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FINAL REPORT

Contract No. NAS9-14404

SwRI Project No. 16-4118

Prepared for

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Approved:

Douglas N. Travers
Vice President
Electromagnetics Division

ABSTRACT

A biotelemetry system for measuring and transmitting EKG, EMG, and EEG data by an RF link to a receiver was designed, developed, and delivered. The system is battery operated with the batteries and transmitting electronics an integral part of the electrode sensors. The low frequency response of 0.05 Hz assures faithful reproduction of detailed EKG and all measurements are made by the utilization of two electrode sensors.

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I. PURPOSE

The purpose of the program was to design, develop, test and deliver a biotelemetry system for transmitting EKG, EMG, or EEG information to a radio receiver. Two (2) transmitter and battery pack units and one (1) receiver unit with two (2) fixed frequency tuning plug-ins corresponding to the transmitter frequencies shall be delivered. The battery and the transmitter must each be mounted as integral parts of separate electrodes. The transmitter data amplifiers which receives the electrode signals shall have two selectable gain settings. The lower gain setting shall be used for EKG and EMG signals while the higher gain setting shall be used for EEG signals.

A receiver with two tuning units, each to match one of the two transmitter frequencies shall be delivered. The receiver's data output shall be capable of displaying the data on an oscilloscope or oscillograph.

The data amplifier, transmitter, and receiver circuits desired specifications are:

Signal	Level	Frequency
EKG	0.1 - 10 mV	0.05 - 100 Hz
EMG	0.1 - 10 mV	0.05 - 4000 Hz
EEG	10 - 250 μV	0.5 - 100 Hz

Input Impedance: Greater than 1 megohm
Transmit Frequency: Crystal controlled, 165 MHz region
Rang 25 feet minimum with a goal of 75 feet
Receiver Output: Five volts P-P into 1 K ohm load

II. PROGRAM DESCRIPTION

The program can be described in two major phases as follows:

(1) Design and Breadboard Construction
(2) Final Construction and Testing

Each of the two phases will be discussed as follows.

