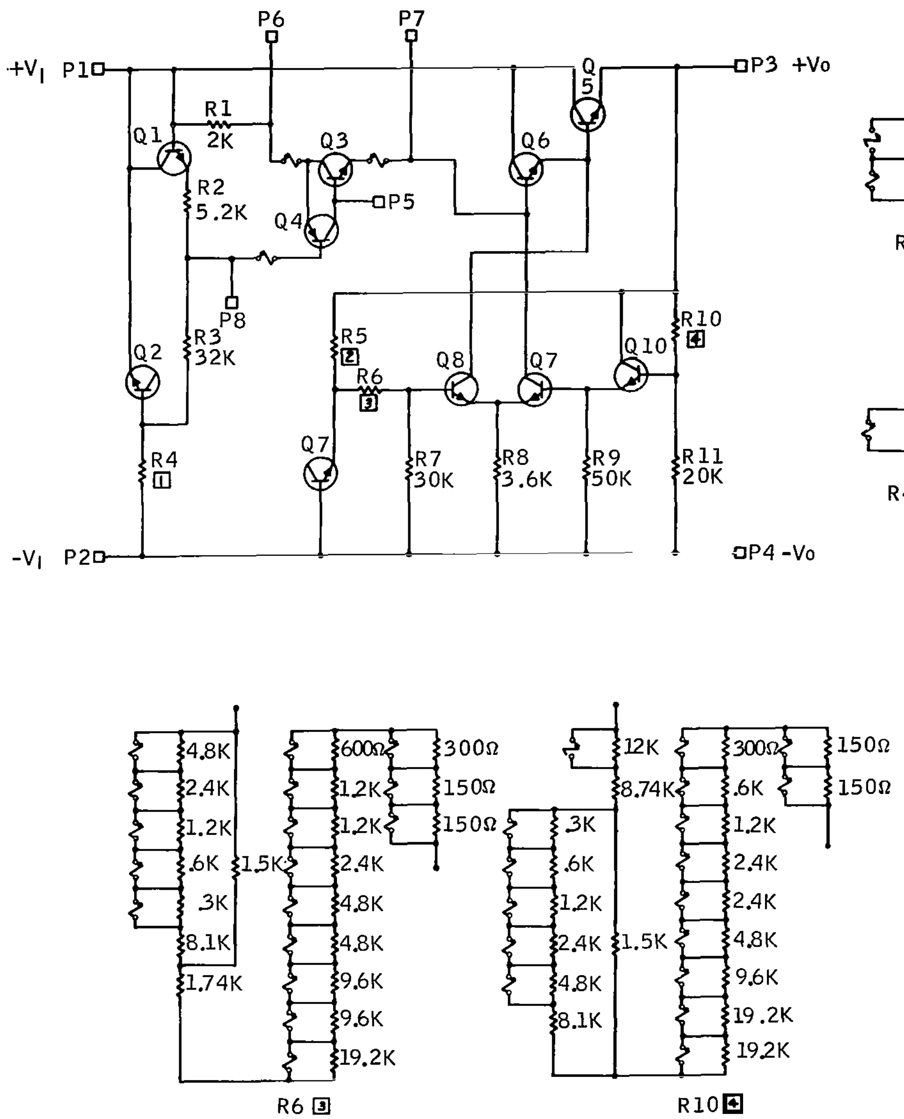


Figure 25. - Converter voltage regulator (VR3-5) schematic, 15-volt.

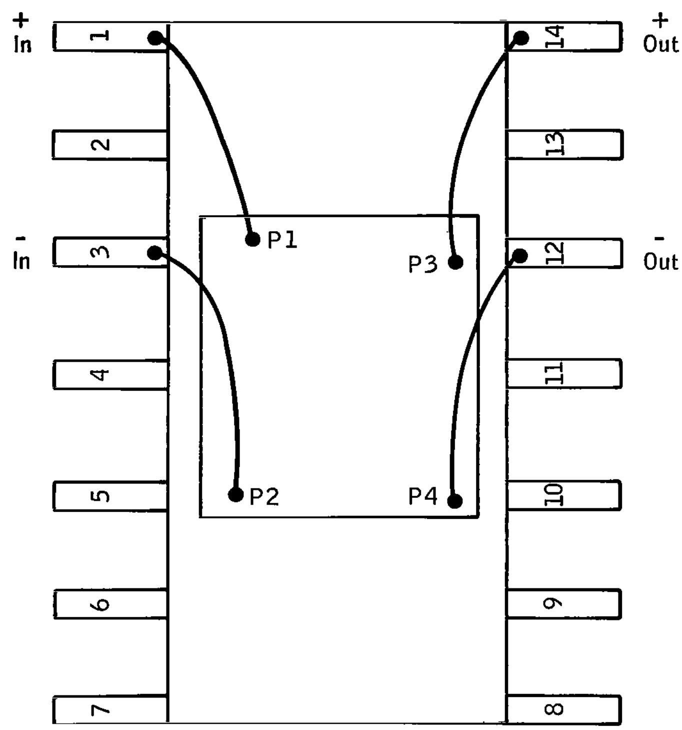


Figure 26. - Converter voltage regulator (VR3-5), 15-volt.

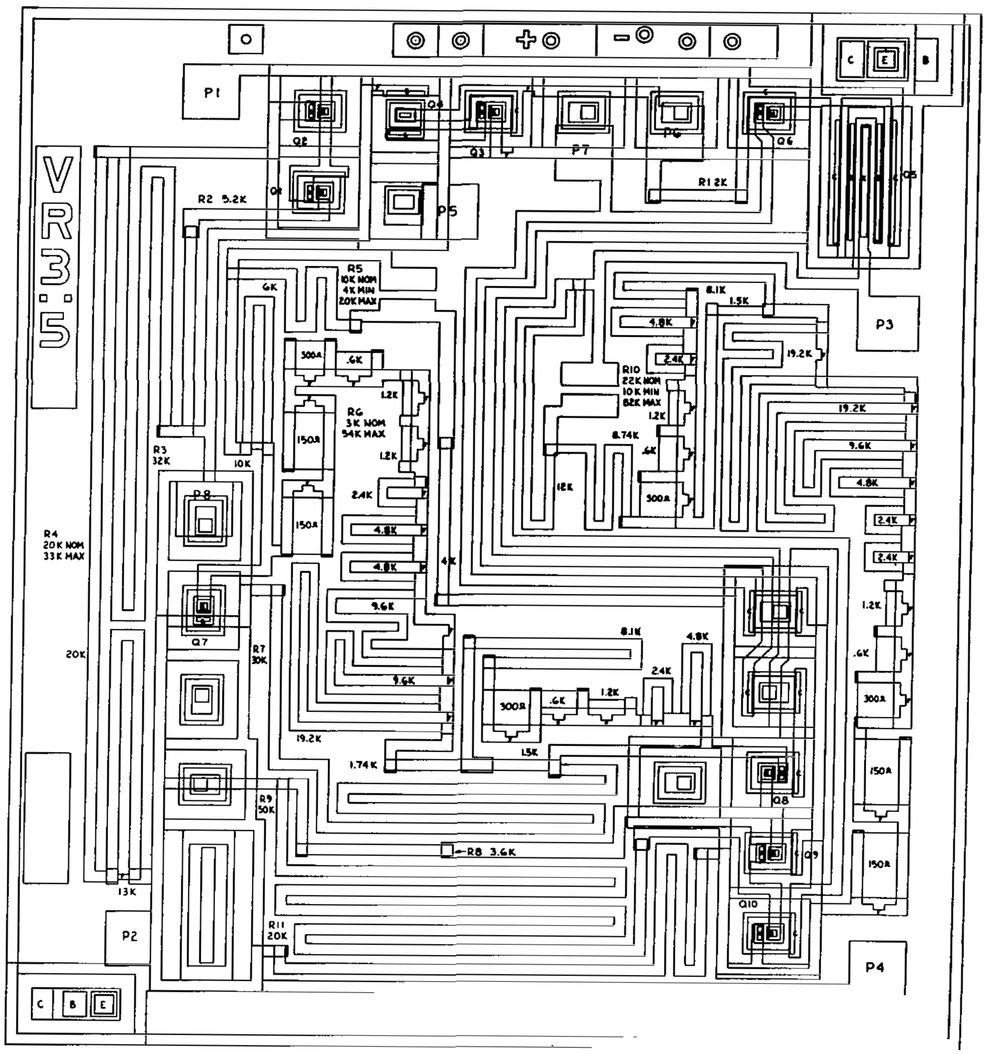


Figure 27. - Layout of the converter voltage regulator (VR3-5) die.

