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Annual Report
A-B2299-4

Report

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SPACE RELATED BIOLOGICAL
AND
INSTRUMENTATION STUDIES

by

R. J. Gibson
R. M. Goodman

Annual Report

March 1969 to March 1970

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Contract NSR-039-005-018



THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
BENJAMIN FRANKLIN PARKWAY • PHILADELPHIA, PENNA. 19103

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FOREWORD

Experimental and research effort has continued on high reliability, multichannel telemeters. The first four-channel fm/fm implant was completed and put through bench evaluation. Results are reported. Long-life two-channel units were completed and packaged. Bench results are also included for these units.

Preliminary data shows great promise for the successful development of long-life, pressure-sensing implants. Based on our earlier predictions, use of piezo-junction devices for this purpose shows feasibility.

Studies of implantable, ion concentration transducers have been continued at a somewhat reduced effort level. Results to date are reported.

Details on the formulation of a flexible, paraffin-base, encapsulating material are included in this report.

ACKNOWLEDGEMENTS

The authors acknowledge contributions to the work of this report by Mr. J. Price.

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1.0 MULTICHANNEL TELEMETRY

During the past period, primary effort in multichannel telemetry was put into the reduction to practice and the evaluation of performance of the developments reported earlier (1-1, 1-2, 1-3, 1-4). This step was considered essential because of the very high circuit component densities involved, unanswered questions concerning fabrication techniques, related encapsulation and sealing methods to be used and the acquisition of performance data.

Figures 1.0-1, 2, 3 and 4 illustrate the circuit densities involved and give some idea of the inter-component wiring.

The entire fabrication exercise provided the opportunity to evaluate initial chassis design, assess the performance of specific adhesives, assess the effects of newly available components and to determine *total system* performance in actual operation.

1.1 The Subcarrier Oscillators

These circuits are basic to the operation of the Mark V-type implants. All of them consist of Wien-Bridge oscillators susceptible to fm'g by varying either the control network resistors or capacitors. These circuits are quite stable and were described in some detail in our previous report (1-4). The average current drain for the Wien-Bridge SCO is ca 6.5 μ a.

In this first inclusion in the Mark V system, all four SCO's were packaged on the main circuit chassis (See Figures 1.0-1, 1.0-2).

The output performance for the four SCO's is illustrated in Figures 1.1-1 to 1.1-4 inclusive. Channel-1, (Figure 1.1-1) as built shows a relatively high value for the second harmonic as does Channel-2 (Figure 1.1-2). Channels-3 and -4 are very good in this regard. Nevertheless, these data indicate some room for improvement in the gain stages of the SCO's. It should be possible to obtain excellent sine wave purity.

Center frequencies (f_c 's) came quite close to predicted values once initial difficulties were cleared up. For example the sensing thermistors used in Channels 1 through 3 were 0.043" microbead units (VECO) of nominal 300K Ω $\pm 20\%$ value at 25°C. This tolerance proved unacceptable. As a consequence we selected thermistors for similarity between units and padded them to critical values for proper f_c at 37°C.

Center frequency adjustment for Channel-4 proved to be dependent on the bias status of the particular field-emission-transistor used in that SCO. In a sense, this was not surprising since operation at the low voltage (1.35V) and extremely low currents of the Mark V circuits almost assures the need for tailoring of circuits for certain critically functioning semiconductors. In the case at hand, the compensated bias network involved was not adequate for the specific FET inserted. The circuit was modified with a final stability of f_c $\pm 3\%$, -1% for a 10°C ambient range. A $\pm 2^\circ\text{C}$ ambient shift about the 36°C point produced an f_c of $\pm 0.6\%$. A total stability of $\pm 1-1.2\%$ over the range of 32-41°C was

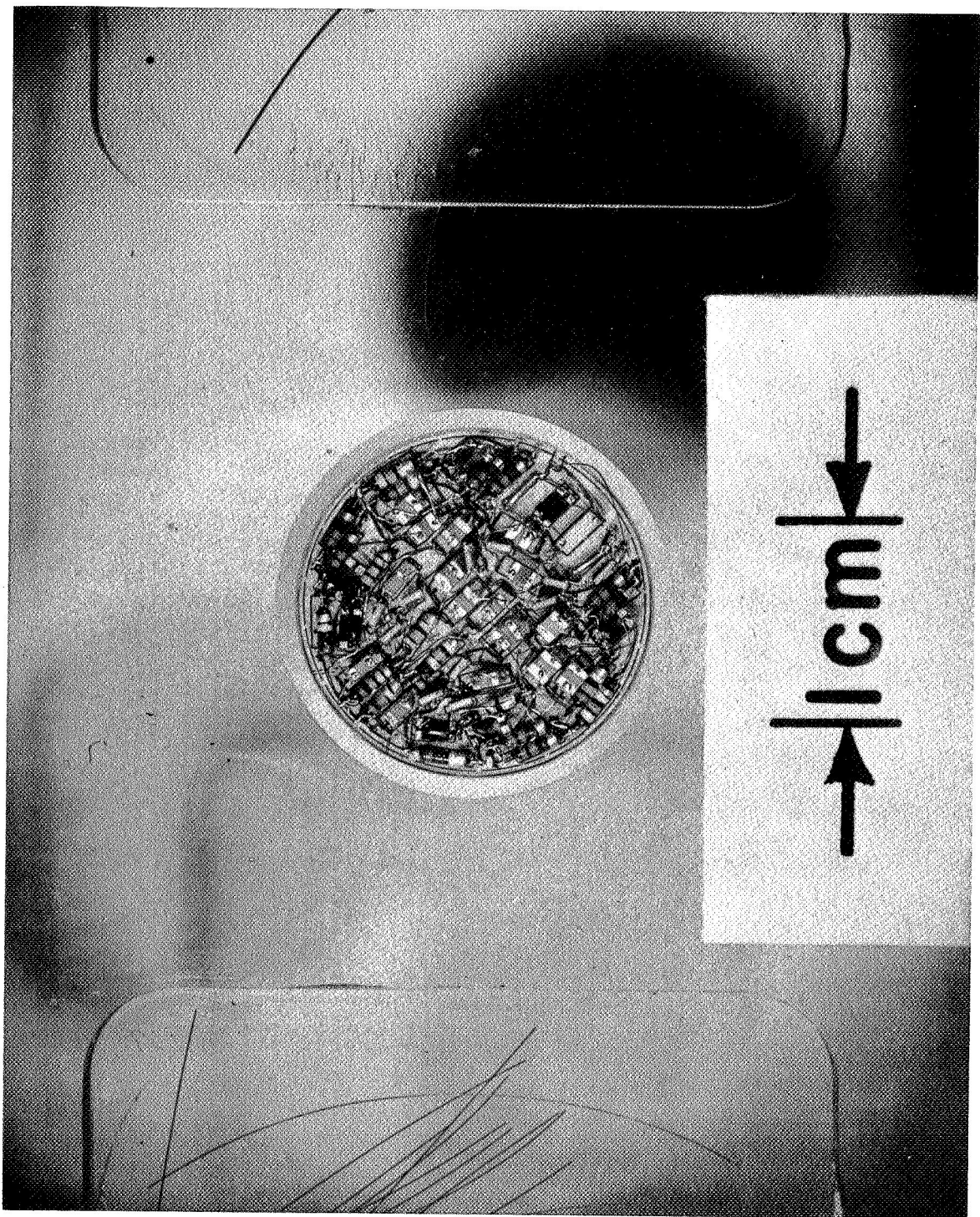


Fig. 1.0-1. Main Chassis, Bottom-Side (MKV, 4-Channel Unit)