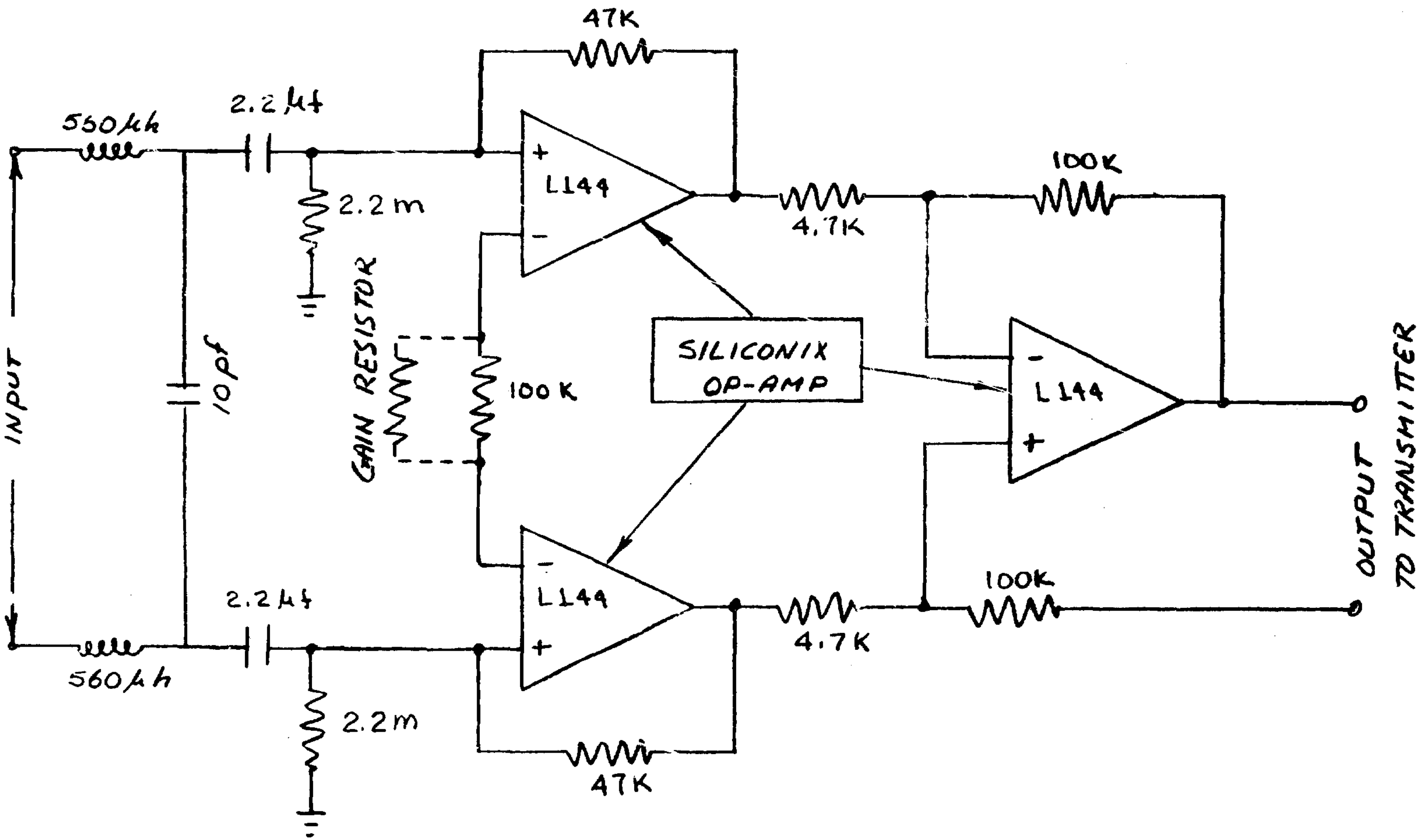
A. Design and Breadboard

The initial concern was to locate components which would meet the circuit requirements for size and performance. The three stage instrumentation amplifier shown schematically in Figure 1 designed to receive the electrical signals from the sensors was chosen for its ability to convert from balanced input to single-end mode outputs, high common-mode rejection, and ease in gain change. As the system requires one gain value for EKG and EMG, while a second higher gain is required for EEG, the ability to provide a simple gain step adjustment while maintaining circuit balance was necessary. This was accomplished by changing the value of the gain resistor.

