A MINIATURE BIO-POTENTIAL TELEMETRY SYSTEM

by

Gordon J. Deboo and Thomas B. Fryer*

March 1964

*Ames Research Center, Moffett Field, California

N66-86116
(ACCESSION NUMBER)
18
(PAGES)
TMX 54931
(NASA CR OR TMX OR AD NUMBER)
(THRU)
None
(CODE)
(CATEGORY)
FACILITY FORM 602

[redacted]
NASA Centers Only.

Summary

A sub-miniature, high-performance, multipurpose, bio-potential telemetering system has been developed. Features of the transmitter include an extremely small size even though conventional, easily available, inexpensive components are used; an assembly technique which permits relatively easy construction in spite of the small size; and a two day operating life when powered by a single miniature 1.4-volt battery.

The use of a single battery is significant in the attainment of small size, since it is an order of magnitude larger than any of the other components used. Careful circuit design and the use of new high-reliability silicon transistors, which are capable of operations at very low current levels, allow these features to be attained without sacrificing performance.

[redacted]

Introduction

A large part of NASA's effort in the life sciences is being conducted at the Ames Research Center at Moffett Field, California, where the work described in this article was performed. One part of this effort involves the measurement of bio-potentials from both animals and humans.

In making any measurement, it is important that the measuring device does not significantly affect the ~~magnitude of the measurement~~ measurement. In earlier years, both baseline physiological measurements and measurement of response to controlled environmental stimulus were seriously affected by encumbering electrical connections between the subject and the monitoring equipment.

Much excellent work has been accomplished in this field[1, 2] but a combination of requirements necessitated the development of the improved transmitter discussed here. The device had to be small enough that it could be used on small animals as well as humans without sacrificing performance, it had to be unaffected by movement of the animal and capable of operation in a centrifuge. In spite of its small size, it must not sacrifice performance and the assembly technique must permit relatively easy and repeatable construction.

Design Philosophy

Since the transmitter was to be battery operated, the smallest available mercury cell was selected as a starting point for the design, the Mallory RM 312, a 1.4-volt cell 5/16 inches in diameter by 9/64 inches thick, having a capacity of 36 milliampere-hours. For a battery life of 40 hours the current drain, therefore had to be kept below one milliampere.

The 88 to 108 Megacycle FM band was selected as the operating frequency because good, inexpensive receivers operating in this band are readily available and can be used for ~~ground~~ laboratory applications. Also, this is a frequency

region at which present transistors can be made to oscillate readily and the radiating properties of small coils used as transmitting antennae, while not optimum, have been found to be adequate. Finally, the FCC has assigned the 88 to 108 megacycle FM band to low-power telemetry devices[3], such as the presently described bio-potential transmitter.

For the simplest system, the bio-potentials would be made to frequency modulate an r-f oscillator directly, but under certain circumstances, such a scheme has a serious disadvantage. If the bio-potential were the only thing affecting the oscillator frequency, this technique would probably be adequate; but changes in frequency also occur due to changes in transmitter-to-body capacitance. This problem is especially acute when unrestrained animals are used because frequency changes due to body movement do occur and cannot be separated from frequency changes due to modulation by the signal. The result is that the received data appears on a randomly shifting baseline.

There are two ways to overcome this problem—one is to use crystal controlled phase modulation of the transmitter and the other is to use a sub-carrier oscillator. The latter method was selected because crystal control would have involved more parts and greater complexity. An additional advantage of a sub-carrier system is that the transmitter can be deviated to its full extent at all times, without having to leave a large margin for signals having a variable input level or occurring on a shifting baseline, which might cause over-deviation. This helps to maximize the transmitting range for a particular radiation power, since the signal-to-noise ratio is more optimum.

Circuit Design

Referring to the block diagram of the overall system shown in figure 1, the bio-potentials are preamplified and then used to control a frequency

modulated sub-carrier oscillator (SCO). The output of the SCO is a signal the frequency of which is linearly related to the original signal voltage. This SCO output is used to frequency modulate the radio frequency (R.F.) transmitter stage, the oscillator coil of which is used to radiate energy to the receiver. The receiver output is a signal having the same repetition rate as the SCO and is fed to the SCO demodulator, which recreates the original bio-potential waveform.