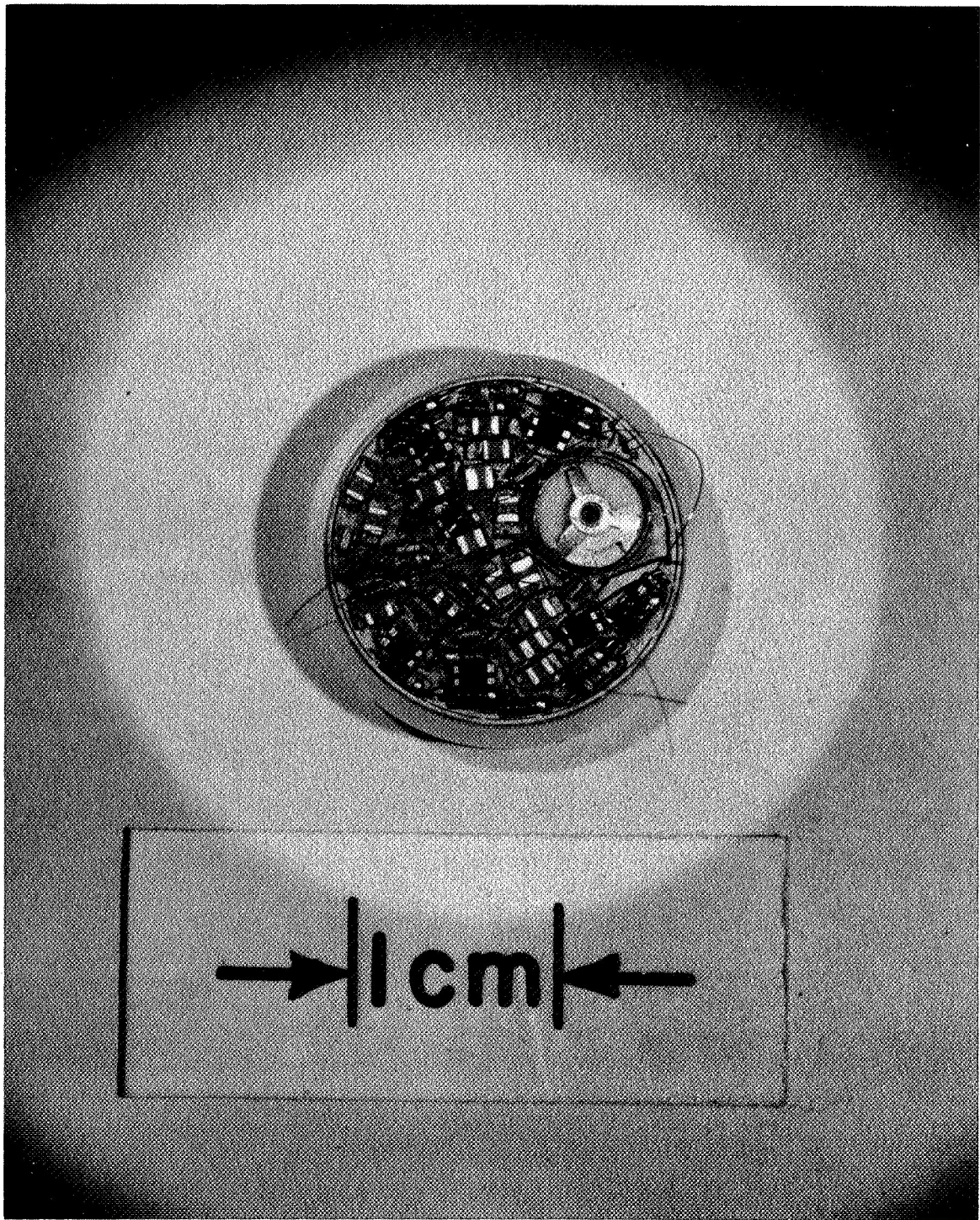


Fig. 1.0-2. Main Chassis, Top-Side (MKV, 4-Channel Unit)

