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A TRANSISTORIZED HIGH QUALITY CARRIER AMPLIFIER FOR ELECTROCARDIOGRAM

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FOREWORD

A miniaturized ECG transistor amplifier was developed under Project No. 7222, "Biophysics of Flight," and Task No. 71751, "Instrumentation Research," by the Medical Electronics Section, Biophysics Branch, Biomedical Laboratory. The research began in July 1959 and was completed in January 1960.

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ABSTRACT

A miniaturized electrocardiogram transistor amplifier employing a high efficiency, low level modulator circuit has been developed. This amplifier combines the advantages of a carrier system with the low noise level and high input impedance of a resistor-capacitance coupled straight amplifier. Circuit diagrams and operating characteristics are included.

PUBLICATION REVIEW

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INTRODUCTION

The electrocardiogram (ECG) is an important aid not only in medical diagnosis, but also in medical research and space flight problems. Recording the ECG in laboratories and hospitals is a well standardized procedure. Recording the ECG in space vehicles requires not only a drastic restriction in weight, size, and power consumption, but also a high degree of independence from other disturbing factors, such as temperature, motion of the subject, vibration, and acceleration.

Simple miniaturization of common ECG amplifiers does not meet the requirements completely. Resistor-capacitance (R-C) coupled amplifiers with the necessary frequency range from 0.5 to 150 cps are highly affected by disturbing impulses generated from muscles, skin potentials, and other changes in electrode resistance. These factors cause blocking and other undesirable effects. A power source with large filter components and low internal resistance is necessary to prevent low frequency oscillations. A carrier amplifier system would eliminate these troublesome factors, but new difficulties are introduced because of the relatively high noise level from the known modulator methods. High input impedance is also difficult with most of the modulators available.

A miniaturized ECG transistor amplifier employing a high efficiency low noise modulator circuit has been developed at the Aerospace Medical Laboratory. This amplifier combines the advantages of a carrier system with the low noise level and high input impedance of a R-C coupled straight amplifier and delivers a high quality ECG free of blocking effects. Power requirements, weight, size, sensitivity to vibration and shock are reduced to a high degree.

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CIRCUIT DIAGRAM

Technical surveys of common modulator circuits, (diamond, ring, bridge, etc.,) show that common shortcomings are (1) instability in balancing, and (2) low modulation efficiency. It is not too difficult to balance a modulator for a carrier leak of less than one ten-thousandth of the applied carrier voltage, but this balance is affected by temperature and voltage to a high degree. In the described circuit (Figure 1), a d-c feedback is employed to restore balance automatically.