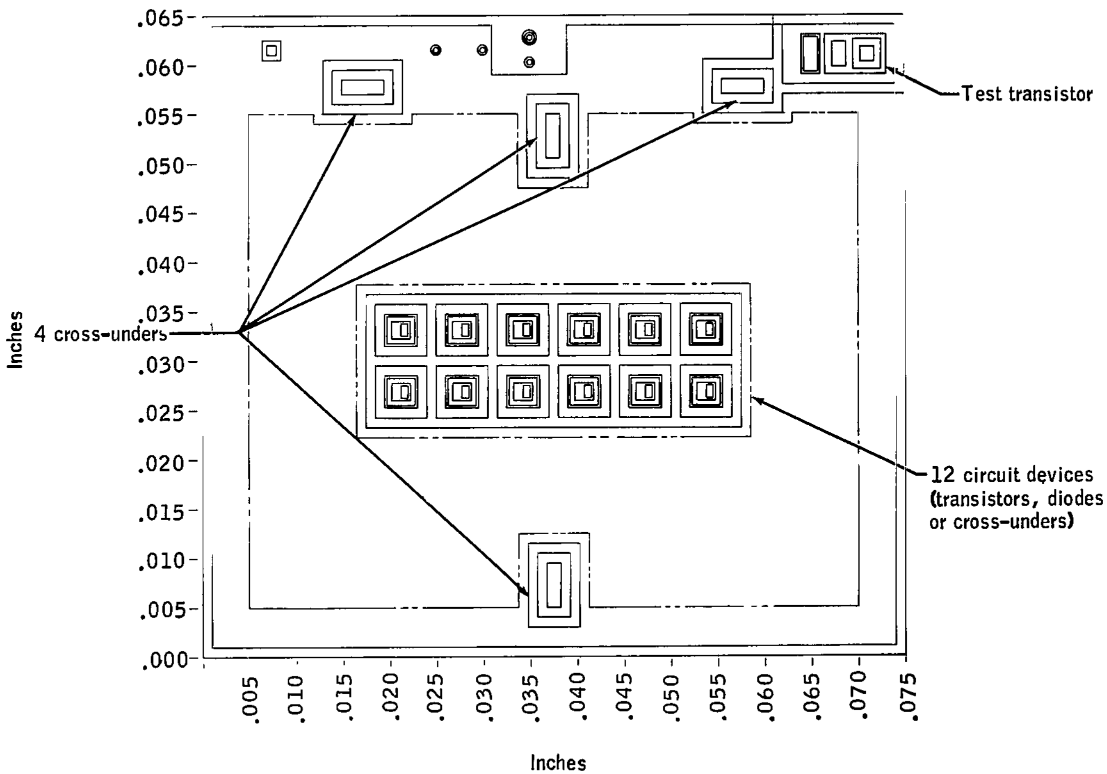


Figure 28. - Multicircuit die (MDC-1).

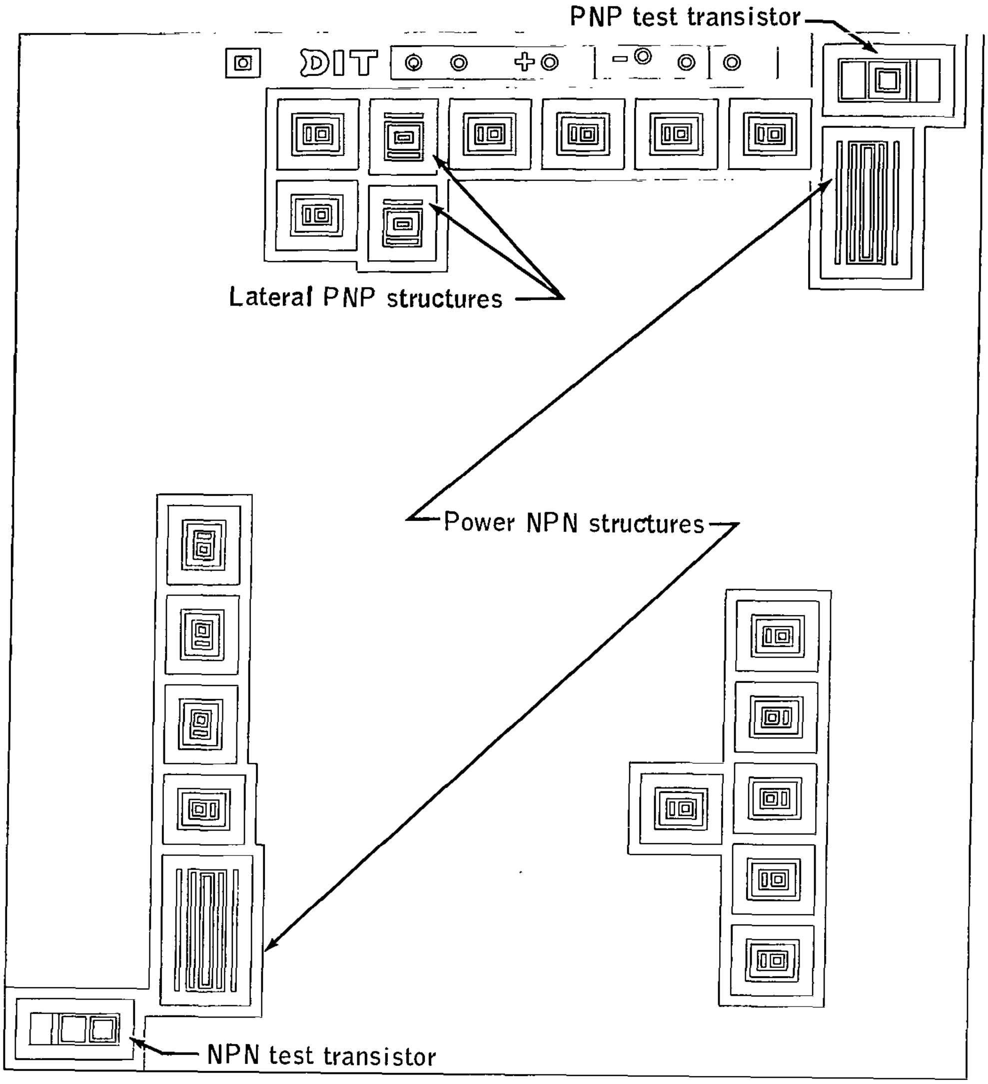


Figure 29. - Multicircuit die (MCD-3).

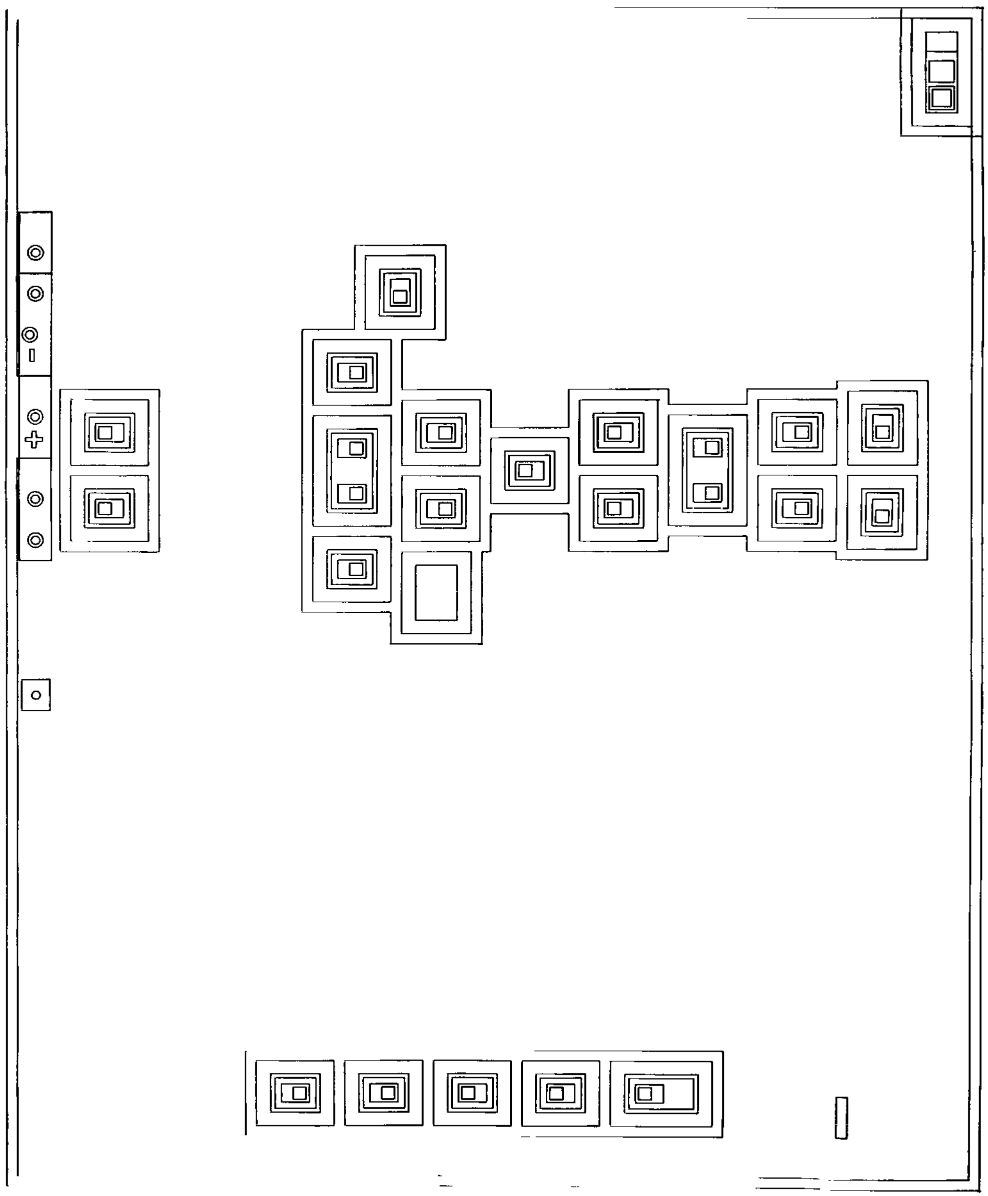
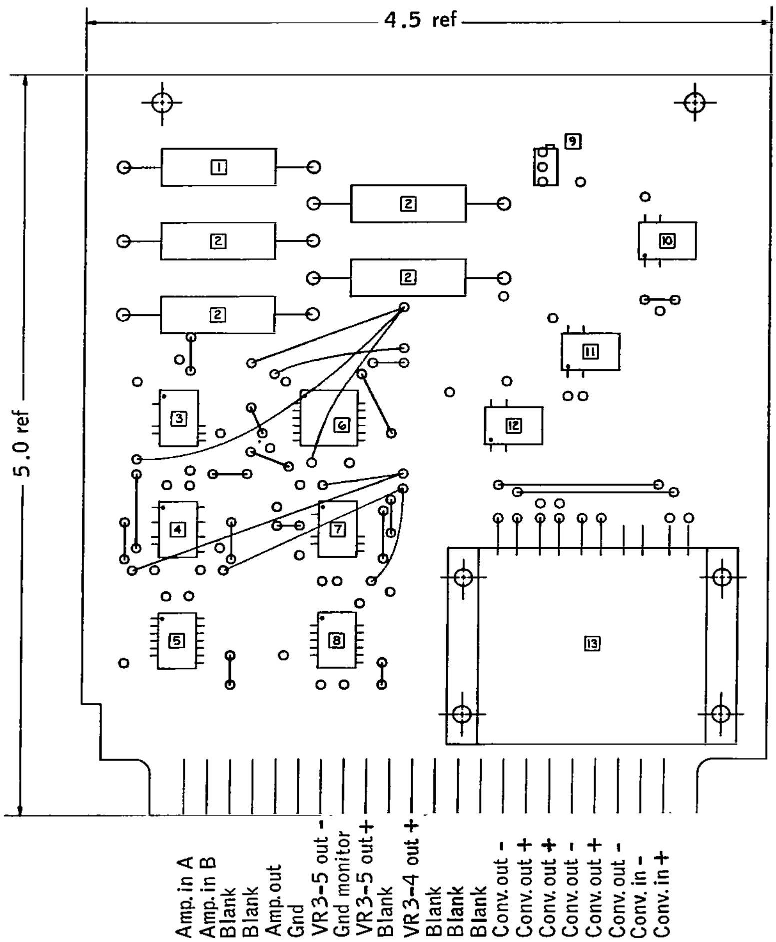