The transmitting unit is battery operated and required an operational amplifier which will work at low voltages. A Siliconix L144 triple op-amp was chosen for the data amplifier portion. (The data is information received from the electrodes and used to modulate the RF signal.)

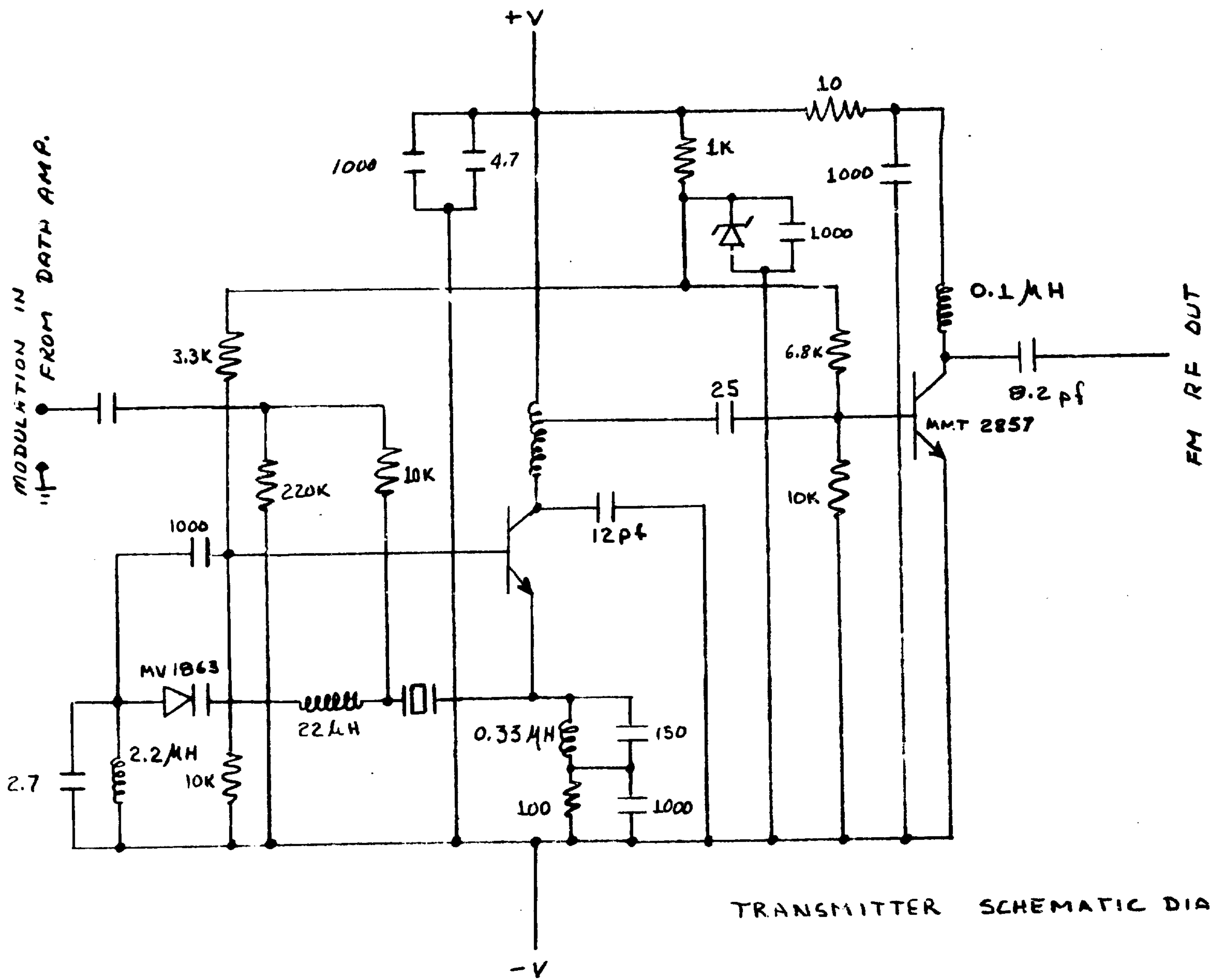
Capacitive coupling was required between the electrode and the data amplifier due to the low supply voltage (± 1.5 volts) and the potentially high galvanic bias potential. This coupling eleminates any direct current flow between sensors and skin from the battery source. The input parameters of the data amplifier are such that excellent low-frequency response is obtainable with the capacitance coupling. Inductive and capacitive filtering between the electrodes and the data amplifier inputs assure adequate isolation from the transmitters RF output.