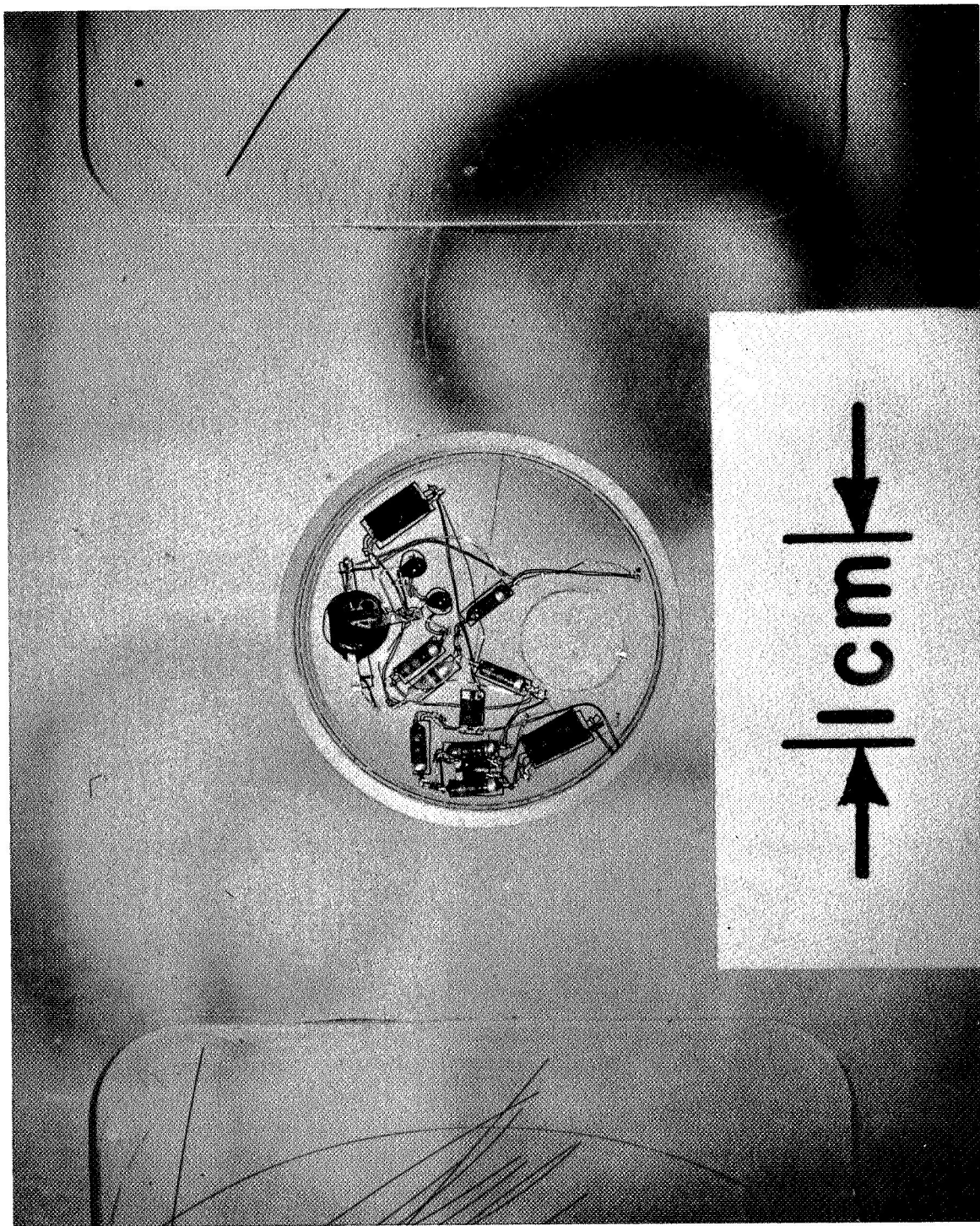


Fig. 1.0-3. Top Chassis, Under-Side (MKV, 4-Channel Unit)



Fig. 1.0-4 Main Chassis Wired in Place, with Cell and Thermistor Leads

demonstrated. We know that a stability of $\pm 0.4\%$ is achievable, but it was not worth the individual, additional tailoring required.

The SCO's worked remarkably well considering that components used were not taken from pre-bread-boarded circuits. The only components measured for precision were the Wien-Bridge tuning capacitors and resistors.

Oven tests were run on the three temperature channels with their sensing thermistors padded and in place. The transmitted signal was picked up with a low-cost fm-radio which fed the decoder; separated SCO sine wave signals were fed to an electronic counter.

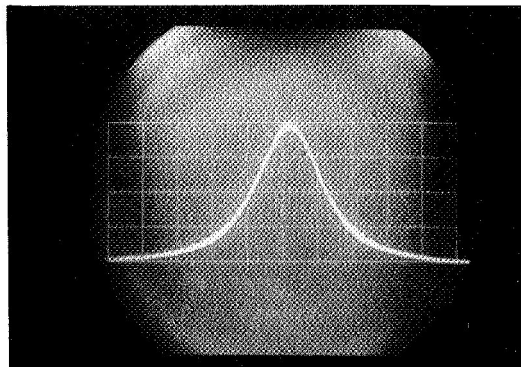
<u>Temperature(°C)</u>	<u>Ch-1(Hz)</u>	<u>Ch-2(Hz)</u>	<u>Ch-3(Hz)</u>
28.20	1601	2803	5186
29.60	1617	2861	5226
31.80	1641	2916	5304
33.60	1663	2962	5362
35.60	1690	3023	5445
37.65	1718	3088	5533
39.65	1754	3155	5628
41.70	1788	3223	5726

These data show sensitivities of:

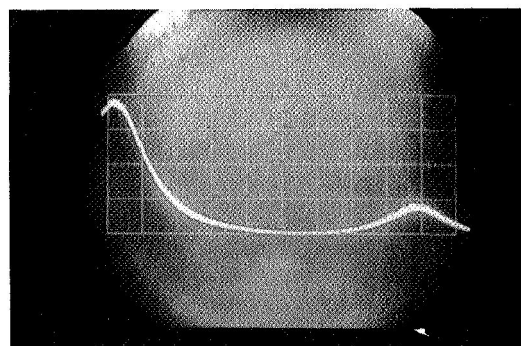
Ch-1: 16Hz/°C at 37°C, or .063°/Hz; predicted value was .059°/Hz

Ch-2: 32Hz/°C at 37°C, or .031°/Hz; predicted value was .033°/Hz

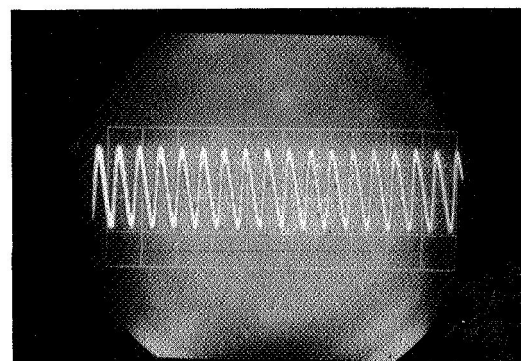
Ch-3: 44Hz/°C at 37°C, or .023°/Hz; predicted value was .019°/Hz



(a)



(b)

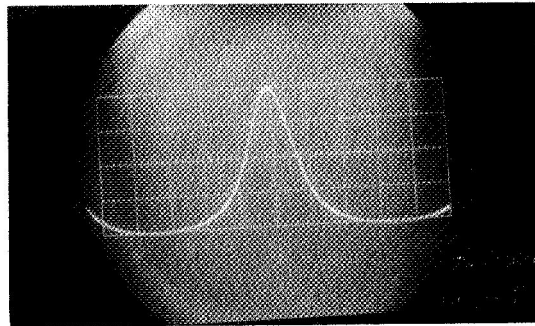


(c)

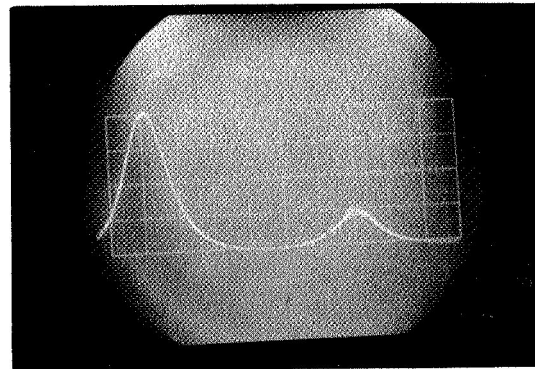
Channel-1 SCO Performance

- a. Carrier, $f_c = 1.7$ KHz
dispersion = 200 Hz/cm
- b. Carrier and first harmonic
 $f_c = 2.7$ KHz, dispersion = 200 Hz/cm
- c. Carrier waveform, 1.7 KHz