Figure 30. - Multicircuit die (MCD-4).



Notes:

1. Bridge adjust
2. Bridge resistors
3. SCA4-2 (X233757)
4. Two CA-01's (X223694)
5. SCA4-1 (X232884)
6. SCA4-1 /SCA4-2 /CA3-1
7. SCA4-2
8. SCA4-1 / two CA-01's
9. Bridge adjust potentiometer
10. VR3-4 (X231932)
11. VR3-5 (X233756)
13. VR3-5
14. 3-watt converter (X231447) or (X235202)

Figure 31. - Printed-circuit test-board assembly.

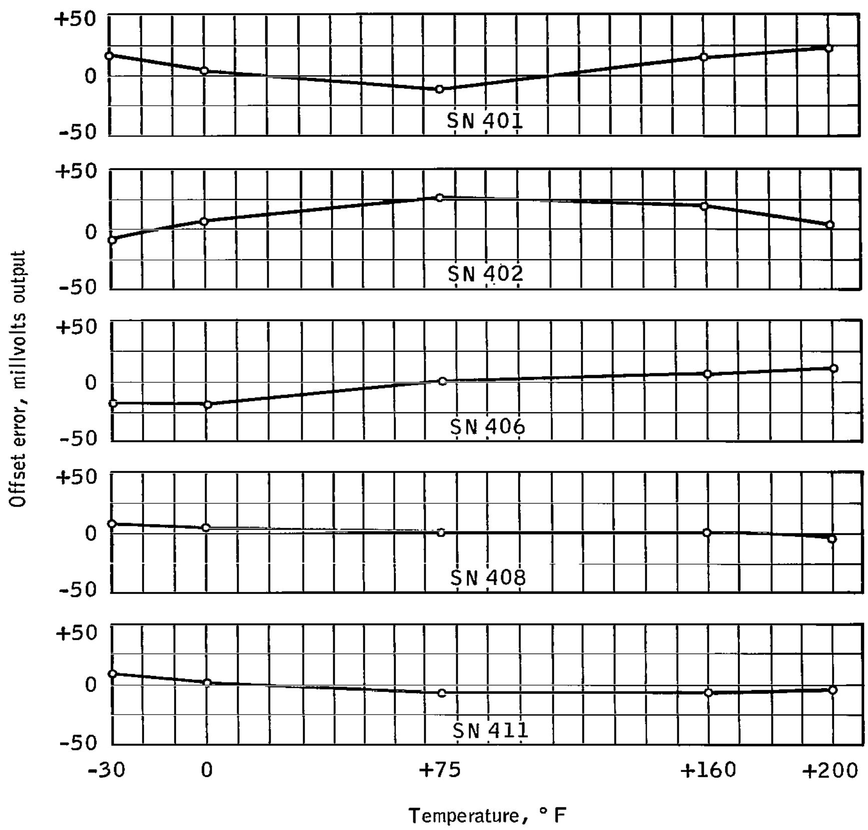


Figure 32. - Offset stability with temperature (gain = 50).

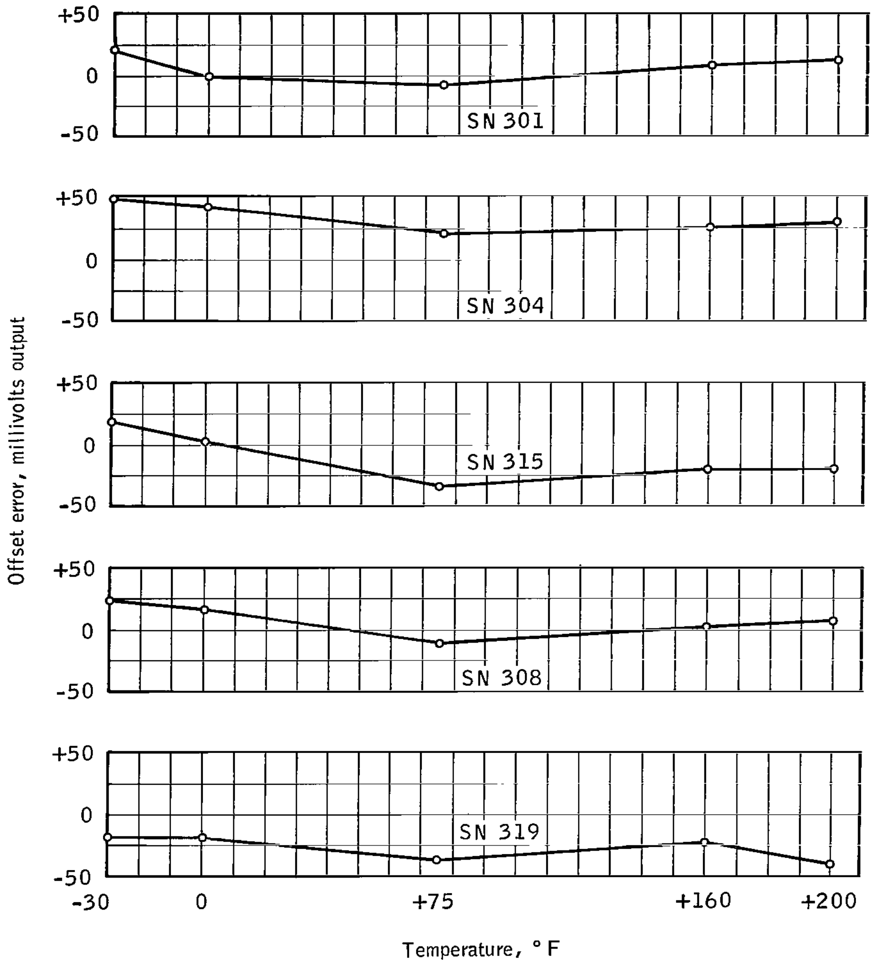


Figure 33. - Offset stability with temperature (gain = 1000).