The transmitter is crystal controlled and frequency modulated producing a maximum carrier deviation of 10 kHz. The modulated oscillator output frequency is multiplied by 7. The RF amplifier is tuned to the final frequency and the output is coupled to a short wire antenna. This short wire conforms to the circular shape of the transmitter package. Figure 2 shows the simplified schematic of the transmitter circuit.



DATA AMPLIFIER

FIGURE 1



TRANSMITTER SCHEMATIC DIAGRAM

FIGURE 2

The receiver circuit amplifies the received RF signal, demodulates the FM data, and amplifies the modulation data for display by an oscilloscope or oscillograph. Difficulties were encountered in the demodulation, IF sensitivity, and initial turn-on time for stabilization of data amplification. A phase-locked loop demodulator was used to replace the original differential peak detector and additional IF amplification was provided to eliminate the sensitivity and demodulation problems. An excellent RF link was therefore established with the transmitter. Additional design eliminated objectional slow stabilization of the receiver data amplifier after initial power turn-on. The receiver schematic is shown in Figure 3.

All system problems were solved in the breadboard phase as well as tests accomplished to insure compliance with desired specifications.

B. Assembly and Testing

The initial electrode/circuit design was based on providing the smallest package size. The initial electrode/circuit packages resembled a small cylinder. At the sponsor's request, a repackaging was performed which allowed smoother physical transition from the cylindrical shaped sides to the round top. A slight increase in size was required. This new packaging design allows the transmitter and battery package to be secured in place without encapsulation of the circuit elements.

To insure reliability, the breadboard circuits were reconstructed using new parts and circuit boards. New sponsor-furnished electrodes were also installed. The design allows electrode replacement without destruction of the electronic circuits; however, a new base plate for electrode mounting is required. The complete deliverable units consisting of the transmitter, battery package, and the receiver with each tuning unit are shown in Figure 4. Each of these units have been tested for compliance with the desired specifications. In addition, a brief chart recording of EKG and EMG signals has been made. These recordings are shown in Figure 5.

Test data was obtained by mounting the sensor electrodes to a test conductor using electrode jel, the test conductors being wired to a signal generator. This testing method is very difficult due to unequal RF and 60 Hz signals picked up in the leads to the signal generator. The RF energy received by the test electrode leads may be rectified by the input amplifier causing a bias shift. The 60 Hz appears as noise. The test results are given in Table 1. Both transmitters have been operated during such tests at distances over 40 feet.