Figure 2 is a circuit diagram of the miniature transmitter. The input appears between the base of transistor Q1 and the junction of R1 and R2, a potential divider which serves to bias Q1. C1 by-passes R1 and R2 at signal frequencies, partly to avoid a small signal loss, but mainly to retain the high common-mode rejection of the amplifier, which results from the whole circuit being isolated from ground. C2 is an r.f. by-pass, which prevents any of the transmitted energy from the output stage from entering the input, being rectified, and appearing as a shifting baseline.

Transistor Q2 is a conventional feedback amplifier which has a gain of 5, when loaded by Q3 and its bias network.

Transistors Q3, Q4, and Q5 comprise a voltage-controlled oscillator, the design of which is unusual in that it consumes less than 20 microwatts, yet has a high frequency deviation sensitivity (±10% for only ±10 mv. at the base of Q3). Transistor Q3 is a current generator, the collector current of which is linearly related to the amplified signal voltage, appearing at the base of Q3. ~~which appears at Q3 base~~. C5 is charged by the collector current, which controls the period of the oscillator formed by Q4 and Q5. The oscillator works as follows: at the instant power is applied to the circuit C5 is uncharged, but current from Q3 charges it through R12. Q4 is initially off, because its base and emitter are at the same potential. Q5 is off

because Q4 is off, there being no base current into Q5. C5 now charges and the base of Q4 becomes increasingly positive with time until Q4 turns on, which also turns on Q5. There is positive feedback to the base of Q4 via C5, resulting in a fast switching action, which causes both Q4 and Q5 to switch on in about 1 microsecond. The transistors remain in this condition for about 10 microseconds, being held there by storage time effects and then, since there is no sustaining current, Q3 and Q4 rapidly turn off. Both transistors are "on" for only about 1% of the time because C5 takes about 100 times longer to charge to the "on" potential at the base of Q4, than Q4 and Q5 can stay on due to storage effects. An SCO repetition rate of approximately 1100 cps is obtained with the component values shown. Q5 is operated in the inverted connection because in the normal configuration its gain was excessive, causing the oscillator to lock in one state. A square wave therefore appears at the junction of R12 and C5, having a 1% duty cycle and is used to frequency modulate the r.f. transistor Q6.

Transistor Q6 performs two functions, those of a frequency modulated r.f. oscillator and of a transmitter. It is used in a grounded-base Colpitts oscillator circuit, employing positive feedback to the emitter from capacitative divider C7-C8, in the collector circuit. L1 serves as both a tuning coil and a transmitting antenna. Frequency modulation is accomplished by varying the operating point of the transistor, which in turn varies its collector capacitance, thus changing the resonant frequency of the tank circuit. The transmitter output therefore consists of an r.f. signal ~~turned~~ tuned to approximately 90 megacycles, frequency modulated by the SCO, which in turn is frequency modulated by the input signal.

The transmitter output is sensed by a half-wave dipole antenna feeding a conventional, high sensitivity FM receiver with automatic frequency control,

(AFC). The high sensitivity provides additional range, helping to overcome the inefficiency of the transmitting coil antenna, while the AFC ensures that SCO signals are not lost because of any slight detuning due to body capacitance.

The receiver output consists of the original SCO signal, which must itself be detected in order to ~~record~~ recover the original signal and this is accomplished by the SCO ~~demodulator~~ discriminator shown in block diagram form in figure 1, the circuit diagram of which appears in figure ~~2~~ 3.

Q1 is an emitter follower which provides a reasonably high input impedance for the demodulator and at the same time approximates the zero-impedance source necessary to drive the constant-k band-pass filter. This 800 to 1400 cps. filter improves the signal-to-noise ratio of the overall system by reducing spurious signals, by removing slow baseline shifts in the SCO due to slight detuning, and by converting the SCO signal to a sine wave, which is a more suitable drive for the following zero-crossing detector. R5, D1, and D2 clip the resulting sine wave, which is then amplified and limited by Q3 and Q4.

Transistors Q5 and Q6 form a monostable multivibrator, triggered at the SCO repetition rate. R17 and C8 provide initial averaging of the monostable circuit output, while the UTC LPM 200, a low-pass filter with a cut-off of 200 cps. removes most of the residual ripple. Thus the monostable multivibrator and the filter form a conventional pulse-rate integrator, which converts frequency to a proportional voltage, capable of accepting inputs of 1100 cps. ±10% and able to deliver an output signal varying from 0 to 200 cps.