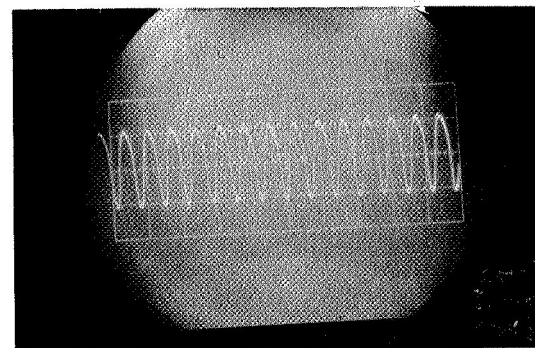
Fig. 1.1-1. Channel 1, SCO Performance



(a)



(b)

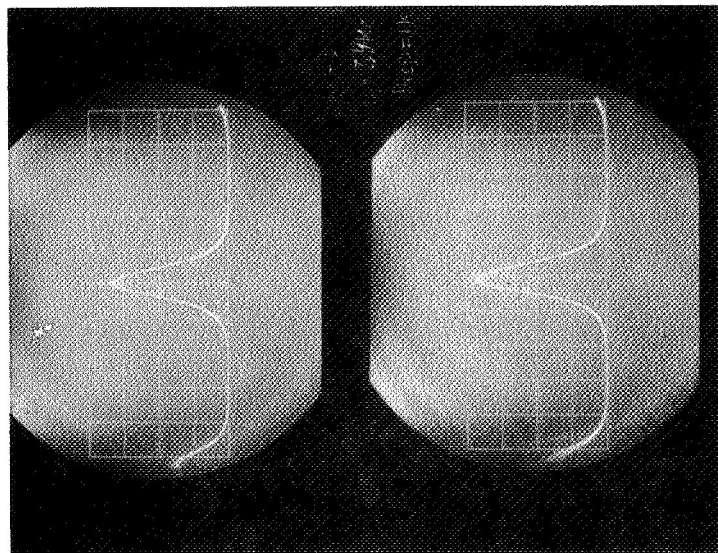


(c)

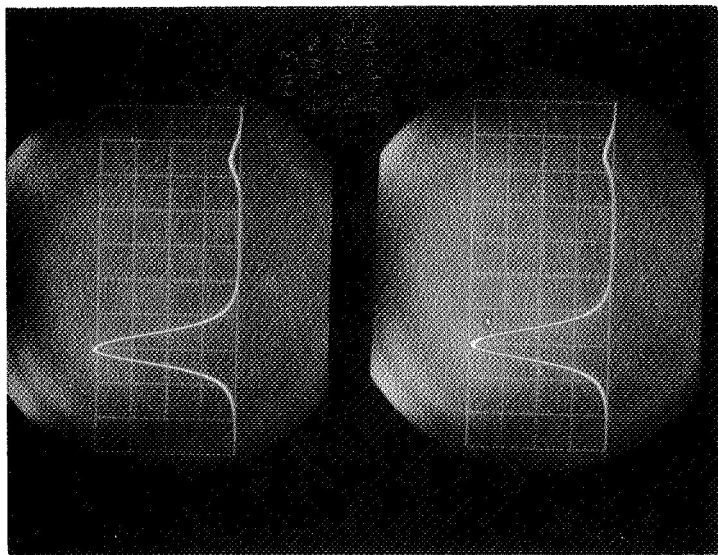
Channel-2 SCO Performance

- a. Carrier, $f_c = 3 \text{ KHz}$
dispersion = 500 Hz/cm
- b. Carrier and first harmonic,
 $f_c = 5 \text{ KHz}$, dispersion = 500 Hz/cm
- c. Carrier waveform, 3.0 KHz

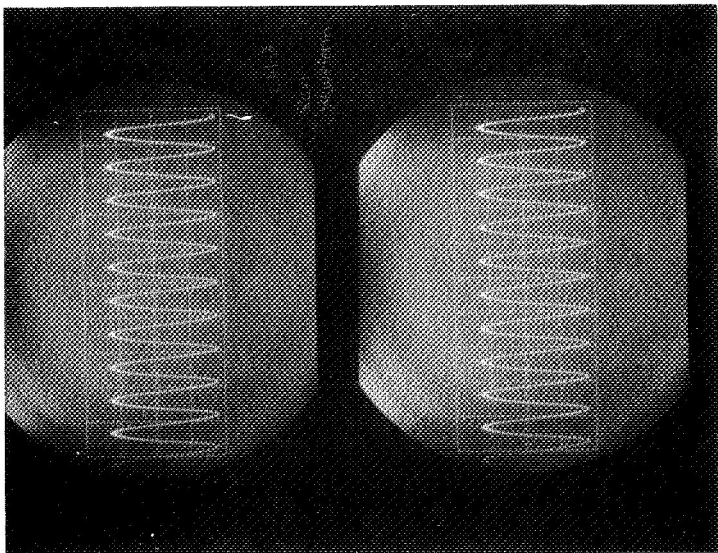
Fig. 1.1-2. Channel 2, SCO Performance



(a)



(b)

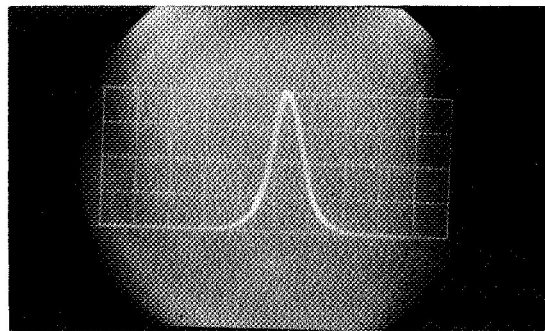


(c)

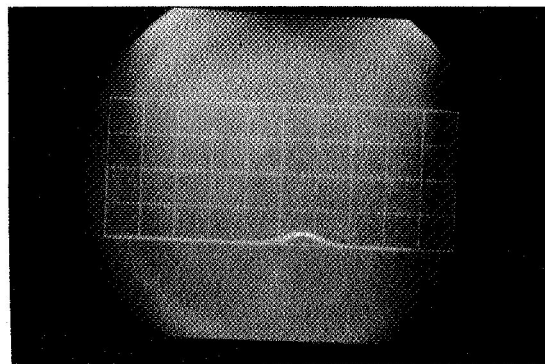
Channel-3 SCO Performance

- a. Carrier, $f_c = 5.4 \text{ KHz}$
dispersion = 1 KHz/cm
- b. Carrier and first harmonic
 $f_c = 7.4 \text{ KHz}$, dispersion = 1 KHz/cm
- c. Carrier waveform, 5.4 KHz

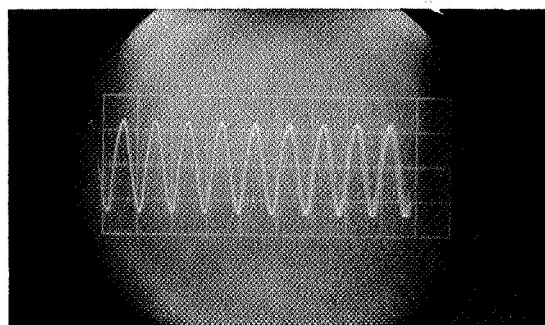
Fig. 1.1-3. Channel 3, SCO Performance



(a)