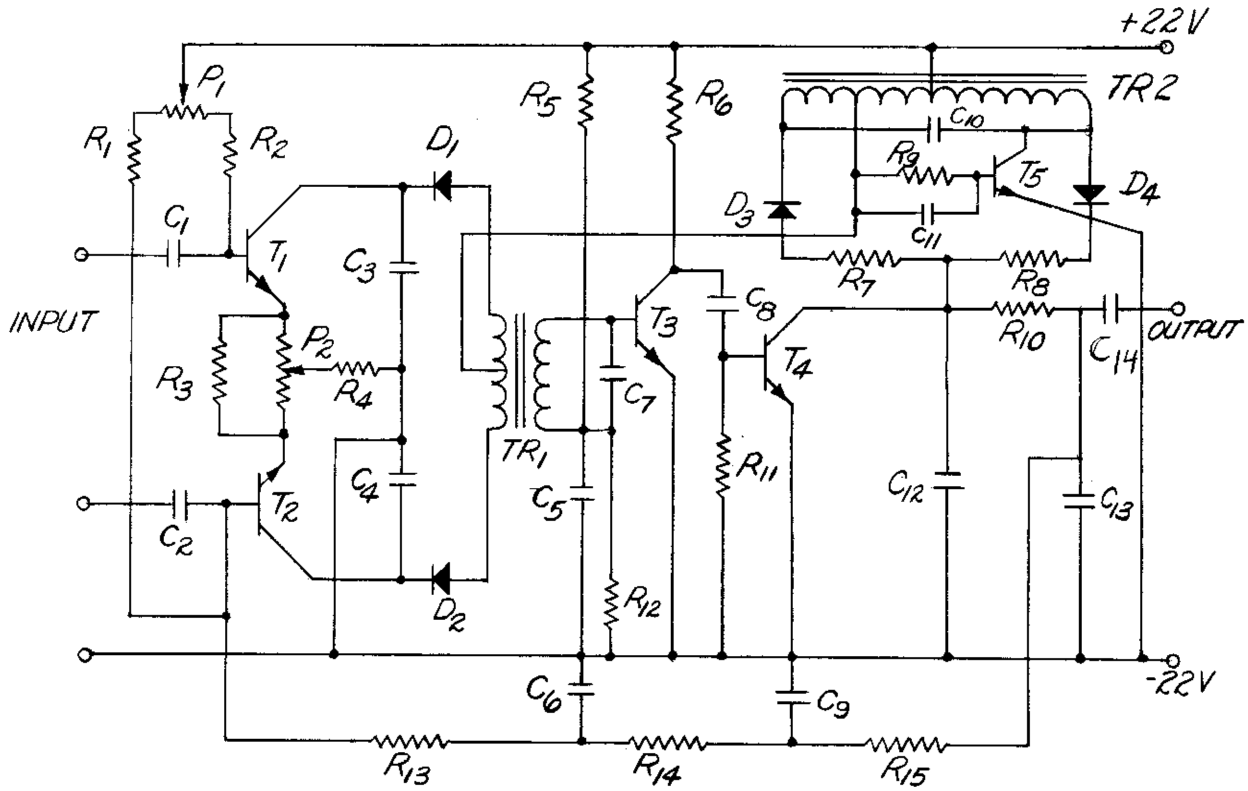

Figure 1. Circuit Diagram

The low modulation efficiency of common modulator circuits (approximately 30 percent) is an important factor if low input signal amplitudes of 1 millivolt and less are handled, because the signal-to-noise ratio limits the lowest useful input voltage.

The modulator circuit employed in this carrier amplifier gives a modulation efficiency approximately 10 times higher than other comparable diode modulators. A quick check of the literature showed no evidence of similar circuits, but a more complete survey is necessary before it may be called an original circuit.

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Two selected transistors (T_1 and T_2, with equal collector cutoff current (I_{co}) and Beta) receive the input signal through two capacitors, C_1 and C_2. The low frequency cutoff and baseline stability is determined largely by the capacity and leakage current stability of these capacitors. Testing the capacitors for equal capacity and stability low leak current is essential for best results so far as common mode rejection and baseline stability is concerned. In our laboratory model, nine microfarad (µf) capacitors with less than tantalum 0.3 microampere (µa) leak current at 22 volt were selected. The impedance of the collector circuit containing capacitors C_3 and C_4, transformer TR_1, and diodes D_1 and D_2 must be low for the carrier frequency and high for the signal frequency. In this case the impedance of C_3 and C_4 is 1400 ohms for the carrier frequency and 140,000 ohms for the highest desired signal frequency. This provides a useful compromise between high frequency cutoff and carrier suppression on the input.

Diodes D_1 and D_2 are silicon diodes selected for equal dynamic characteristic. Figure 2 shows the circuit used to select dynamically matched diodes. Table I lists the parts of the ECG transistor amplifier.