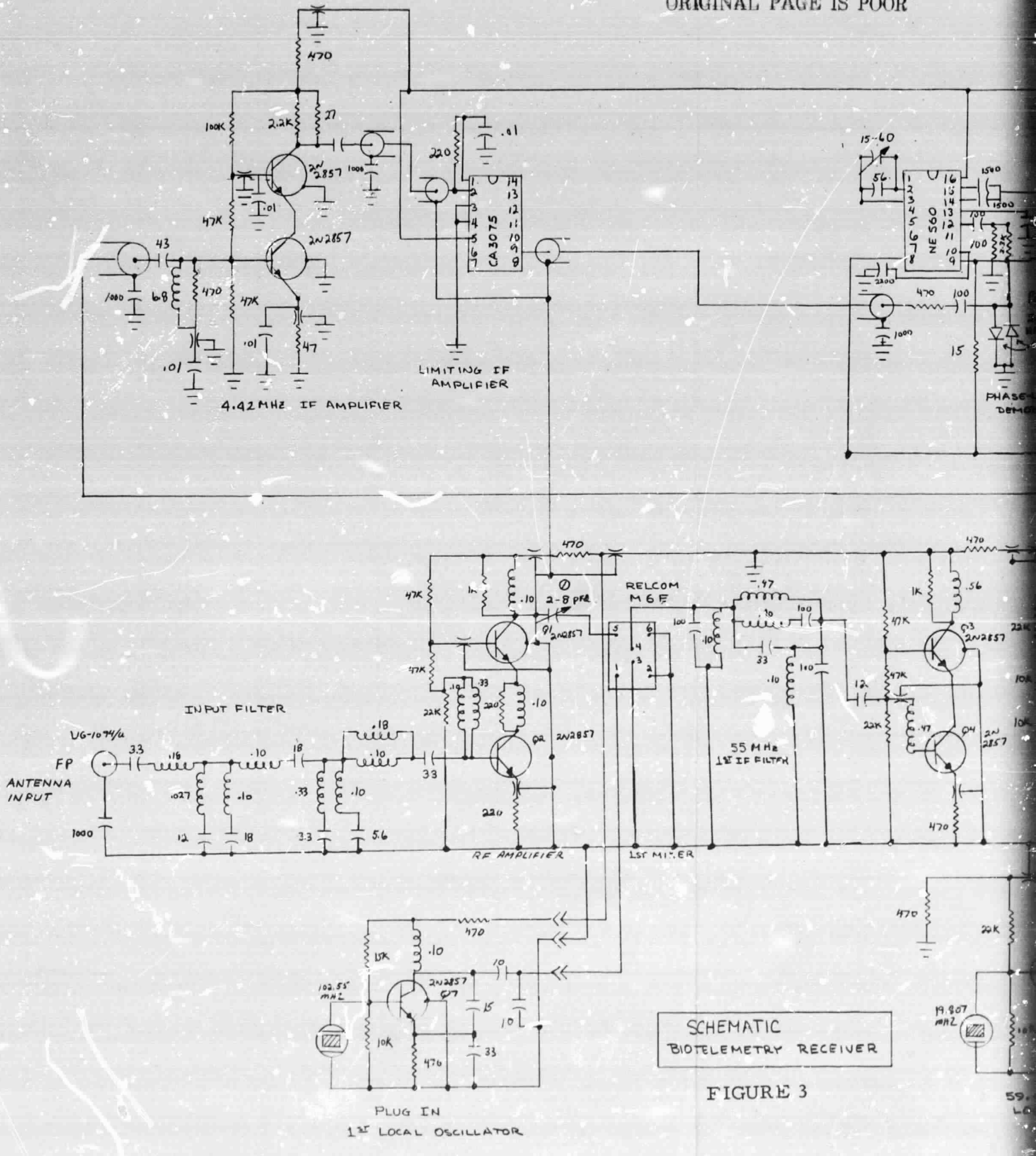
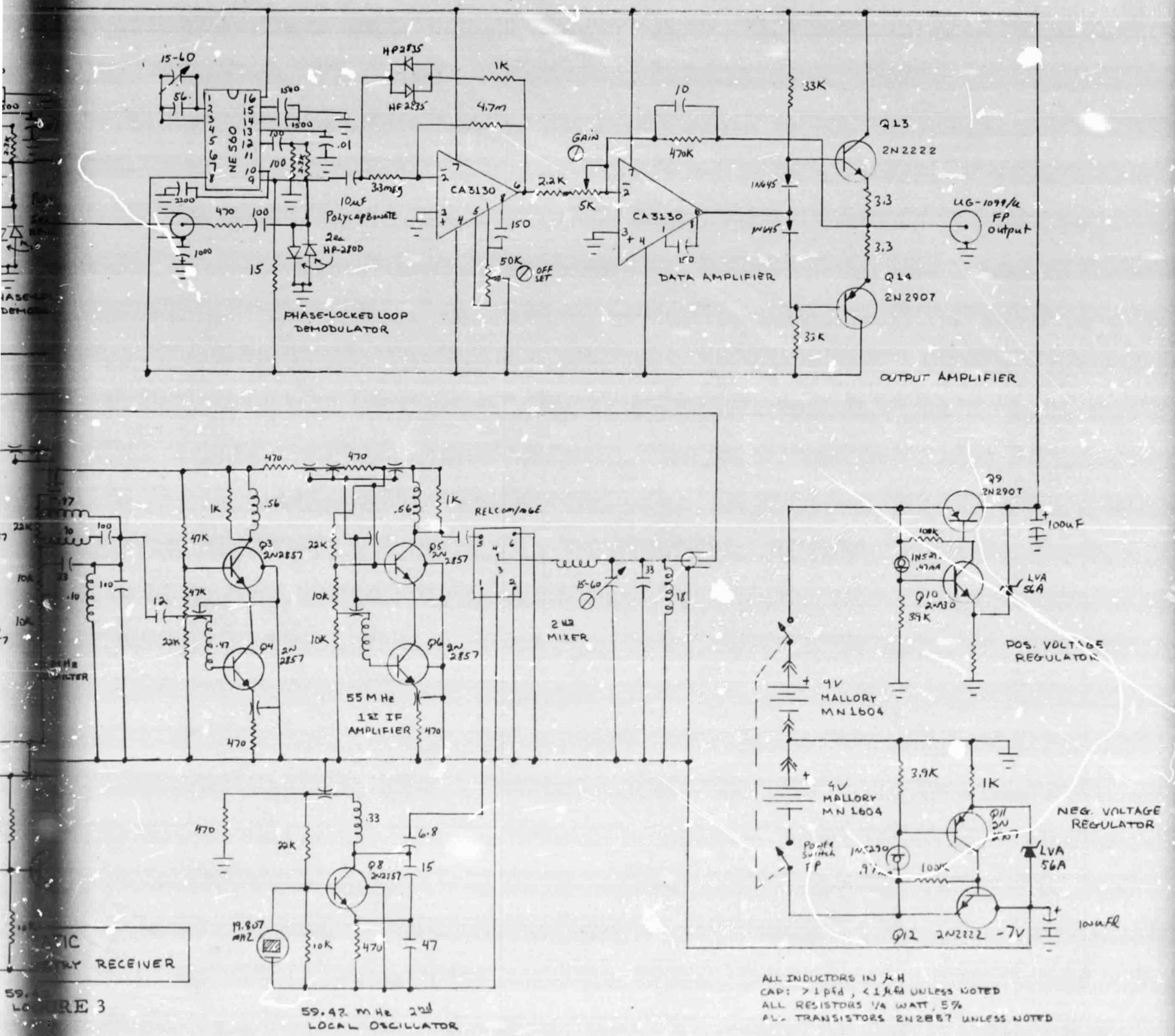