(b)



(c)

Channel-4 SCO Performance

- a. Carrier, $f_c = 10.5$ KHz,
dispersion = 1 KHz
- b. First Harmonic, $f_c = 21$ KHz
- c. Carrier waveform, 10.5 KHz

Fig. 1.1-4. Channel 4, SCO Performance

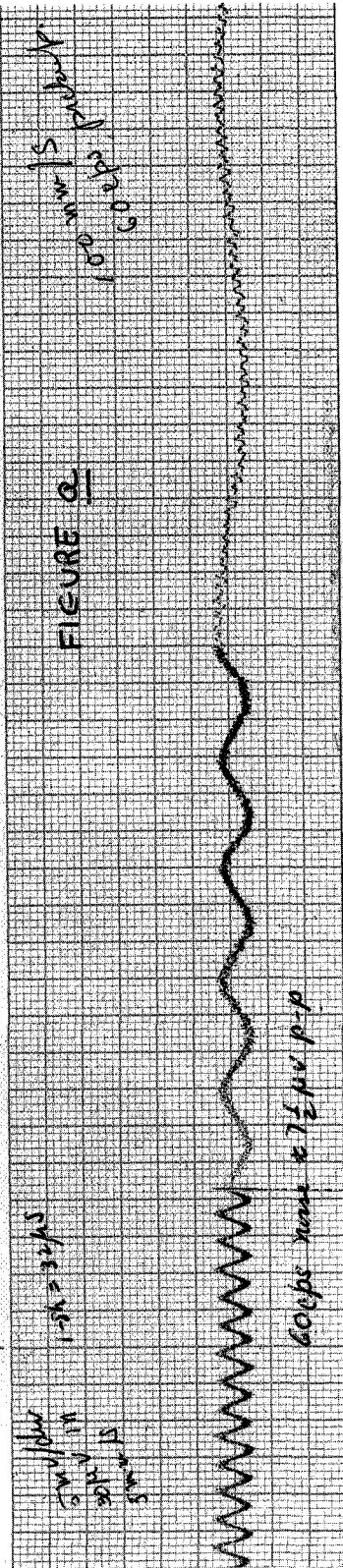
Figure 1.1-5 shows signals sensed at the stainless steel electrodes, feeding the Channel-4 implant-amplifier, and processed out via the decoder. The band pass for the telemeter amplifier (signal conditioner) is down about 6db at 1KHz. However, the total system band pass (telemeter-receiver-decoder) cuts off just beyond 200Hz as designed. System band pass for Channel-4 is shown in Figure 1.1-6.

Referring again to Figure 1.1-5, a noise figure of 4:1 can be seen for a $30\mu\text{V}$ (peak to peak) sensed signal. On examination we see that the noise is primarily 60Hz pickup and will be presumably almost completely eliminated in the situation where the telemeter is implanted. A noise level of less than $4\mu\text{V}$ (peak to peak) is anticipated under implant conditions and with present circuitry.

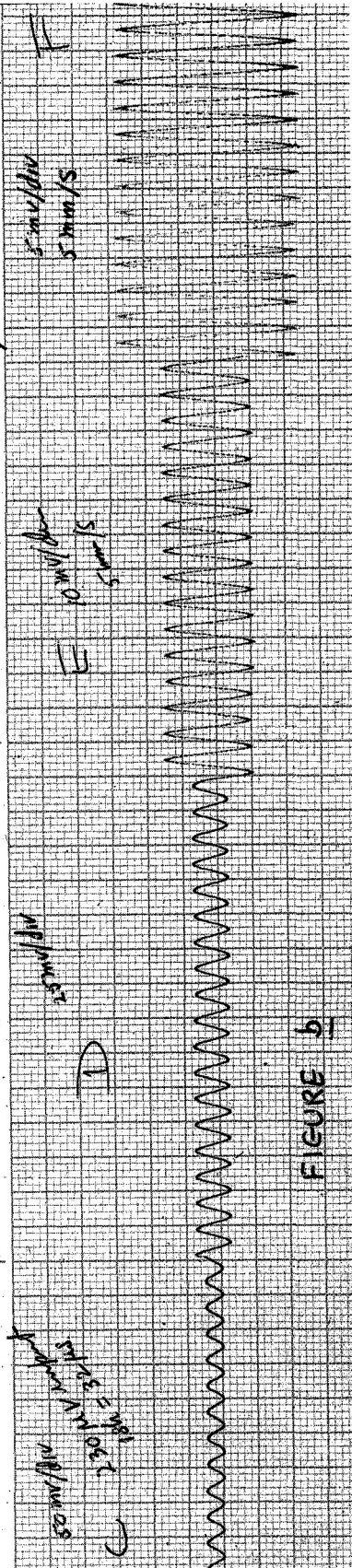
1.1.1 Signal Conditioning

Based on our experience with the three temperature channels discussed above, it is clear that the thermistors must be selected for a predetermined value at 37°C (approximately $160\text{k}\Omega$). This can be accomplished by procuring microbead thermistors which are pre-calibrated at 37°C and then selecting suitable units, or by using Yellow Springs Instrument Co. thermistors which are manufactured to very close tolerances at modest cost. The only known disadvantage to the use of the YSI thermistors is their size. In this latter regard, highly localized temperature measurements are more difficult to attain.

The ECG amplifier used in Channel-4, has more gain — and thus produces greater frequency deviations — than our decoder is designed to



15 Jan 70 / ~~Ans~~



Channel-4 Output

- a. Input 30 μv (p-p), ~ 1 cps
Equivalent input noise = 7.5 μv (p-p)
- b. Input 230 μv (p-p), ~ 1 cps