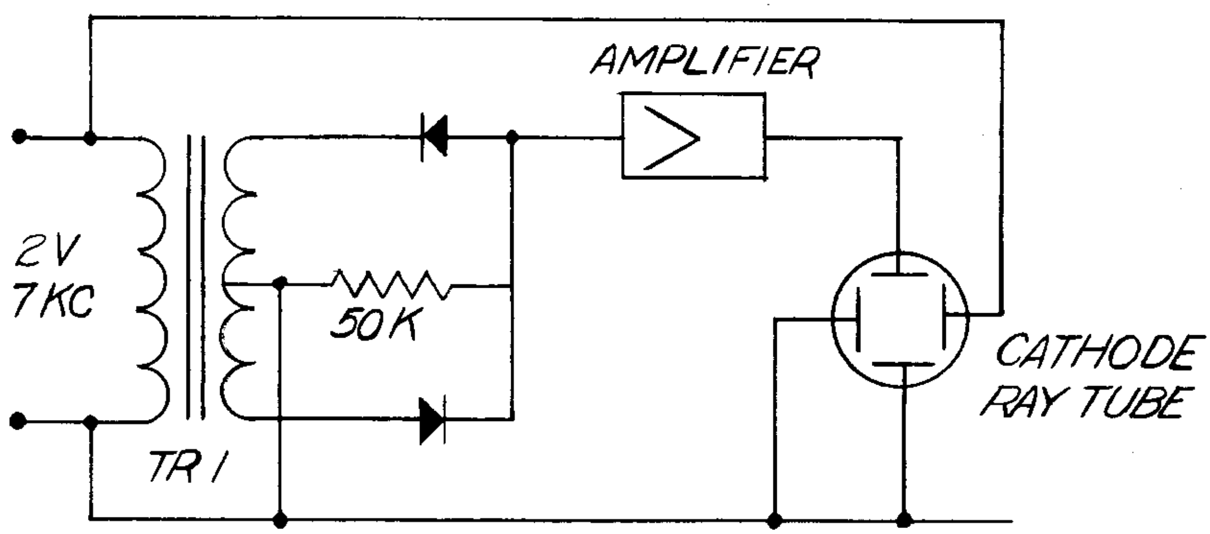

Figure 2. Diode Testing Circuit

Transformer TR_1 has a centertapped primary winding. Equal induction and distributed capacity in both halves of the primary is absolutely necessary. Bifilar winding of the primary was found to be the simplest and most effective way to achieve this. Ferramic or powdered iron pot cores with a one-half-inch diameter are employed. The secondary winding of the transformer is tuned by C_7 to the carrier frequency. High Q in this transformer circuit and impedance matching through step-down to the secondary are most important for this input stage. Balancing is accomplished in two ways. Equalizing d-c current in transistors T_1 and T_2 is adjusted with potentiometer P_1. Equalizing gain is controlled by potentiometer P_2. Potentiometer P_2 is adjusted to attain the highest common mode rejection (see Operation).

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TABLE I

RESISTORS (1/4 WATT)

R_1, R_2	1, 2	Meg Ohm
P_1	1	Meg Ohm
P_2	25	Kilo Ohm
R_3	6, 2	Kilo Ohm
R_4	47	Kilo Ohm
R_5	100	Kilo Ohm
R_6	22	Kilo Ohm
R_7, R_8	220	Kilo Ohm
R_9	510	Kilo Ohm
R_{10}	47	Kilo Ohm
R_{11}	1, 2	Kilo Ohm
R_{12}	5, 1	Kilo Ohm
R_{13}	510	Kilo Ohm
R_{14}, R_{15}	510	Kilo Ohm

CAPACITORS:

C_1, C_2	9 Microfarad	25 volts
C_3, C_4	0.01 Microfarad	100 volts
C_5	3 Microfarad	6 volts
C_6	25 Microfarad	25 volts
C_7	0.05 Microfarad	100 volts timed to approximately carrier frequency
C_8	0.01 Microfarad	100 volts
C_9	16 Microfarad	25 volts
C_{10}	0.05 Microfarad	100 volts
C_{11}	0.001 Microfarad	100 volts
C_{12}, C_{13}	0.0033 Microfarad	100 volts
C_{14}	9 Microfarad	25 volts

TRANSISTORS: 2N118

DIODES: D_1, D_2 IN137

D_3, D_4 IN486

TRANSFORMERS

TR_1: PRIMARY: 2 x 100 + 34 WIRE
SECONDARY: 60+ 34 WIRE

TR_2: 200 + 34 WIRE
TAPS on 75 and 100 turns.

CORES: FERROXCUBE 383P250-B8-36

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Transistor T_3 is the carrier amplifier stage providing a gain of 20 and biased from a voltage divider. Since the total current in this stage is only in the range of a fraction of 1 milliampere, no special protection against thermal runaway is necessary. Transistor T_4 acts as a gated amplifier and phase detector.

Transistor T_5 is an oscillator generating the carrier frequency (approximately 14,000 cps). A high Q coil is also used in order to attain stability of the carrier frequency. The peak-to-peak voltage on the two demodulator diodes is around 20 volts. The 25-turn tap on the oscillator winding delivers 5 volts peak-to-peak carrier to the center tap on the modulator Transformer TR_1 in addition to the battery voltage. Single R-C filtering on the output removes the carrier sufficiently for most uses. Resistors R_{13}, R_{14}, and R_{15} feed a portion of the output voltage back to the input for stabilization of modulator.

The a-c components in this feedback circuit are removed by two electrolytic capacitors to ground. Adjustment of potentiometer P_1 influences the proper operation of this d-c feedback (see Operation). This feedback provides the stable operation over a wide temperature range.

PERFORMANCE

The laboratory model was enclosed in a sheet metal box 3 by 3 by 1 inch. Except for the two transformers, standard parts were used. The transistors for the first stage were selected for equal I_{Co} and Beta, the diodes D_1 and D_2 for equal dynamic characteristics with the circuit shown in figure 2. Stability tests and temperature tests were made over a period of several days. Figures 3 and 4 show the average of the results of these tests. Common mode rejection measured with 20 cycles per second was better than 12,000:1, and stable. Input impedance on this model was 100,000 ohms. The gain was 2,500. The current drain was 2, 3, milliampere, equivalent to a total power consumption of 51 milliwatts. Increasing the battery internal resistance up to 2,000 ohms did not disturb the performance. The model has also been used in actual field tests for monitoring ECG.