FIGURE 3

FOLDOUT FRAME 1



...URE 3

FOLDOUT FRAME 2

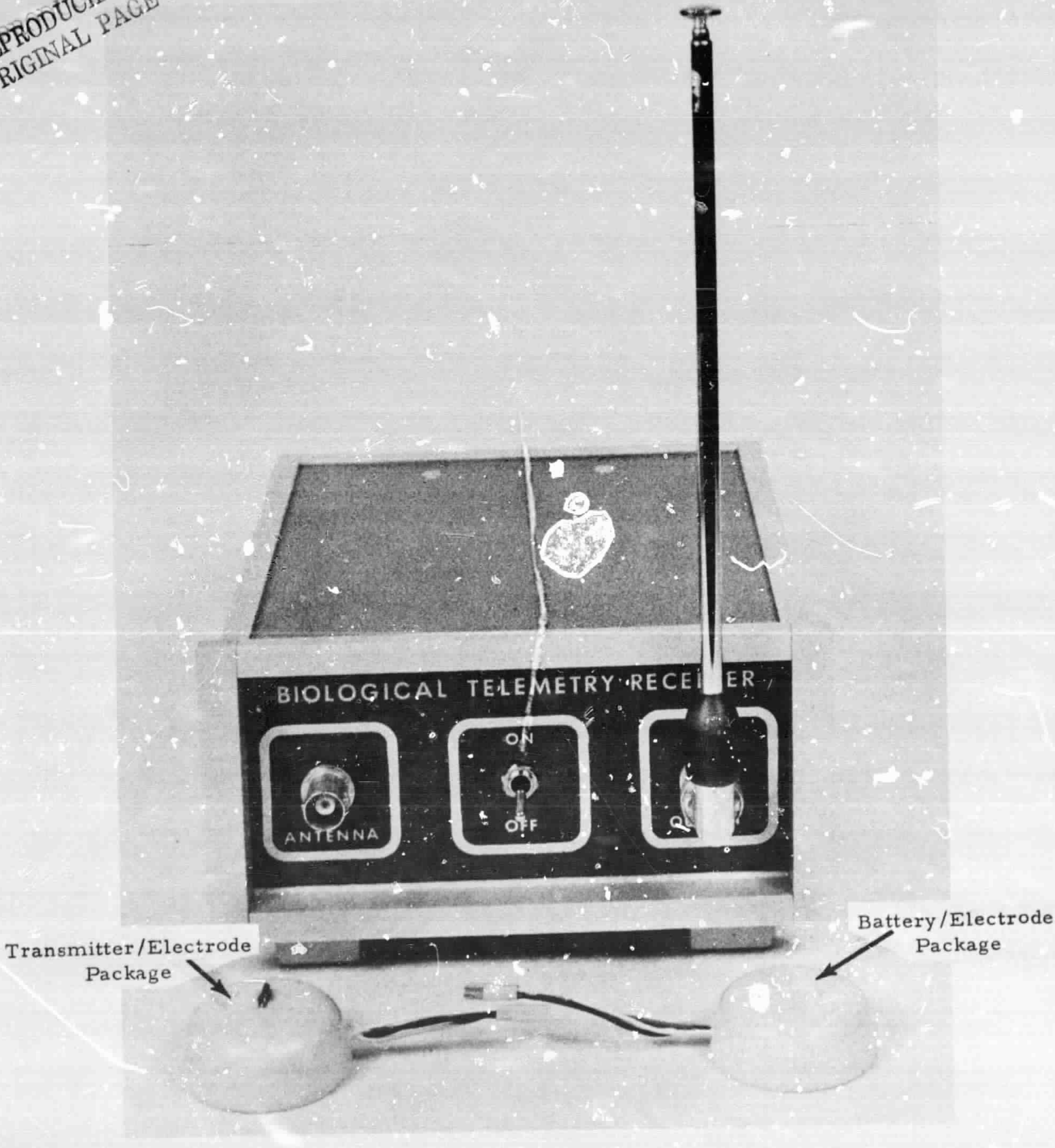


FIGURE 4. BIOTELEMETRY SYSTEM

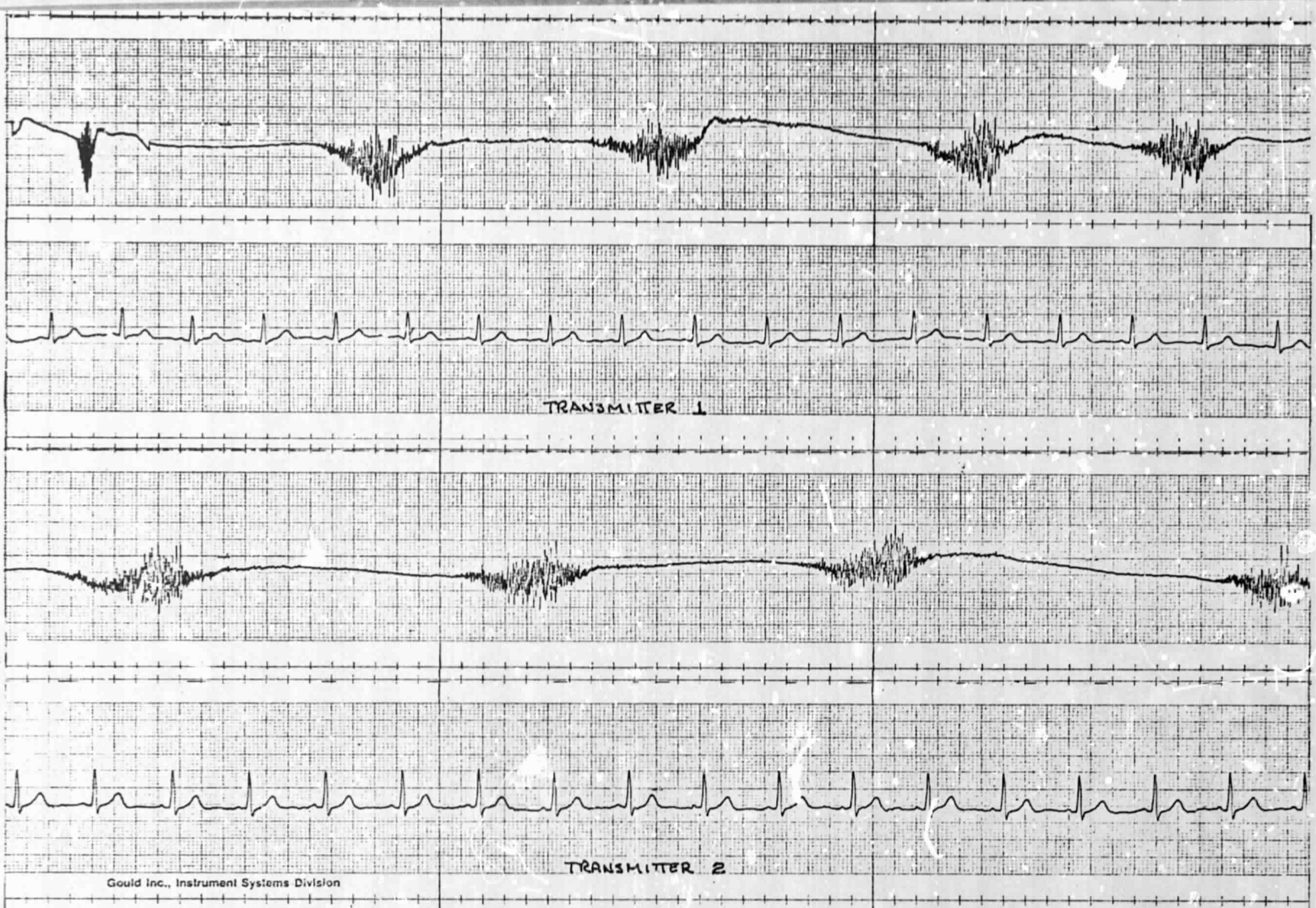


FIGURE 5

EKG AND EMG RECORDINGS

TABLE 1. EQUIPMENT PERFORMANCE

Overall System

Transmitter No. 1 (157.5 MHz)

	High Gain	Low Gain
Gain	2500	250
Frequency Response	0.07 Hz to 1 kHz	0.07 Hz to 2 kHz
Input Impedance	4.4 megohms	4.4 megohms
Battery Life	6 hrs	6 hrs

Transmitter No. 2 (172.05 MHz)

	High Gain	Low Gain
Gain	2500	230
Frequency Response	0.07 Hz to 1.5 kHz	0.07 Hz to 3 kHz
Input Impedance	4.4 megohms	4.4 megohms
Battery Life	6 hrs	6 hrs

Transmitter

Output RF Frequencies	
Transmitter No. 1	157.55 MHz
Transmitter No. 2	172.05 MHz
Battery Current	10 milliamps
Frequency Deviation	10 kHz
Antenna	Untuned short wire
Data Frequency Response	0.05 Hz to 7 kHz

Receiver

Data Frequency Response	0.05 Hz to 7 kHz
Output Voltage Level	5 volts P-P into 1 K ohm with 10 kHz input signal deviation
RF Sensitivity	2 μV (tangential sensitivity)
Dynamic Range	120 dB
Image Rejection	60 dB
A.M. Rejection	40 dB for 1 mV input signal 34 dB for 100 μV input signal 27 dB for 10 μV input signal
Residual DC Level Shift at Output	0.5 volts for input from 2 μV to 2 volts
Discriminator Capture Range	± 0.3 MHz
DC Current Required	30 ma
Receiver Type	Double conversion crystal controlled FM

It should be noted that under certain conditions, fading and loss of RF signal will be encountered due to standing wave (multipath) interference. This is especially noticeable as the receiver-transmitter separation distance increases or if interferring metal structures are present which reflect out-of-phase signals to the receiver. Care should also be exercised in insuring fresh battery supplies for both the transmitter (recharging the battery supply) and the receiver (replacing the batteries).