Fig. 1.1-5. Channel 4, Output

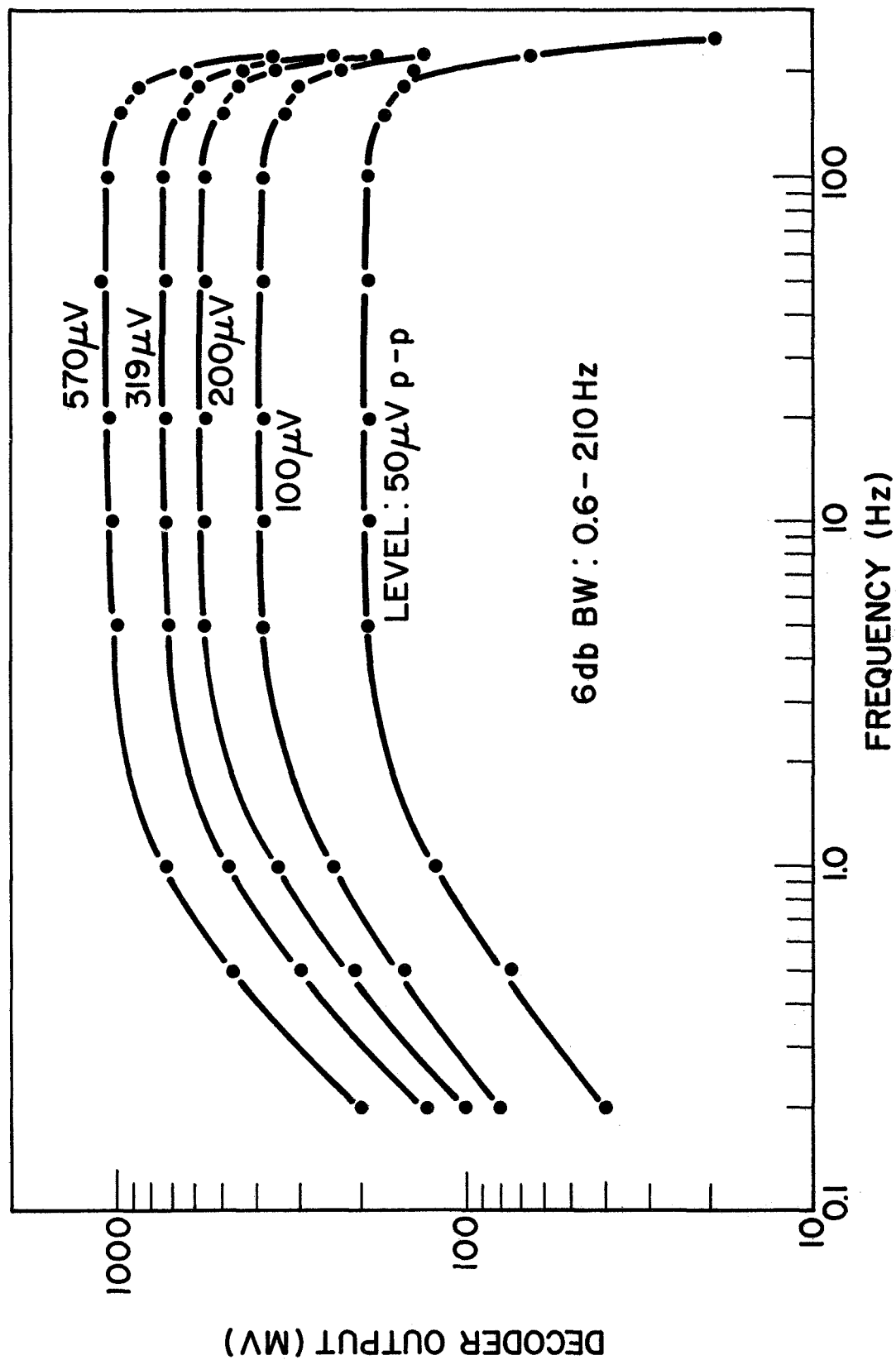


Fig. 1.1-6. System Band-Pass, Ch-4

handle. While this is an inconvenience for ECG signals which can be in excess of 1.5mV in peak magnitude, an excellent response in the range of 0-300 μ V (peak) is obtained. This range is of definite interest in the area of electromyographic signals. For the ECG case, the amplifier gain must be reduced by a factor of ca. 5X. Correction of this difficulty in future units will be accomplished by insertion of negative feedback. Such feedback can be expected to be beneficial in at least two respects: the low end of the pass band response will improve and the input impedance will be increased.

Preliminary work initiated on conditioning signals from piezo-junction pressure sensors is showing real promise. Our experimental setup, utilizing a standard Mark V, SCO with $f_c = 5.4\text{KHz}$, was modified by introducing the piezo-junction unit in place by one of the frequency-controlling resistors in the Wien-Bridge network. A calibrated pressure chamber is now under construction to facilitate our study of this approach. The possibility appears excellent that pressure channels requiring no more than 35-40 μ A of current can be designed. Such an achievement will make a reality pressure sensitive implants for chronic studies; *continuous* data for circadian rhythm studies as well as toxicologic and clinical situations will be forthcoming.

1.2 The Mark V, Four Channel Implant and Signal Decoder

The reader is referred to Figures 1.0-1 through 1.0-4 for views showing component placement and wiring. All function points are soft-soldered and interconnecting "hookup" wire is 2. mil, bare copper

wire. All components are "glued" at appropriate locations using our photo-reference technique described in earlier reports (1-4).

Umbilicals are brought out through an outer casting and through a channel (in the casing) for strength. Because of this arrangement, the point at which the umbilical exits from the casting can be subjected to great stress with no ill-effects accruing. It is at such exit points that encapsulant breaching often has occurred in the past. The completed unit is shown in Figure 1.2-1. All the circuit-boards shown in the aforementioned figures are enclosed within syntactic foam castings which are then overcoated with flexible paraffin. The resulting package is very strong, light and impervious to body fluids.

This first unit (SN.1) has the following characteristics:

Total weight, including umbilicals:	7.9 gm
Total volume, including umbilicals:	6.5 gm
Total current drain	: 62. μ a
Anticipated continuous operational life:	4000 hours

For this first unit, the umbilicals were designed to permit implantation in the thoracic cavity of a primate. Temperature sensors are located so as to permit localized surveillance of the kidneys, the spleen and some reference point. The ECG-Complex, electrode umbilicals are of a convenient length. Thermistor umbilicals utilize platinum-iridium, Teflon-coated wire leads within silastic-filled, polyethylene tubes. Each end of each tube is sealed with a flexible paraffin mix which is welded to the polyethylene. The thermistors are .043 inch diameter microbeads and permit