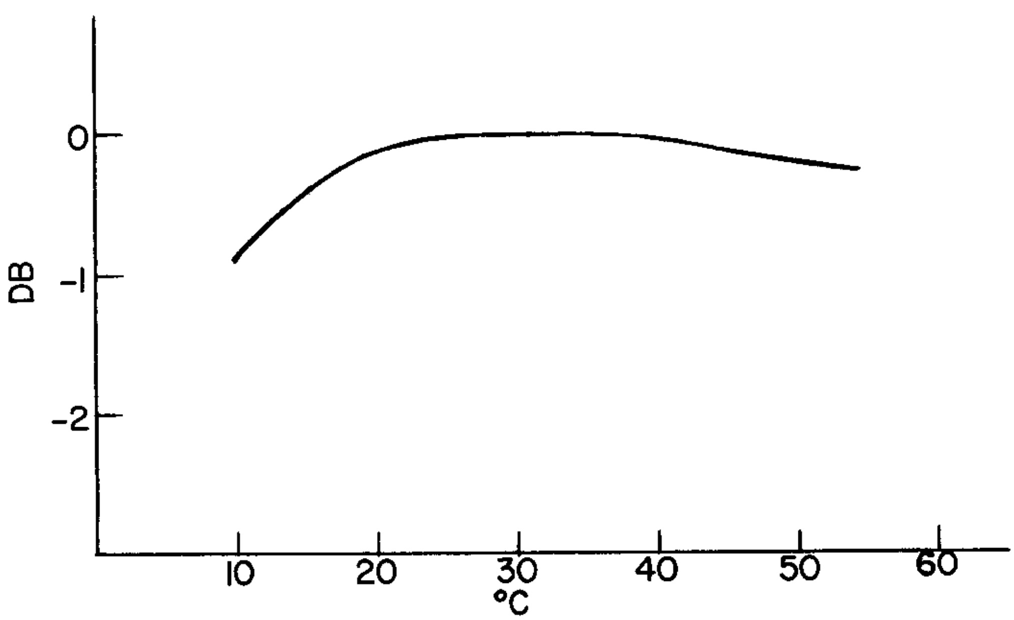

Figure 3. Gain Stability with Temperature

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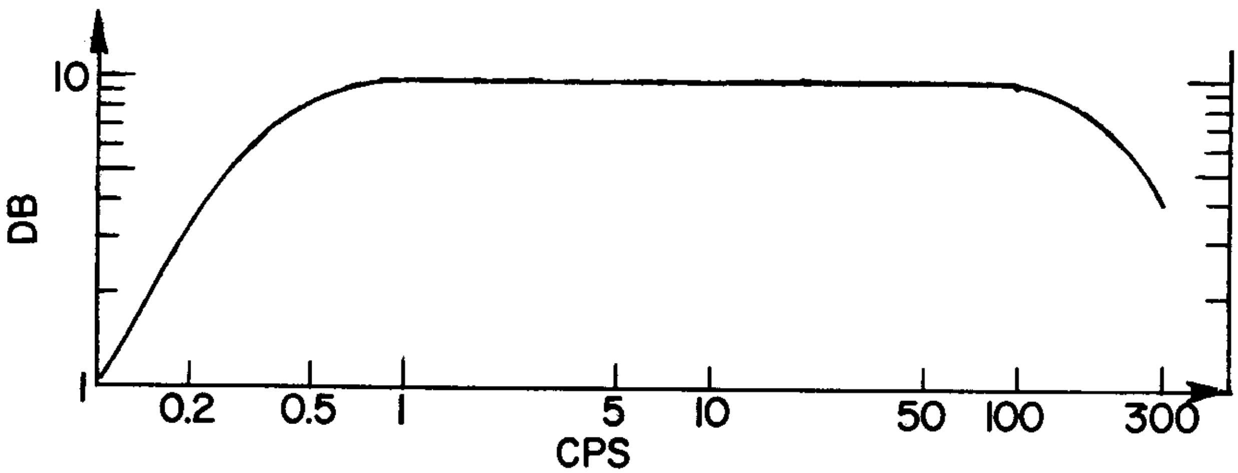

Figure 4. Frequency Response

OPERATION

After the battery and the output are connected, the input leads should be connected with a signal generator having the proper voltage range (1-5 millivolt and frequency range (0.1 to 200 cps). A d-c voltmeter (100,000 ohms per volt) is connected to the output in front of the output coupling capacitor C_{14}. Potentiometer P_1 may now be adjusted until the d-c feedback circuit automatically compensates for any small change in the position of P_1. For setting P_2, a signal of 200 millivolts is applied between ground and both input terminals in parallel, and adjusted for minimum output reading on the oscilloscope. A slight correction of P_1 will probably be necessary after setting P_2. After the potentiometers are once adjusted, they need not be readjusted except as parts of the amplifier are replaced, or after considerable aging of components, such as the electrolytic capacitors.

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