Owing to the small deviation, the output of the UTC LPM 200 is of the order of tenths of a volt, so an amplifier with a gain of 10, consisting

of Q9, Q10, and Q11, is incorporated to raise the signal level to volts, to provide for d.c. output level adjustment, and to provide a low output impedance.

The demodulator output is therefore the same waveform as the original signal which modulated the transmitter. It is to be noted that the demodulator circuit is entirely d.c. in that it does not affect the low frequency cut-off point of the system.

Measured Circuit Data

The measured performance of the system is as follows:

Transmitter:

Size	.74 inches diameter by .20 inches ~~long~~ thick
Weight	2 grams
Power Supply	Mallory RM312 mercury cell, 1.~~35~~ 4 volts
Battery drain	0.8 milliamps
Battery life	45 hours
Radio frequency	90 Mcps
SCO frequency	1100 cps
Input impedance	20 Megohms

Overall system:

Frequency response	0.5 to 120 cps
Gain	3000
Equivalent input noise	1 microvolt RMS
Maximum transmitting range	100 feet

Construction

When an electronic circuit is to be constructed in as small a package as possible serious consideration must be given to integrated circuits, which have two main advantages, those of extremely small size and potentially high reliability.

However, they do have disadvantages including high cost in small quantities, relatively high power requirements, poor component tolerances, low yields, limited component value ranges, the fact that some components such as tantalum capacitors cannot be integrated and the experimental nature at present of r.f. integrated circuitry. It can happen, therefore, that in some cases an integrated circuit, while solving one problem - that of size - can generate new problems which would otherwise not exist. Many of the limitations of integrated circuits will probably be eliminated in the future, but at the present time the use of small, discrete components was the best choice for cost, power consumption, and off-the-shelf availablity.

Some further considerations entered into the choice in this case between conventional packaging and integrated circuits. Since the circuit contains a battery, which is an appreciable part of the total volume, there is a limit to how small the device can be made regardless of what type of packaging is used. Also, if the battery becomes too large a percentage of the total volume, the radiating efficiency of the transmitter's coil antenna is reduced. Finally, after investigating methods of assembling standard components, it was found that with these the transmitter could be made small enough for the majority of applications.

The first step in construction involved the selection of components. The transistors used are all Fairchild Semiconductor types in the TO-51 Corning Glass case. Tantalum capacitors are Minitan solid tantalum made by Components Inc., while the other capacitors are Scionics disc pellet ceramic types with ribbon leads attached. The resistors are Allen-Bradley one-tenth watt size.

One problem that arises in the construction of an instrument using such tiny components is that of holding the various parts in their correct

location while their leads are being soldered. This was solved in the present instance by using a Rexolite former - a plastic material with good high-frequency properties - with holes of a size suitable for each component, as shown in figure 4. A large hole in the center located the battery and a groove cut around the outside of the cylinder fixed the coil spacing. The connection to the negative side of the battery was made through a spring contact washer in the bottom of the battery hole. The positive connection was made by means of a "V"-shaped spring retainer which also secured the battery in place. The individual parts were fixed in position with a drop of Humiseal and their leads were then bent over and soldered.

Applications

So far the device has been used to measure the electrocardiogram of both a man and a chicken. In the case of the man, variations in heart-rate were monitored for a period of nearly a week. The chicken's electrocardiogram was monitored while the bird was roaming free in a large room. Other applications in the near future will include recording the EEG of a cat, ~~the ECG~~ nerve potentials of a pigeon in free flight, and further studies on the circadian rhythms of both humans and animals, as well as short term centrifuge studies.

Figure Titles

1. Bio-potential telemetry system block diagram.
2. Bio-potential transmitter circuit diagram.
3. FM sub-carrier oscillator demodulator circuit diagram.
4. Bio-potential transmitter construction.
5. Photograph of transmitter.
6. Typical system noise level and a human exercise electrocardiogram.