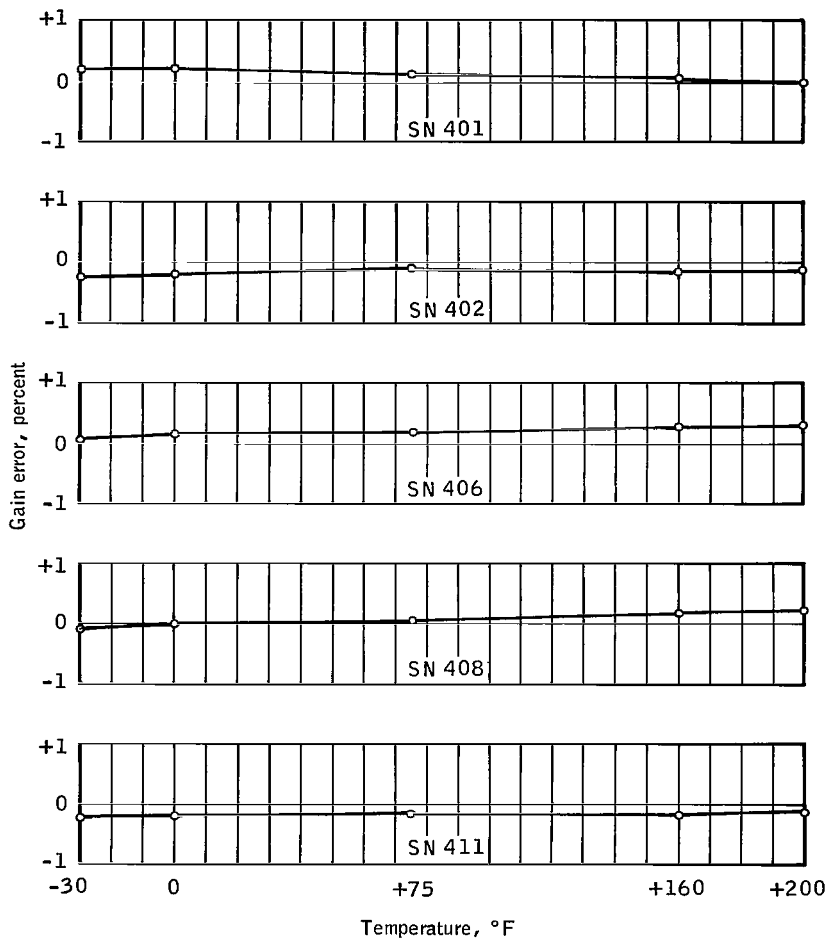


Figure 34.- Gain stability with temperature (gain = 50).

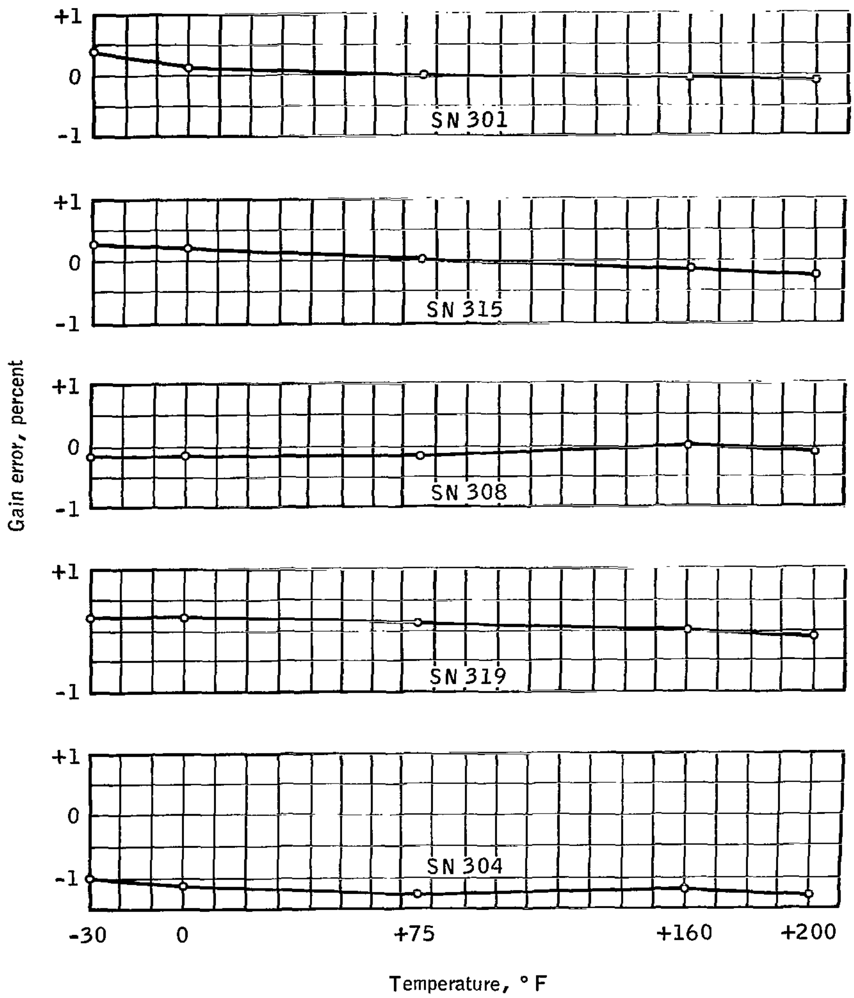


Figure 35. - Gain stability with temperature (gain = 1000).

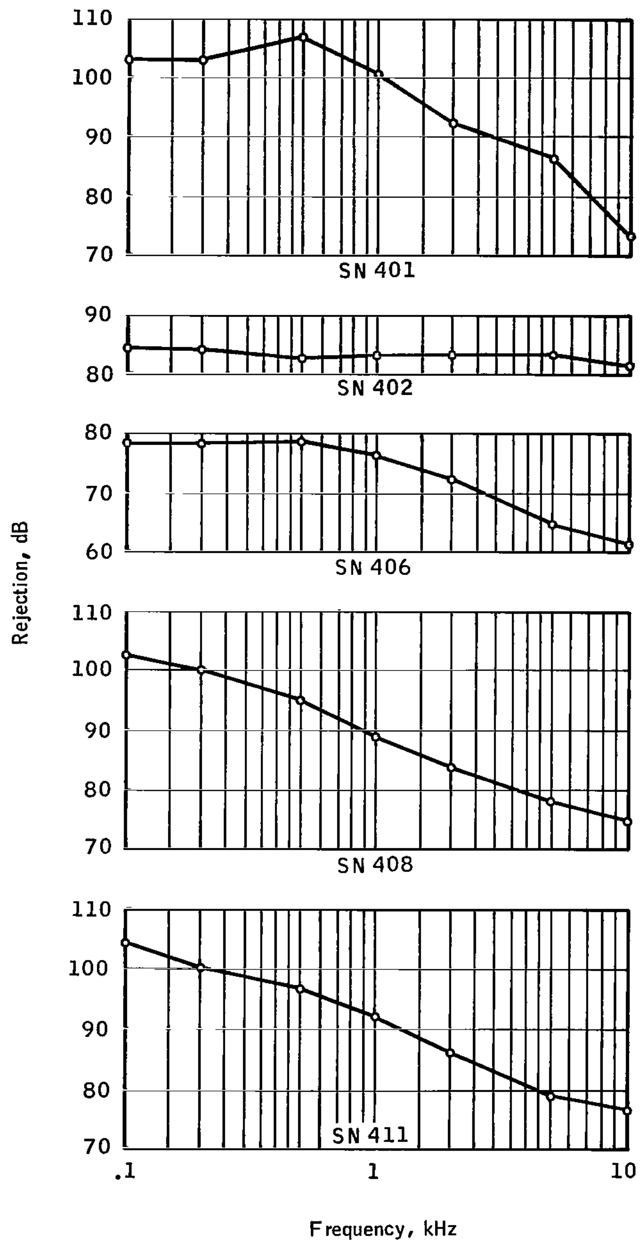


Figure 36. - Common-mode input-signal rejection (gain = 50).

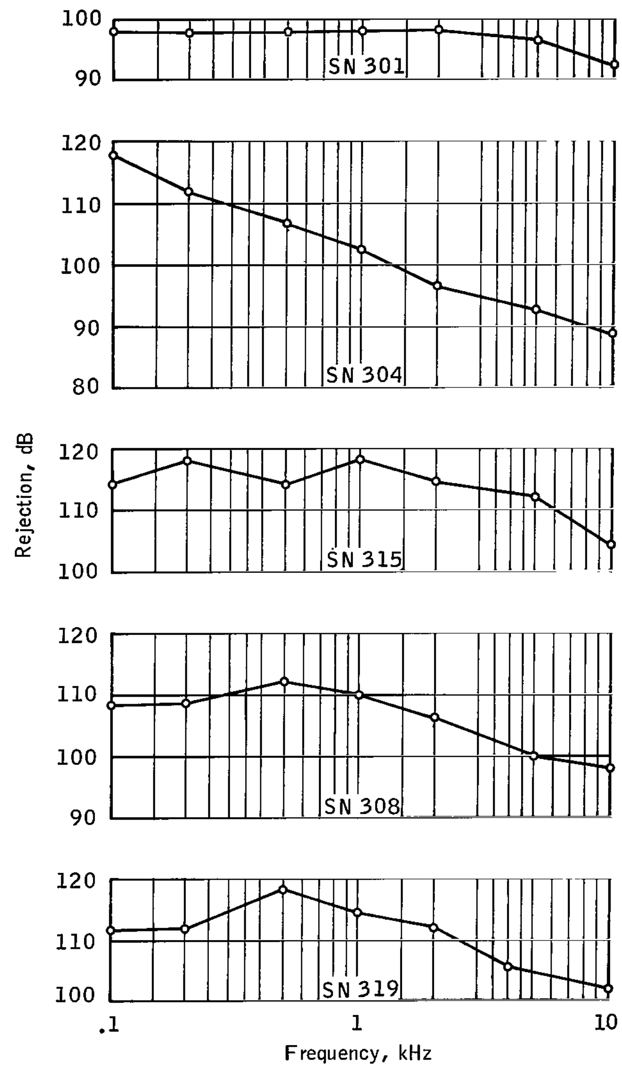


Figure 37. - Common-mode input-signal rejection (gain = 1000).