III. SYSTEM OPERATION

A. General

In order to operate the system, select the matching receiver tuning unit with the appropriate transmitter. Each pair is coded with a matching color dot. Attach the electrodes and connect the battery and transmitter by plugging the two ends of the respective cables together. Turn the receiver on and adjust the desired gain of the recording device. For the high gain setting of EEG measurements, insert a jumper wire into the two holes located on top of the transmitter-electrode package.

B. Identification of Transmitter-Receiver Tuning Unit Pairs

Each transmitter and associated receiver tuning unit have been color coded. The color coding is placed in the channel of the gain selector plug for the transmitter and on the crystal can for the receiver tuning unit. The color coding is as follows:

157.55 MHz Units - GREEN
172.05 MHz Units - BLUE

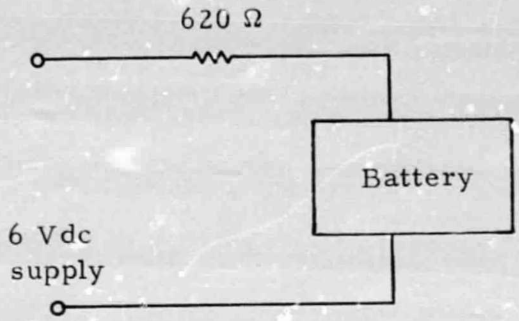
When changing the receiver's tuning unit, the color code should be nearest the chassis side of the receiver. The tuning unit will not fit in the other positions but observing the position of the color code will prevent possible damage to the guide pins.

C. System Optimizing

In order to minimize the effect of baseline shifting of the receiver output when the RF signal is at a very low value, the gain of the data amplifier should be at a maximum value tolerable for the available data input. This setting will produce the optimum overall results. The data amplifier gain has been adjusted to provide an acceptable output for the maximum allowable signal input. When making measurements many variables control the amount of signal received by the input sensors, therefore, optimizing the system gain for the particular set of variables will produce optimum overall system performance. A method of doing this is available in this system. It consists of placing an 1/8 watt resistor in the "gain control" jumper pins as shown in Figure 4. As an example, when recording EMG from the lower part of the arm, immunity from baseline shift sensitivity was greatly improved by placing a 3 K ohm resistor in the "gain control" jumper pins. This method should be considered for producing the best obtainable results.

D. Battery Charging

The batteries used to power the transmitter electronics are rechargeable Nicad type. The suggested charging circuit is shown below:



The batteries should be connected through a 620 ohm resistor to a 6 volt dc source. This connection should remain for approximately 10 hours. An accessory plug has been furnished with the resistor value in the line. Connect the red color wire to the plus terminal and the black color wire to the negative terminal of the power supply. Connect the battery to the plug for the charging operation.

E. Special Considerations

Some precautions which should be observed during operation are:

(1) Ensure that all batteries are fresh or recently charged.

(2) In order to prevent standing waves and reflected signals from causing cancellation of the received signal, try and position the receiver-transmitter group away from large metal posts, etc.

(3) If intermittent operation is observed, test for interference signals broadcasted by other radio sources.

IV. CONCLUSIONS AND RECOMMENDATIONS

Several areas for improvement of the overall system have become apparent during the final construction and testing. In order to keep the size and weight at a minimum, two batteries were used. This provided a ±1.5 V source. When using low supply voltages, the galvanic off-set potential becomes very important. For this reason, input coupling capacitors were required. Using a higher supply voltage, these input capacitors could be eliminated.

Due to the low current requirements of the data amplifier, very low input biasing current is used. This is in the order of ·0 na. The placement of the input leads and isolation from the RF power circuits is critical and must be carefully determined for each individual circuit. This is especially important for the high gain setting. A higher radiated RF field providing reception at greater distances and less susceptibility to interfering signals could be provided by limiting the sensor measurement to EKG and EMG. These two measurements do not require the high gain of the EEG measurement and thus the bias is not as sensitive. This would also eliminate the leads necessary to accomplish the plug-in gain change which also influences the sensitive bias requirements.