References

1. A bibliography of radio - telemetry

   L. A. Geddes. Amer. Journal of Medical Electronics

   October 1962

2. Endoradiosonde techniques - a survey

   B. Jacobson. Medical Electronics and Biological Engineering

   April 1963

3. Amendment of Part 15 of the FCC rules - Docket No. 14376

4. Transistor Circuit Engineering, page 314

   R. F. Shea

   Pub. Wiley, New York, 1957

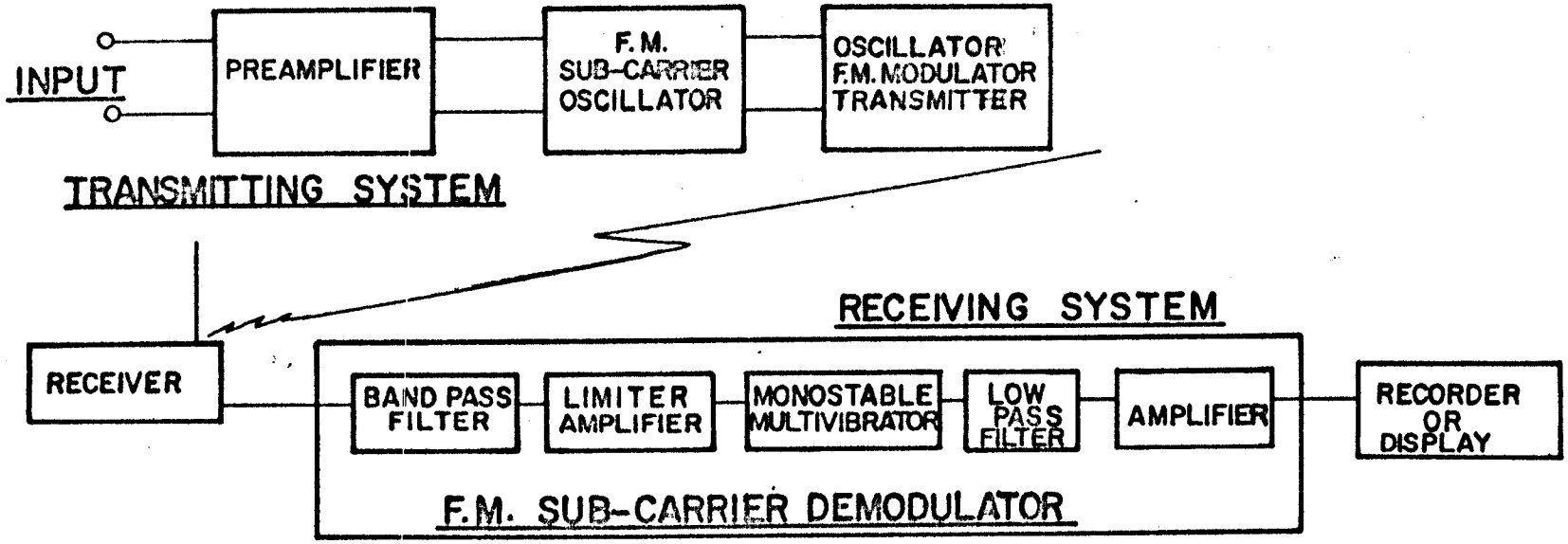
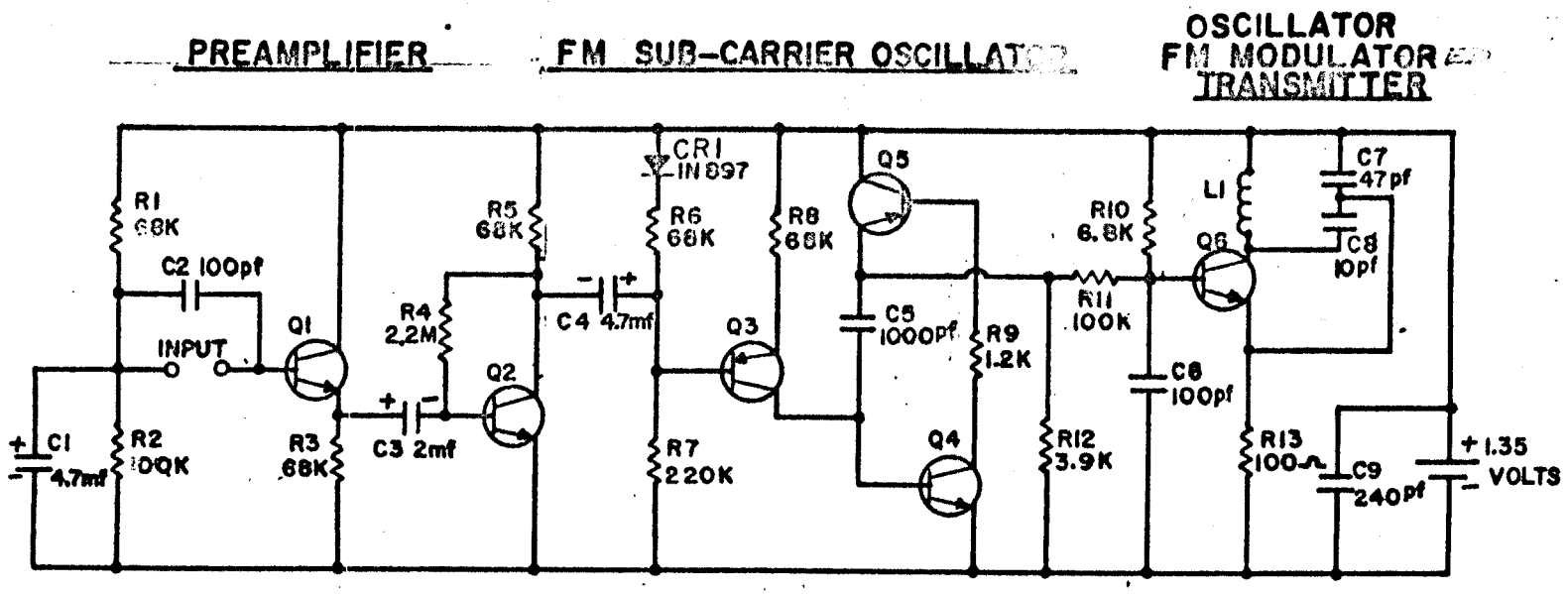