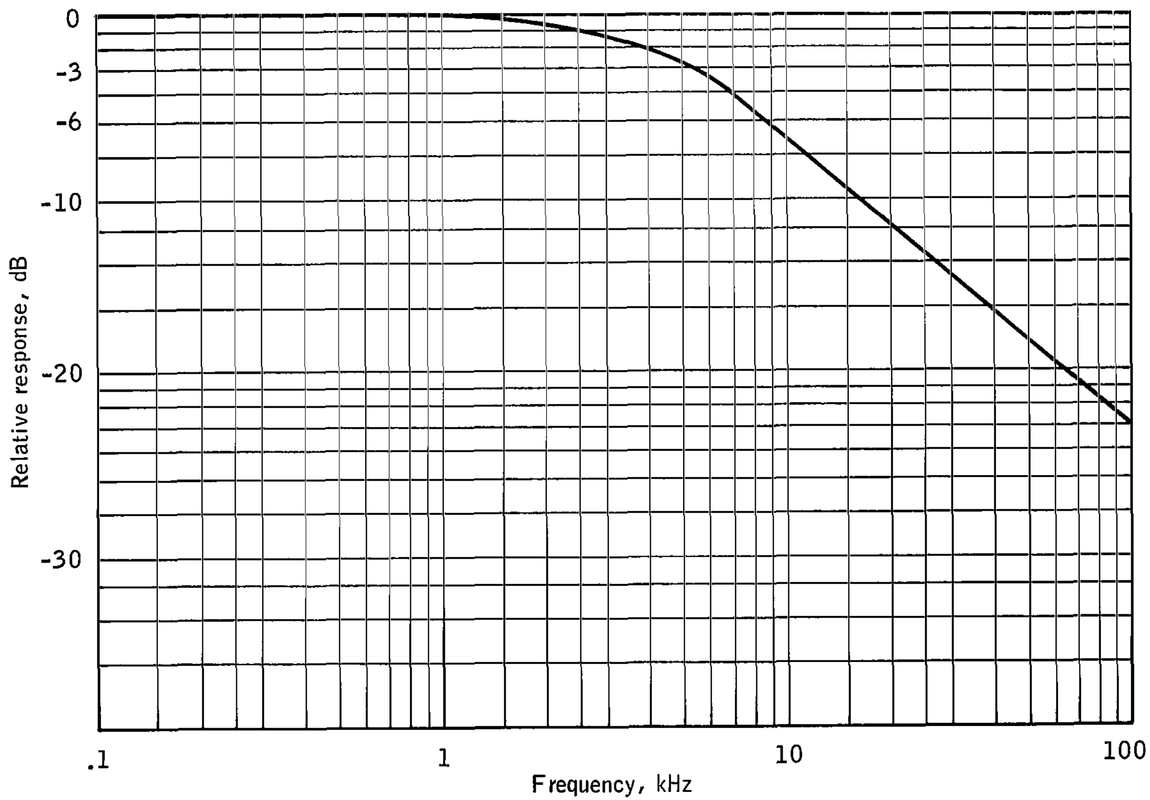


Figure 38. - Frequency response (gain = 50).

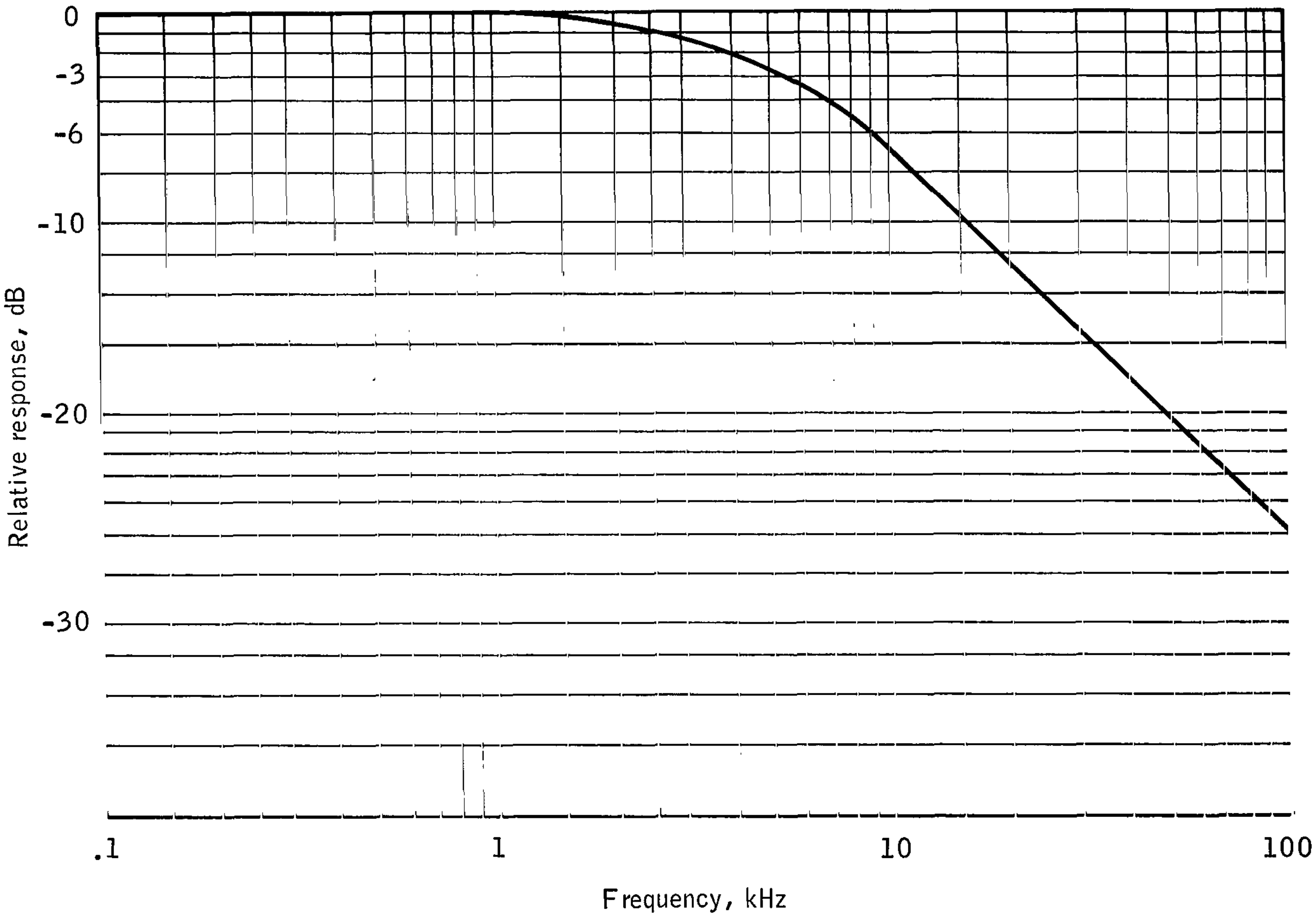


Figure 39. - Frequency response (gain = 1000).