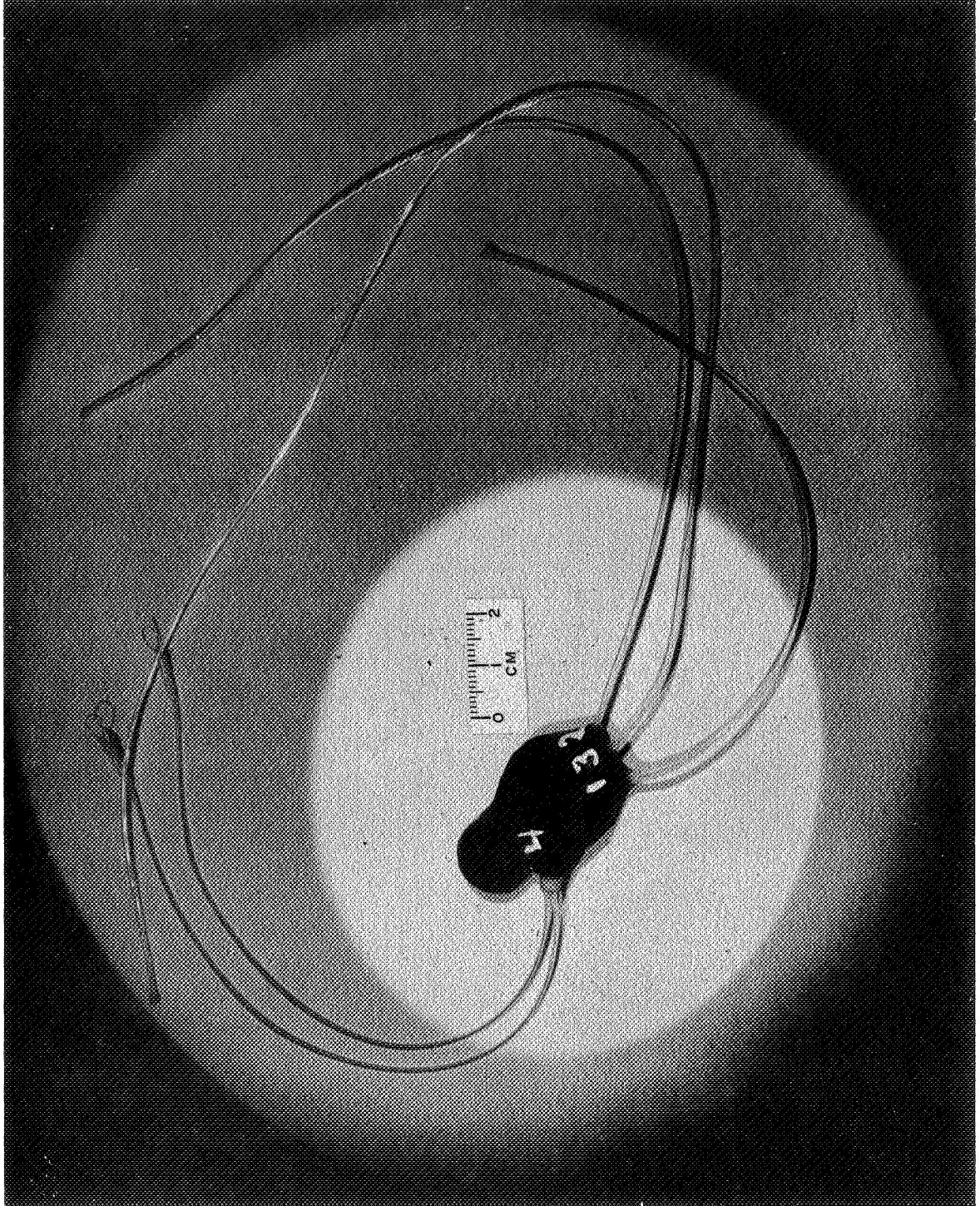


Fig. 1.2-1. MKV, 4-Channel Implant

very fast (ca. 5 seconds time constant) and highly localized temperature sensing. The ECG electrodes are small diameter loops fabricated from annealed, stainless steel, suture wire. These loops are attached to extremely flexible, multi-strand, copper cable (oxygen-free). The entire lead system is contained within two insulating tubes: one, a special plastic supplied as lead coating and the second, a close-fitting polyethylene tubing. Both ends of each umbilical are capillary-sealed with flexible paraffin.

The decoder for the four-channel unit operates as follows (refer to Figure 1.2-2):

The multichannel implant, composite signal is picked up with an fm-radio receiver. A first discrimination occurs in the receiver and its audio output is a composite containing all of the subcarrier oscillator signals (from the four channels). This composite audio signal is accepted by the decoder.

The first decoder stage, in each of its four channels, consists of an input driver feeding a standard IRIG, 7-1/2% pass band, network tuned to the center frequency of its channel. Thus the composite signal is separated into the four SCO signals with center frequencies of 1.7, 3.0, 5.4 and 10.5 KHz.

The first three decoder channels are all identical and are designed to provide voltage outputs analogues to sensed temperature. The desired output is zero to ten volts for a sensed temperature range of 28°C to 42°C. In each of these channels, the subcarrier oscillator