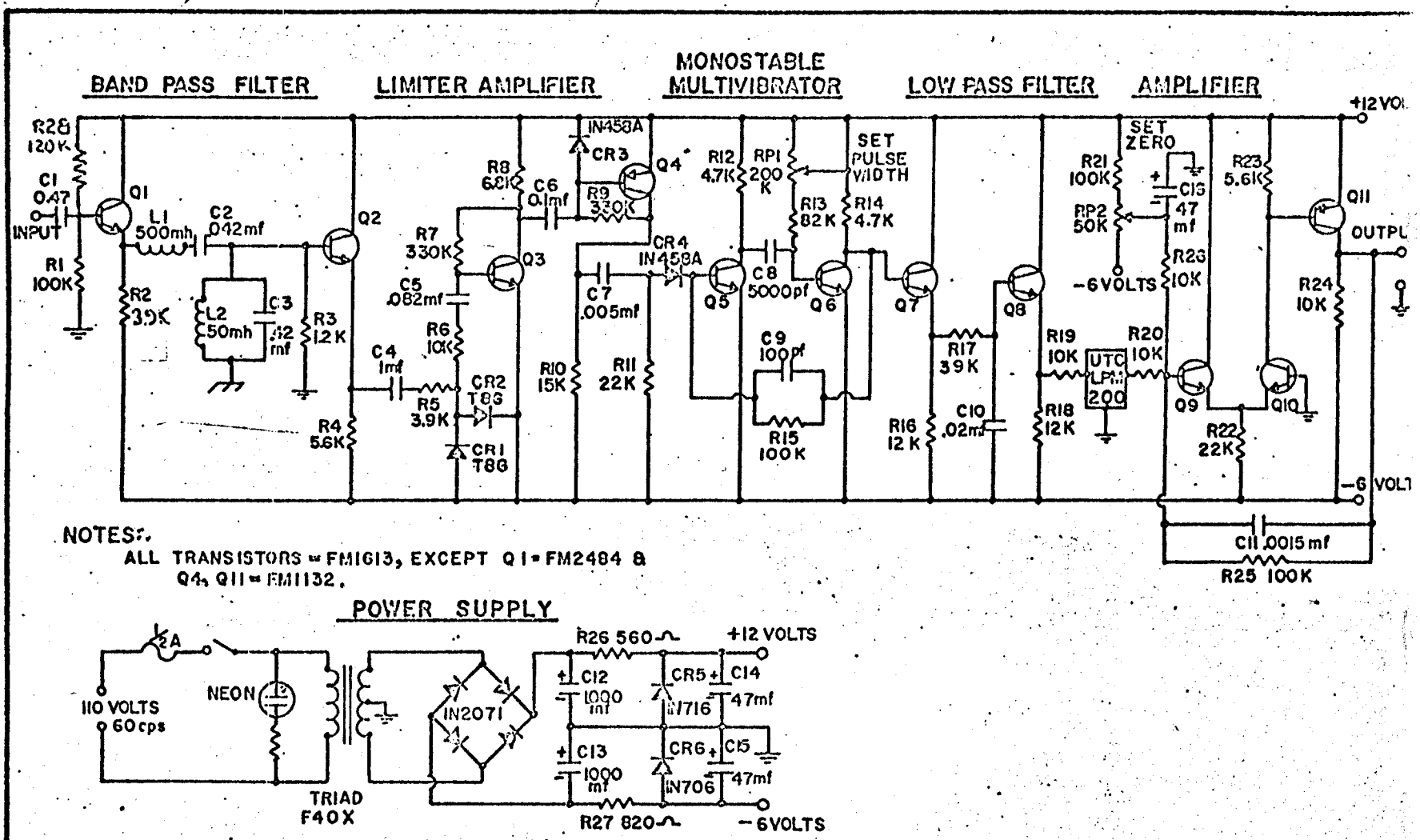
FIG.1 BIO-POTENTIAL TELEMETRY SYSTEM BLOCK DIAGRAM