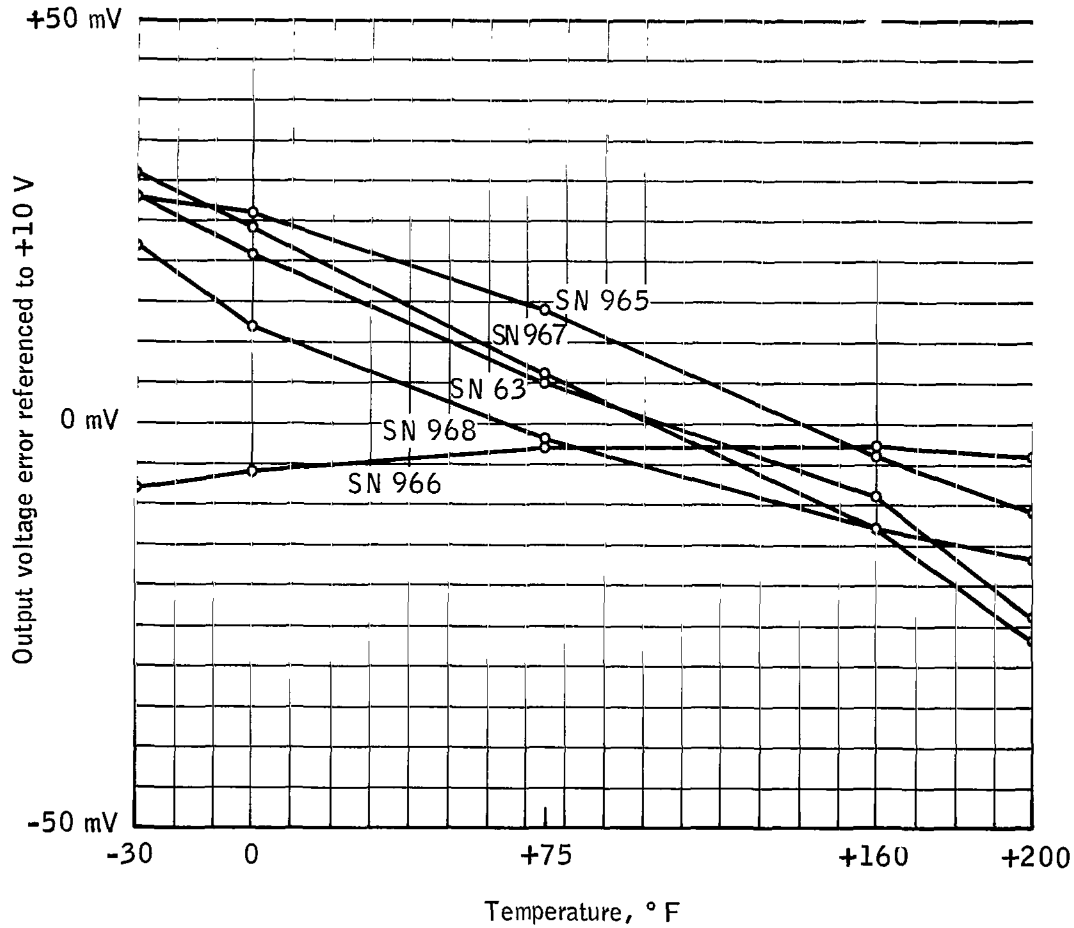


Figure 40. - Transducer power-supply error with temperature.

APPENDIX A

CHOPPER AMPLIFIERS AND CHOPPER-STABILIZED AMPLIFIERS

Although the chopper amplifier and the chopper-stabilized amplifier are two different types of circuits and are used in different applications, confusion often exists as to which name belongs to which type of circuit. A brief description of both types of circuits is presented to establish the proper terminology and to differentiate between these types of amplifiers and the direct-coupled amplifier.

The chopper amplifier is an amplifier that converts an input signal to a square wave, amplifies the square wave, and reconstructs the amplified signal to its original wave shape. This type of amplifier is sometimes called an amplitude-modulated suppressed-carrier amplifier. The classical circuit is shown in figure A-1.

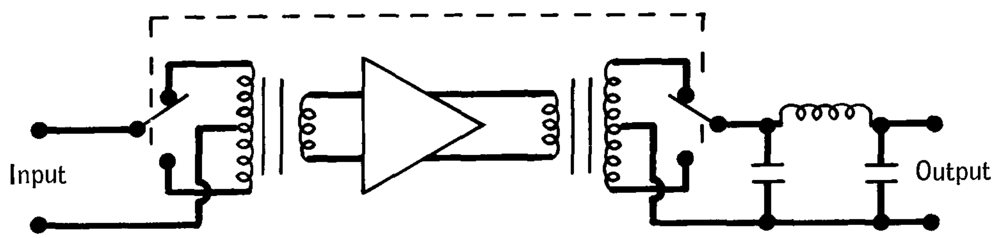


Figure A-1. - Chopper amplifier.

The input chopper (modulator) alternately reverses the signal connections to the input transformer. This action, referred to as full-wave modulation, produces a square wave at the secondary winding of the input transformer. A second method of modulation is to connect alternately the signal source to the amplifier and short the input terminals of the amplifier. This method is referred to as half-wave modulation. The resulting square wave, which has an amplitude that is proportional to the amplitude of the input signal, is then amplified by a conventional ac feedback amplifier. The amplified square wave is synchronously chopped (demodulated) to reconstruct the original wave shape with the proper voltage polarity or phase. A low-pass filter is used to remove any high-frequency chopping spikes. Because the chopping frequency must be greater than the maximum signal frequency (usually by at least a factor of 10), the chopper amplifier is essentially a low-frequency device with a maximum upper frequency of approximately 5 kHz.

The chopper-stabilized amplifier is a direct-coupled amplifier which, for stability purposes, uses a chopper to compare a fraction of the amplifier output signal with the input signal. One use for this type of amplifier is as an operational amplifier. The classical circuit is shown in figure A-2.

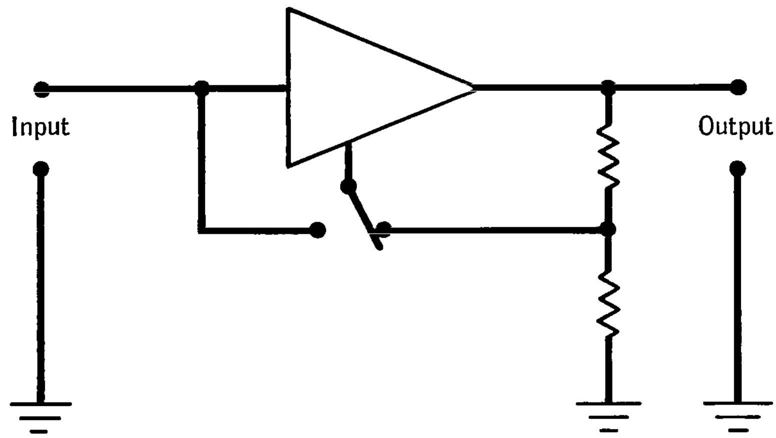


Figure A-2. - Chopper-stabilized amplifier.

The output signal is divided by the same ratio as the amplifier gain. The chopper alternately samples this fraction of the output signal and the input signal. The sampled signal, which is a square wave with an amplitude that is proportional to an error in voltage gain and/or zero drift, is fed back to the amplifier as a correction signal. As figure A-2 indicates, the chopper-stabilized amplifier is basically a single-ended noninverting amplifier. With additional circuitry, inverting and differential input configurations can be accommodated, but these configurations will not allow overall input-to-output signal sampling.

The following table presents the opposing features of the chopper amplifier and the chopper-stabilized amplifier.

Feature	Chopper amplifier	Chopper-stabilized amplifier
Normal configuration of input signal	Differential	Single ended
Type of chopper	Double pole	Single pole
Signal in the amplifier	Square wave	Same as the input and output
Type of stability	Alternating current feedback	Input/output error correction voltage

APPENDIX B

AMPLIFIER SPECIFICATION

Scope

This specification covers a microminiature signal-conditioning amplifier which consists of the following three modules.

1. The dc-dc power converter
2. The differential dc amplifier
3. The voltage regulator

Applicable Documents

The following documents, of the issue in effect on the date of Invitation for Bids, form a part of this specification where applicable.

1. MIL-I-26600, Interference Control Requirements
2. EMI-10A (NASA), Electro Magnetic Interference
3. MIL-STD-130, Identification Marking
4. NPC-200-3 (NASA), Inspection-System Provisions
5. MIL-STD-810, Environmental Testing

Environmental Specifications

The modules shall operate within the electrical specifications (listed in a subsequent section entitled Performance Specifications) when subjected to any combination of the following environmental conditions.

Temperature. - The modules shall be capable of starting and operating after a nonoperating storage period of 6 hours at any temperature between -65° and +230° F. The modules shall operate within specifications at any temperature between -30° and +200° F and with changes in temperature at a maximum rate of 20° F/minute within this range. The modules shall continue to operate and shall not be damaged when subjected to 250° F for 10 minutes.

Vacuum. - The modules shall be capable of operation within specifications while subjected to a vacuum (not to exceed 10^{-6} mm Hg) for a minimum of 5 days.

Acceleration. - The modules shall be capable of operation within specifications while subjected to 20g for 5 minutes in each of three perpendicular axes.

Shock. - The modules shall be capable of operation within specifications while subjected to 18 mechanical shocks (three in each direction of three perpendicular axes) of 50g for a period of 11 milliseconds. The shock is to be a sawtooth waveform with a rise time of 10 ± 1 milliseconds and a decay time of 1 ± 1 millisecond.

Acoustic noise. - The modules shall be capable of operation within specifications while subjected to 165 ± 1 dB of acoustic noise referenced to 0.0002 dyne/cm^2.

The density spectrum is presented in the following table.

Octave band, Hz	Sound-pressure level, dB
4.7 to 9.4	155
9.4 to 18.8	163
18.8 to 37.5	164
37.5 to 75	161
75 to 150	158
150 to 300	155
300 to 600	150
600 to 1200	145
1200 to 2400	139
2400 to 4800	133
4800 to 9600	129
Overall	165

Vibration. - The modules shall be capable of operation within specifications while subjected to random motion applied along each of three perpendicular axes for 15 minutes. The vibration spectra shall be referenced to a log-log plot and with a ±50-percent power spectral density. The motion shall be as follows.

5 Hz	$0.01g^2/Hz$
5 to 75 Hz	Linear increase to $0.14g^2/Hz$
75 to 200 Hz	Constant $0.14g^2/Hz$
200 to 2000 Hz	Linear decrease to $0.05g^2/Hz$

The modules shall be capable of operation within specifications while subjected to sine-wave motion applied along each of three perpendicular axes for 10 minutes. The motion shall be swept logarithmically from 5 Hz to 2 Hz to 5 Hz. The motion shall be as follows.