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, Calif.



NOTES:.
1. ALL RESISTORS IN OHMS.
2. K= X 10^3, M= X 10^6.
3. TRANSISTORS:. Q1, Q2, Q4 = 2N2484 IN A TO-51 CORNING GLASS CASE.
   Q3, Q5 = 2N1132 IN A TO-51 CORNING GLASS CASE.
   Q6 = 2N709 IN A TO-51 CORNING GLASS CASE.
4. L1 = 3 TURNS OF No.28 WIRE.

FIG.2 BIO-POTENTIAL TRANSMITTER CIRCUIT DIAGRAM

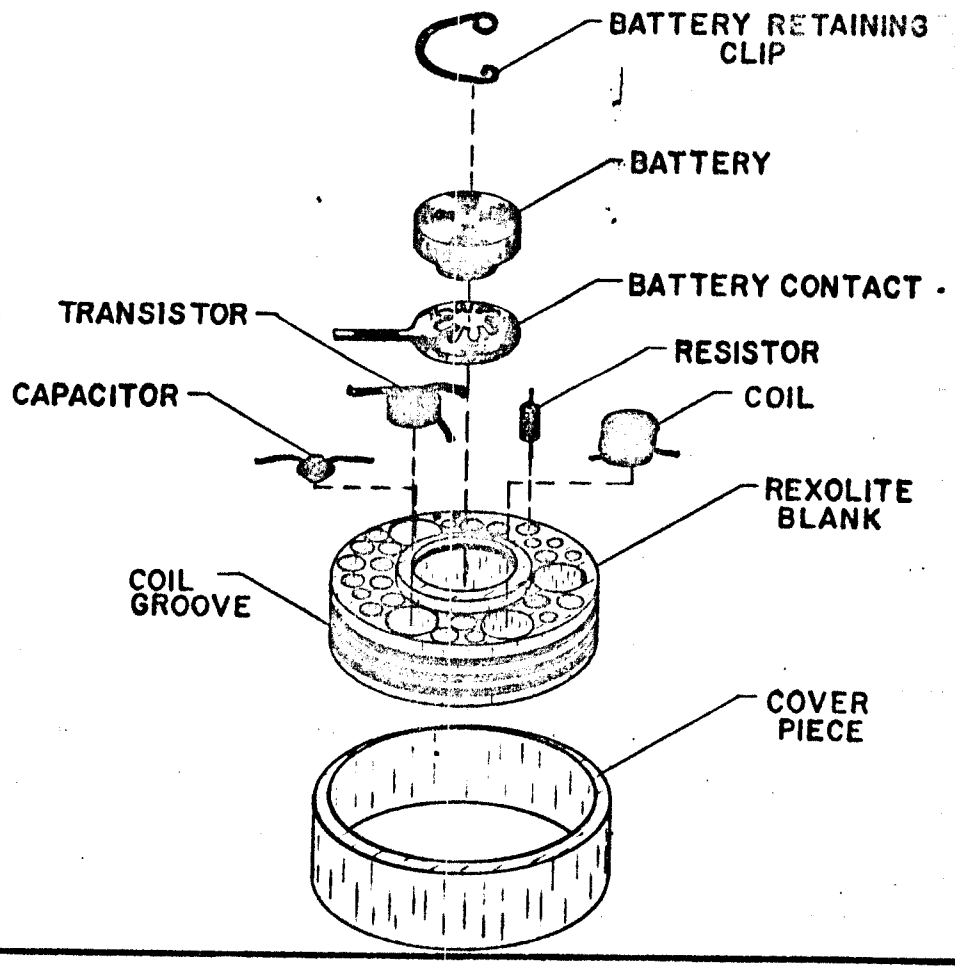


NOTES:

ALL TRANSISTORS = FM1613, EXCEPT Q1 = FM2484 & Q4, Q11 = FM1132.

FIG.3 FM SCO DISCRIMINATOR

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, Calif.



This figure to be turned 90° with title at the bottom.

FIG. 4 · BIO-POTENTIAL TRANSMITTER CONSTRUCTION

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, Calif.

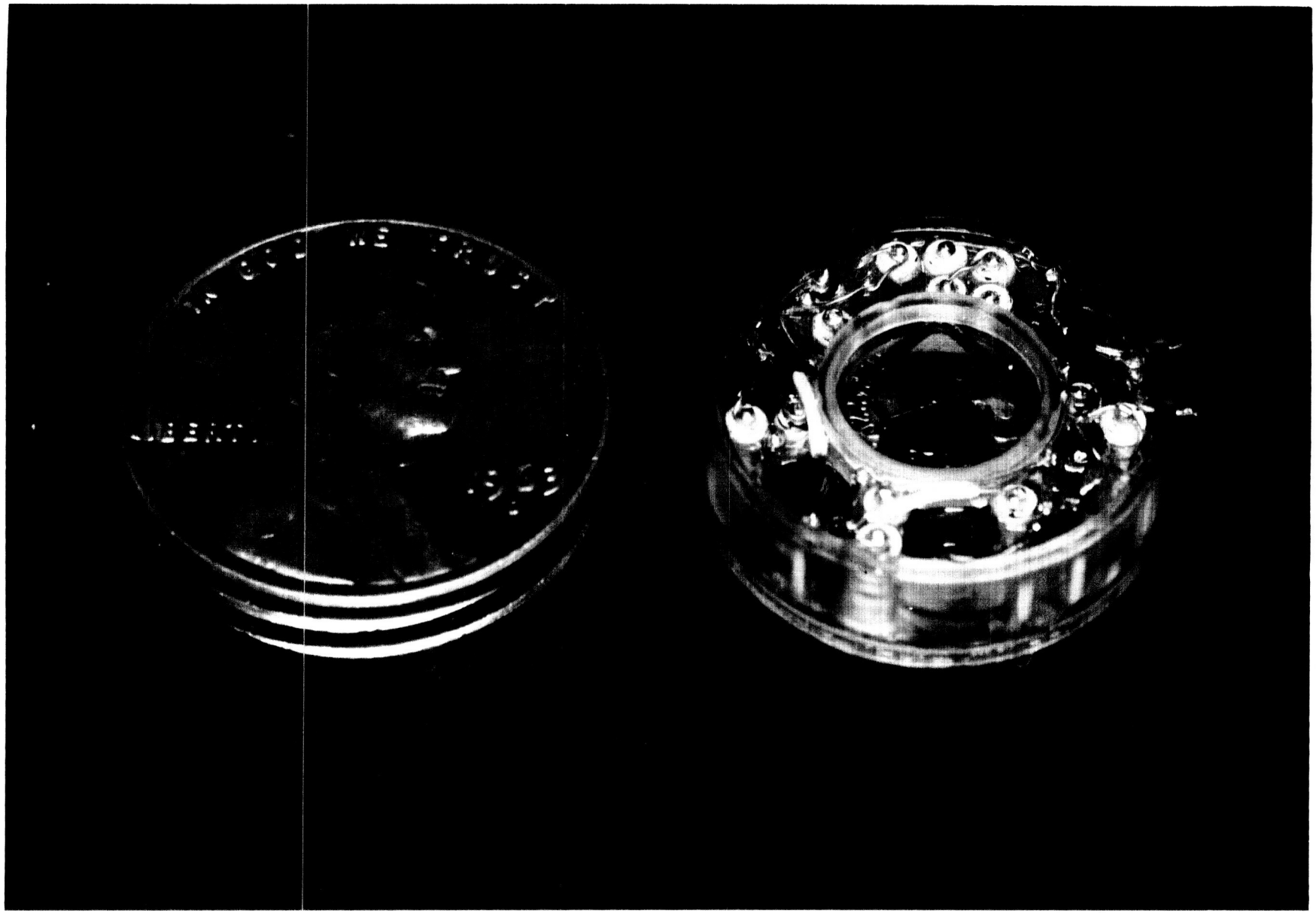
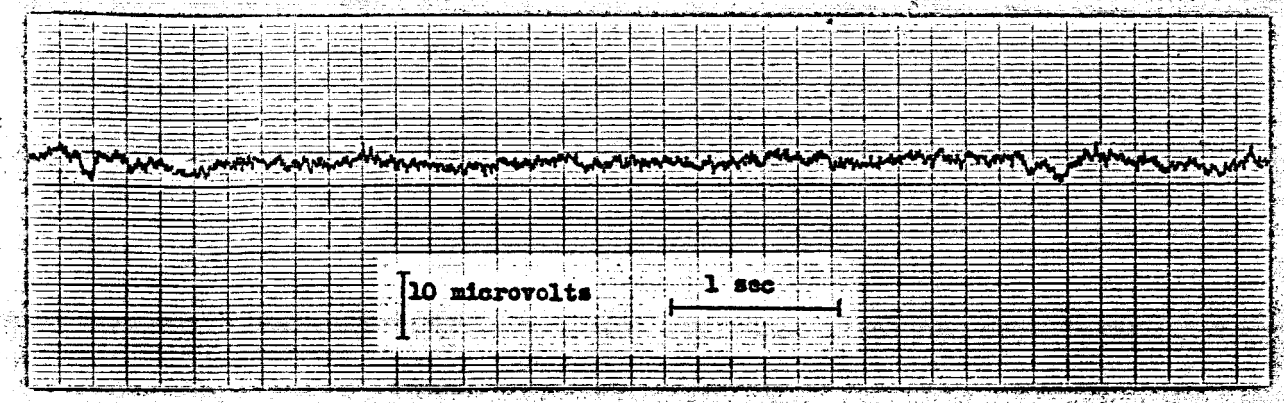