5 to 10 Hz	Constant 0.20 inch, double amplitude
10 to 18 Hz	Constant 1g
18 to 56 Hz	Constant 0.06 inch, double amplitude
56 to 2000 Hz	Constant 10g

Oxygen atmosphere. - The modules shall be capable of operation within specifications while subjected to 100-percent oxygen atmosphere at 7 psia for 1 hour.

Humidity. - The modules shall be capable of operation within specifications while subjected to 100-percent relative humidity, including condensation for 5 days in a temperature range of 80° to 160° F.

Salt fog. - The modules shall be capable of operation within specifications while subjected to salt fog as specified in MIL-STD-810 (USAF) Method 509 (less connector leads).

Shielding and RFI. - The modules shall be adequately shielded to meet MIL-I-26600 and EMI-10A specifications. The modules shall operate within specifications when mounted next to an operating module described by this specification.

Miscellaneous

Power source. - The dc-to-dc power converter shall be powered from an external battery. The characteristics of this power source are as follows.

1. The voltage is between 22 and 32 volts with 28 volts being nominal.

2. A possible maximum 4-volt peak-to-peak ripple (dc-to-2 kHz square wave) is impressed upon the source voltage. The source voltage, including the ripple, will be between 22 and 32 volts.

3. A possible transient exists on the powerline that may reduce the source voltage to as low as 0 volt or increase the source voltage to as high as 43 volts. This transient has a 20-millisecond base-width duration and an 8-millisecond rise time.

The circuitry connected to the source is required to survive this transient, but the specification performance is not required. Operation shall return to normal within 100 microseconds after the duration of the pulse.

Service life. - The modules shall be capable of operation within specifications for a minimum of 2000 hours (continuously or otherwise) during a service life of 1 year.

Warmup time. - The converter shall be capable of operation within specifications after a warmup time not to exceed 0.5 minute. The amplifiers and regulators shall be capable of operation within specifications after a warmup time not to exceed 250 microseconds.

Color. - The module cases shall be an opaque color.

Reverse polarity protection. - All circuits connected to the power source shall be protected from destruction by polarity reversal. Operation shall return to normal with proper polarity connections.

Product marking. - The modules and all external leads shall be marked in a permanent manner for identification purposes.

Workmanship. - Uniformity of shapes, dimensions, and performance shall provide interchangeability of the complete modules.

Performance Specifications

The dc-to-dc power converter. - The module shall be designed to operate from the battery and shall provide power to the two regulator modules.

Volume: The module shall be constructed in a rectilinear configuration, and the volume of the module shall not exceed 1.0 cubic inch.

Isolation: The module shall be designed so that the output circuits shall be transformer isolated from the input circuit.

Efficiency: The module shall be designed with considerations for efficiency without sacrificing performance. The power requirements shall not exceed 2.5 watts.

Voltage and current: The module shall be designed to provide the proper voltages and currents to power the two regulators.

Regulation and stability: The module shall be designed to properly power, at the same environment, the two regulators.

Powerline feedback: The feedback ripple from the module to the battery shall not exceed 30 millivolts peak-to-peak as measured across a 1-ohm series resistor with an oscilloscope which has a pass band of 15 MHz.

Ripple: The ripple on the output voltages shall be of such value that the regulators will operate the amplifiers and transducers within their respective ripple specifications.

Mounting considerations: The external leads shall be in a plane parallel to the flat-bottom surface and located in a predetermined precise manner. These shall be bare bus bar leads of material suitable for retaining the module to a printed-circuit board for operation in the specified environments.

<u>Differential dc amplifier.</u> - The module shall be powered from the voltage regulator.

Input signal: The module shall be capable of receiving variable differential input signals from 0 to ±5 volts. Those signals too large for linear amplification shall not damage the amplifier.

Input circuit: The module shall not require the signal source to provide bias current.

Input impedance: The module shall have an input impedance of no less than 50 kilohms for an input signal of any frequency between dc and 1 kHz. The source impedance, as seen by the module, is 0 to 375 ohms differential.

Output signal: The module shall be capable of delivering output signals from 0 to +5 volts to a load variable from 50 kilohms to an open circuit.

Output impedance: The output impedance of the module shall not exceed 100 ohms from dc to 1 kHz.

Output offset: With a zero input signal, from a source impedance as specified, the module output voltage shall be 0 ± 50 millivolts.

Voltage gain: The voltage gain shall be within 1 percent of the ideal value of 50 for one type of amplifier and 1000 for a second type of amplifier.

Gain stability and frequency response: The gain of the module shall be within ±1 percent of the dc value at 75° F from dc to 1 kHz. The 3-dB point shall not exceed 15 kHz. The frequency response between dc and 1 kHz shall not change more than ±1 percent over the specified environments.

Output ripple: The maximum output ripple voltage shall be 25 millivolts peak-to-peak as measured with an oscilloscope which has a pass band of 15 MHz.

Linearity: The module shall have a linear output within ±12.5 millivolts of a straight line between the output end points (nominal 0 and +5 volts).

Common mode: The module shall have a common-mode rejection ratio of 80 dB or more for frequencies from dc to 1 kHz and voltages of ±1.0 volt.

Volume: The module shall be constructed in a rectilinear configuration, and the volume of the module shall not exceed 0.015 cubic inch.

Mounting considerations: The external leads shall extend from the module from two opposing surfaces and in one plane. These shall be bare bus bar leads of such material suitable for retaining the module to a printed-circuit board for operation in the specified environments.

Voltage regulator. - The module shall be designed to receive power from the dc-to-dc converter and shall deliver regulated power to one external transducer and one external amplifier.

Transducer power specifications: The transducer power specifications are as follows.

1. Voltage and current — The module shall be designed to deliver 10 volts to one 350-ohm (±5 percent) transducer.

2. Regulation and stability — The voltage shall be 10 volts ±50 millivolts when connected to a typical transducer and subjected to the battery fluctuations and the specified environments.

3. Ripple — The ripple on the 10 volts shall not exceed 25 millivolts peak-to-peak as measured with an oscilloscope which has a pass band of 15 MHz.

Amplifier power specifications: The amplifier power specifications are as follows.

1. Voltage and current — The module shall be designed to provide the proper voltages and currents to power one amplifier for the performance previously described.

2. Regulation and stability — The module shall be designed to properly power, at the same environment, one amplifier for the performance previously described.

3. Ripple — The ripple on the supply voltages shall be of such value that the ripple of the amplifier output is within specifications.

Mounting considerations: The external leads shall be in a plane parallel to the flat-bottom surface and located in a precise manner. These shall be bare bus bar leads of material suitable for retaining the module to a printed-circuit board for operation in the specified environments.

Volume: The module shall be constructed in a rectilinear configuration, and the volume of the module shall not exceed 0.01 cubic inch.

APPENDIX C

LABORATORY TEST DATA

The test data compiled in the following pages were obtained in the Signal Conditioning Laboratory of the Instrumentation and Electronic Systems Division at the Manned Spacecraft Center as a part of the hardware-acceptance tests. Some of the tests were extended beyond the specification requirements for the purpose of showing a trend in data degradation when operation exceeded the normal usage. Other tests (RFI and environmental) were not performed because the hardware was not in a metal container and, thus, the tests would not have any significance. The hardware was mounted on printed-circuit cards to aid in testing and evaluation.

TABLE C-I. - AMPLIFIER GAIN CHANGE WITH A VARIABLE TEMPERATURE

Serial number	Ideal gain	Gain at —				
		-30° F	0° F	75° F	160° F	200° F
301	1000	1004.2	1001.6	1000.6	999.6	999.2
304	1000	990.0	989.0	987.8	988.6	987.4
315	1000	1003.0	1002.4	1000.6	999.4	998.2
308	1000	998.2	998.2	998.4	1000.6	999.4
319	1000	1002.2	1002.4	1001.4	1000.4	999.0
401	50	50.18	50.16	50.20	50.24	50.26
402	50	49.89	49.90	49.95	49.92	49.93
406	50	50.03	50.09	50.10	50.13	50.15
408	50	49.96	50.00	50.03	50.07	50.10
411	50	49.89	49.90	49.91	49.90	49.93

TABLE C-II. - AMPLIFIER PERCENTAGE GAIN CHANGE

WITH A VARIABLE TEMPERATURE

Serial number	Percentage of gain change at —				
	-30° F	0° F	75° F	160° F	200° F
301	0.42	0.16	0.06	-0.04	-0.08
304	-1.00	-1.10	-1.22	-1.14	-1.26
315	.30	.24	.06	-.06	-.18
308	-.18	-.18	-.16	.06	-.06
319	.22	.24	.14	.04	-.01
401	.36	.32	.40	.48	.52
402	-.22	-.20	-.10	-.16	-.14
406	.06	.18	.20	.26	.30
408	-.08	0	.06	.14	.20
411	-.22	-.20	-.18	-.20	-.14