Figure 5. PHOTOGRAPH OF TRANSMITTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA



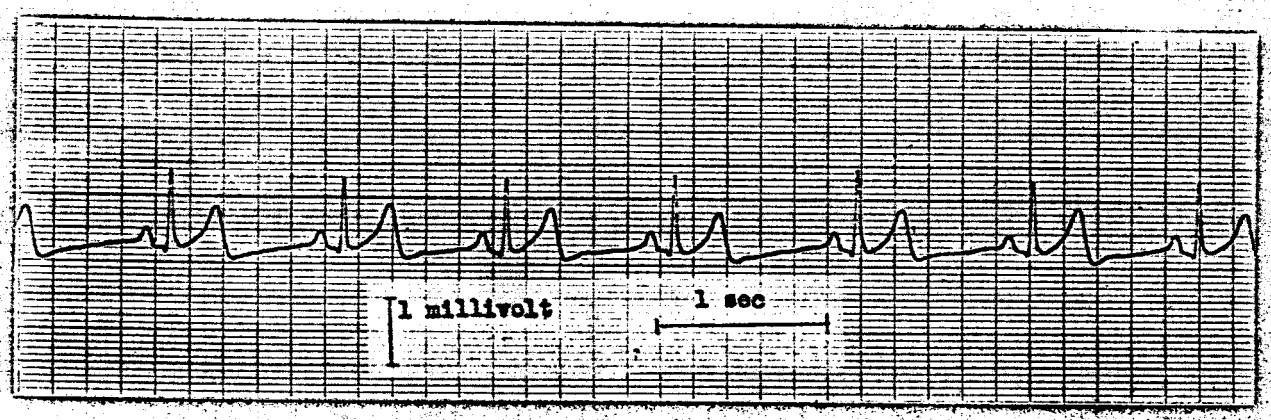


Figure 6

TYPICAL SYSTEM NOISE LEVEL AND A HUMAN ELECTROCARDIOGRAM

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, Calif.