TABLE C-III. - AMPLIFIER OUTPUT OFFSET VOLTAGE

WITH A VARIABLE TEMPERATURE

Serial number	Output in mV at —				
	-30° F	0° F	75° F	160° F	200° F
301	21	-1	-8	8	12
304	50	43	21	27	32
315	20	4	-34	-20	-20
308	24	16	-12	3	7
319	-17	-17	-36	-22	-40
401	18	5	-11	15	23
402	-8	6	26	19	-22
406	-17	-18	1	6	11
408	9	6	2	1	-2
411	5	-2	-10	-5	-2

TABLE C-IV. - ERROR IN AMPLIFIER LINEARITY

AT VARIABLE OUTPUT VOLTAGES

Serial number	Error in mV at —									
	-3 V	-2 V	-1 V	0	1 V	2 V	3 V	4 V	5 V	6 V
301	1	1	1	0	1	1	1	1	0	0
304	1	1	1	0	0	1	0	0	0	0
315		0	0	0	0	1	1	1	1	-1
308		-8	-6	0	1	3	6	8	1	-7
319	-1	-1	-1	0	0	0	0	0	0	-1
401	-1	-1	0	0	0	0	1	1	2	3
402		-2	-2	0	1	1	2	3	3	4
406	1	0	0	0	0	0	-1	-1	0	0
408	0	2	0	0	0	0	0	0	0	0
411	2	0	0	0	0	1	1	1	1	2

TABLE C-V. - LOSS IN AMPLIFIER GAIN WITH AN INCREASE IN SIGNAL FREQUENCY

Serial number	Percentage of loss at —									
	100 Hz	200 Hz	500 Hz	1 kHz	2 kHz	5 kHz	10 kHz	20 kHz	50 kHz	100 kHz
301	0	0.3	0.8	2.4	7.9	30.5	56.5	77.1	92.2	96.45
304	0	-.6	0	1.9	8.6	33.7	60.4	79.6	93.5	97.26
315	0	.1	.3	1.4	5.8	25.9	51.9	73.8	90.4	96.33
308	0	-.4	0	1.4	6.0	26.6	52.4	73.9	90.2	91.14
319	0	0	0	.7	3.1	16.2	39.4	64.0	85.8	93.57
401	0	-.2	0	.8	3.0	15.6	38.6	65.4	87.5	93.96
402	0	0	0	1.2	3.0	14.8	36.6	62.6	86.7	93.58
406	0	0	.4	.8	2.2	13.8	35.2	60.6	84.0	92.48
408	0	.2	.4	1.0	3.8	16.2	38.6	63.6	85.0	92.76
411	0	0	.4	.8	2.8	13.8	35.6	61.0	84.9	93.16

TABLE C-VI. - AMPLIFIER COMMON-MODE SIGNAL REJECTION

Serial number	Common-mode signal rejection in dB at —						
	100 Hz	200 Hz	500 Hz	1 kHz	2 kHz	5 kHz	10 kHz
301	98.06	98.06	98.06	98.06	98.06	96.48	92.04
304	118.06	112.04	107.18	102.50	96.48	91.22	88.52
315	114.54	118.06	114.54	118.06	114.54	112.04	104.08
308	108.52	108.52	112.04	110.10	106.02	100.00	98.06
319	112.04	112.04	118.06	114.54	112.04	106.02	102.50
401	102.50	102.50	106.02	100.00	92.04	86.02	73.06
402	84.44	84.44	83.12	83.76	83.76	83.76	81.94
406	78.06	78.06	78.06	76.44	72.04	65.18	61.68
408	102.50	100.00	95.14	89.54	84.08	78.06	74.90
411	104.08	100.00	96.48	92.04	86.02	79.20	76.48

TABLE C-VII. - PEAK-TO-PEAK RIPPLE ON THE AMPLIFIER OUTPUT WITH A VARIABLE TEMPERATURE

Serial number	Ripple in mV at —				
	-30° F	0° F	75° F	160° F	200° F
301	9	15	20	10	10
304	10	15	10	10	10
315	10	10	10	10	10
308	10	9	10	10	10
319	10	15	10	10	10
401	10	10	9	15	10
402	10	10	3	15	10
406	10	10	5	10	10
408	10	10	5	20	10
411	5	10	10	20	10

TABLE C-VIII. - AMPLIFIER INPUT AND OUTPUT RESISTANCES AND CHANGES IN OFFSET VOLTAGE WITH LARGE VARIATIONS IN THE SUPPLY VOLTAGES

Serial number	Resistance at —		Change in offset voltage in mV at —	
	Input, kΩ	Output, ohm	A +15 volt supply changed to a +16 volt supply	A -15 volt supply changed to a -16 volt supply
301	200	12	-11	-10
304	231	8	-18	-17
315	150	10	-25	-32
308	136	8	-40	-29
319	107	6	-36	-24
401	188	1	-3	-2
402	200	1	-2	-4
406	136	2	8	7
408	137	1	-3	-3
411	146	20	-2	-2

TABLE C-IX. - ERROR OF POWER-SUPPLY VOLTAGES WITH A CHANGE IN INPUT VOLTAGE AND TEMPERATURE

Temperature, °F	Output error in mV at —								
	22-V input			28-V input			32-V input		
	Δ +10 V	Δ +15 V	Δ -15 V	Δ +10 V	Δ +15 V	Δ -15 V	Δ +10 V	Δ +15 V	Δ -15 V
Serial number 63									
-30	25	-57	-72	28	-56	-75	32	-54	-78
0	18	-36	-51	21	-33	-53	24	-33	-56
75	3	19	7	5	22	4	7	24	3
160	-11	46	31	-9	47	31	-8	48	28
200	-25	55	-11	-24	58	-13	-22	58	-13
Serial number 965									
-30	21	-7	17	28	-6	17	28	-4	14
0	18	1	13	26	2	11	24	4	8
75	14	13	0	14	14	-1	14	14	-3
160	-4	12	-3	-4	13	-3	-2	13	-5
200	-10	7	-1	-11	40	-38	-9	9	-4
Serial number 966									
-30	-9	14	-18	-8	19	-19	-4	25	-21
0	-7	10	-19	-6	15	-21	-2	21	-23
75	-3	-1	-19	-3	1	-21	-1	5	-22
160	-3	-20	-14	-3	-18	-15	-1	-16	-15
200	-5	-28	-8	-4	-26	-8	-3	-24	-9
Serial number 968									
-30	20	35	35	22	37	34	24	38	34
0	12	35	33	12	37	33	10	37	31
75	-4	14	31	-2	16	31	-1	17	30
160	-12	-30	41	-13	-28	41	-13	-27	40
200	-18	-51	49	-17	-50	48	-16	-49	47
Serial number 967									
-30	30	-11	42	31	-10	41	31	-9	40
0	23	-5	31	24	-4	28	26	-4	28
75	6	6	-1	6	6	-2	7	8	-2
160	-14	10	-9	-13	11	-9	-13	12	-11
200	-28	4	13	-27	5	13	-26	5	12

TABLE C-X. - PEAK-TO-PEAK RIPPLE ON THE 10-VOLT TRANSDUCER SUPPLY WITH A VARIABLE TEMPERATURE

Serial number	Ripple in mV at —				
	-30° F	0° F	75° F	160° F	200° F
63	60	44	24	30	44
965	50	48	44	60	50
966	60	46	60	38	66
968	54	36	20	52	42
967	45	45	43	47	45

APPENDIX D

SPECIFYING ZERO DRIFT

Under normal operating temperature conditions, the output signal of a dc amplifier varies when the input signal remains at zero. This variation, called zero drift, is generated in the input portion of the amplifier by a shift in the quiescent voltages, thermocouple action, random noise, and other unwanted signal sources. As the ambient temperature changes, each of these unwanted signals changes. At any particular temperature, the sum of these signals can be expressed as an equivalent signal.

One method of specifying the zero drift is to reference the zero drift to the amplifier input signal and define it as an equivalent input signal in units of $\mu V/^{\circ}C$. The value of the zero drift is determined by dividing the output drift by the effective gain and the change in ambient temperature. This method, although widely used, is not accurate and can lead to an erroneous conclusion because the actual drift (observed at the amplifier output) is seldom a linear function of ambient temperature when the ambient temperature varies over a wide range. Although this method of specifying the zero drift of an amplifier is not accurate, it is a convenient method to specify performance and is sufficiently accurate for many applications. The manufacturers of operational amplifiers usually specify the zero drift in this manner because the voltage gain and, therefore, the output zero drift varies according to the particular application.

A second method of specifying the zero drift of an amplifier is to document the actual variation of the output voltage at the desired voltage gain and the anticipated temperature range. The test data can then be expressed in terms of millivolt drift (positive or negative) with respect to some reference voltage V_{ref} which is usually zero. This method of specifying zero drift is not as convenient as the previously described method, but it is perferable for those applications where maximum accuracy is desired.

REFERENCES

1. Wenzel, G. E.: The Development of a Microminiature dc Signal-Conditioning Amplifier. NASA TN-D-4091, 1967.

2. TRW Systems: Microminiature dc Amplifier. Final Report, NASA CR-65483, 1965.

3. TRW Systems: Signal Conditioning Power Programmer. Final Report, NASA CR-65589, 1967.

4. TRW Systems: Microminiature Signal Conditioner. Final Report, NASA CR-65636, 1967.

NASA-Langley, 1968 —— 7 S-167

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS ANI
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 158
Postal Manual) Do Not Retur

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546