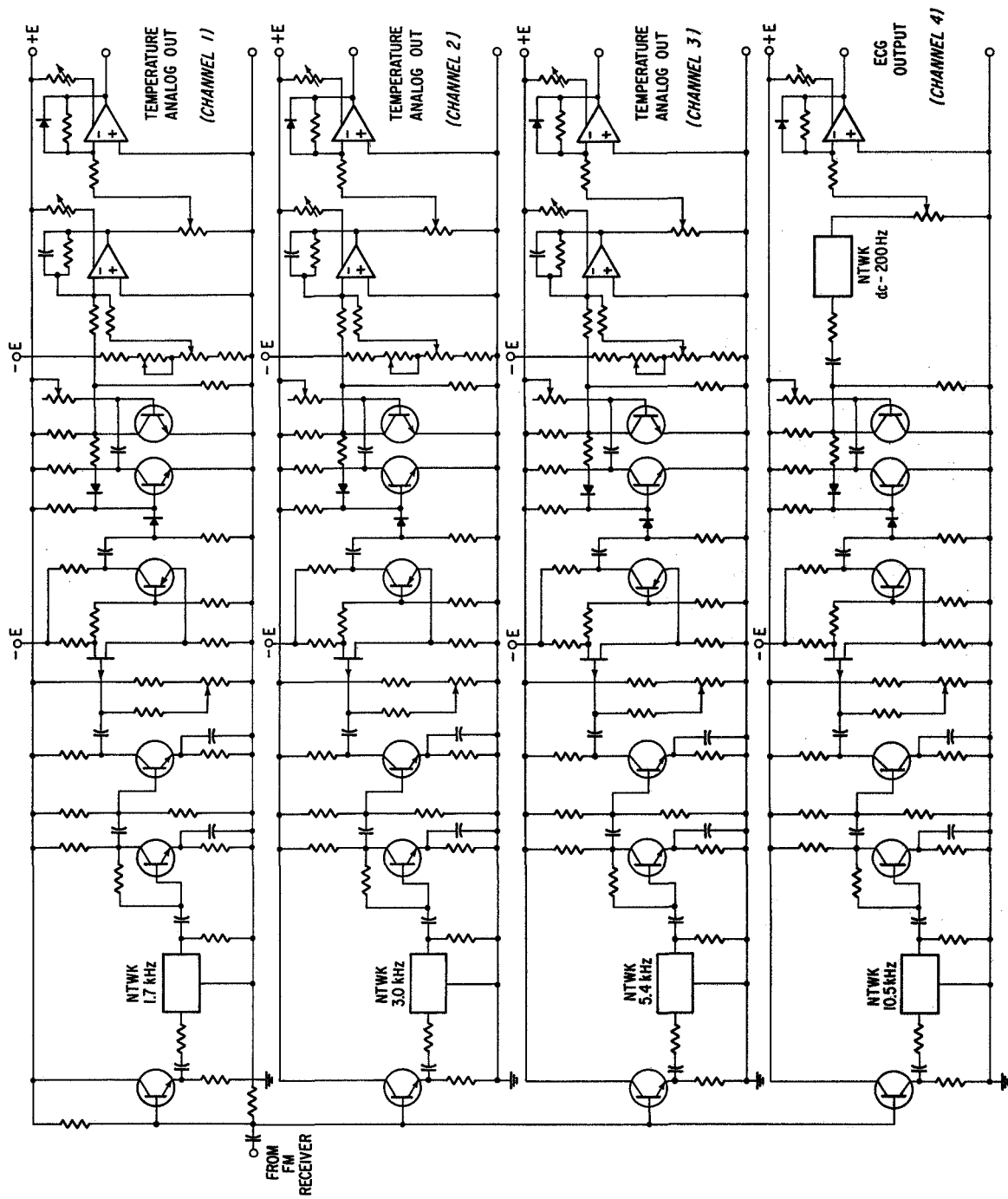


Fig. 1.2-2. Four Channel Decoder Unit

signal is limited in a Schmitt-trigger stage, converted to standardized pulses of fixed amplitude and duration via a monostable multivibrator, integrated and then processed out via an operational amplifier. Figure 1.2-3 illustrates the three channels of output on the temperature range of interest.

The ECG-Complex is processed somewhat differently. The fourth channel of the decoder is similar to the others described above up to the point where standardized pulses are produced. These pulses are then processed directly through a low-pass network which permits on the sub-carrier modulation signal (ECG-Complex) to pass. This detected modulation is then conditioned via an operational amplifier.

Decoder cost is considered to be somewhat high at present. This is particularly true because of the costs associated with the IRIG, band pass filters and the low-pass network used for the ECG signal. We anticipate savings by replacement of the low-pass network with a simple, active, low-pass filter. Similar savings may be possible with replacement of the IRIG, band pass networks by active circuits.

1.2.1 Fabrication Techniques

The telemeter:

Relatively high-density packaging has been attained in the fabrication of the four-channel unit. A density of about 180 components/cc has been reached. This is equivalent to about 2900 components/in.³ and includes no integrated circuitry. With the advent of the smaller resistor chips now available, this density figure can be further increased, if necessary.

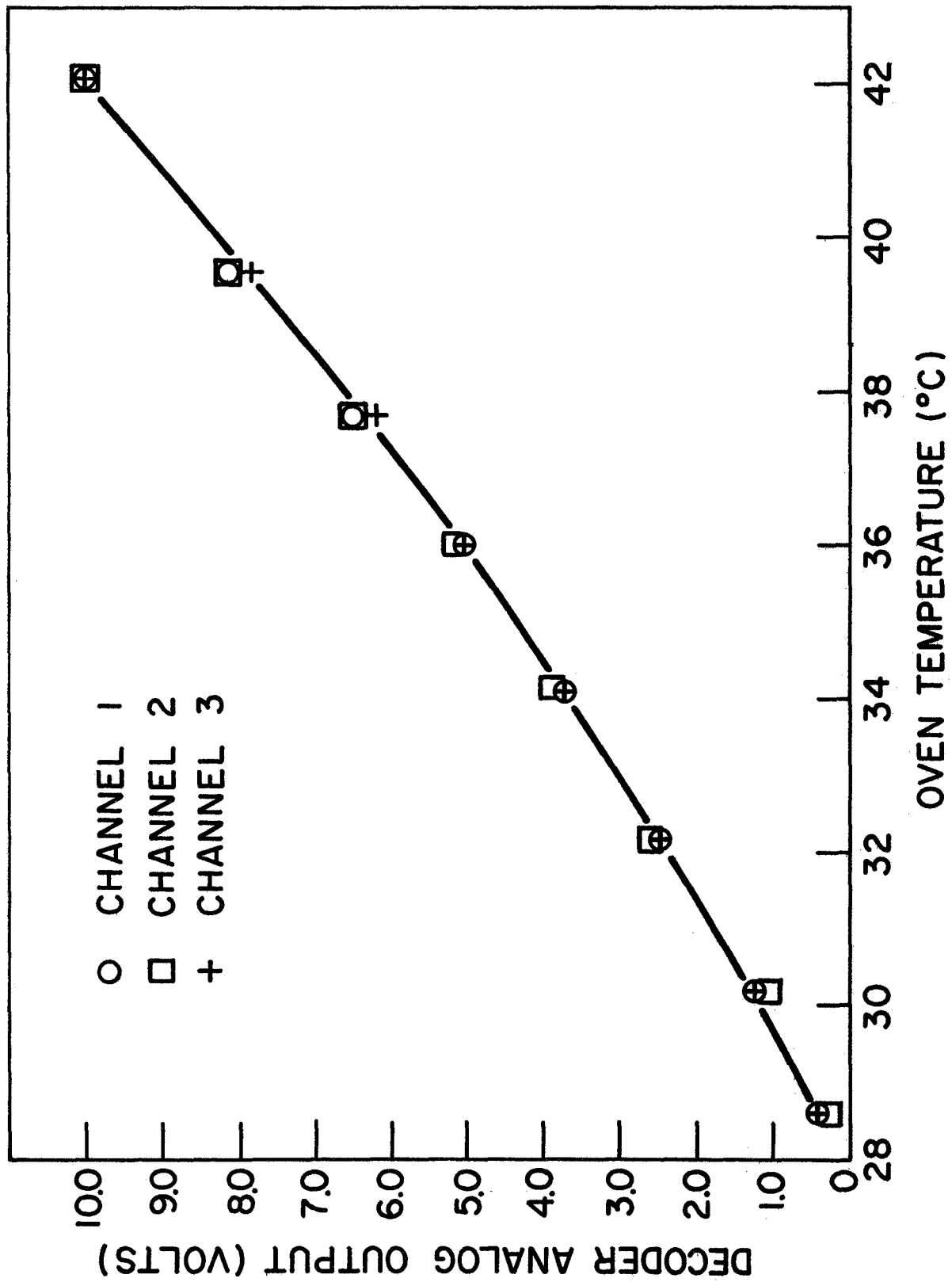


Fig. 1.2-3. Temperature Analog Outputs from Decoder

The use of syntactic foam has produced a package of low mass and great strength and permits improved radiation-circuit matching to the fluid medium with which the implant is normally surrounded.

The decoder:

The experimental decoder was fabricated on plug-in, component boards — hand wired. Future decoders may be designed using etched-circuit boards, miniature operational amplifiers and active-filter networks. We anticipate that this approach will result in economies to the researchers using the system.

1.3 The Two-Channel Implant System

The two-channel implant, first described in an earlier report (1-4), has been markedly improved in both performance and operational lifetime. A simple decoder for use with a standard fm-radio receiver has also been designed, built and evaluated.

The present circuit for the implant is illustrated in Figure 1.3-1. It consists of a complementary multivibrator whose repetition frequency is basically controlled by a temperature-sensitive thermistor; in addition, this basic repetition frequency is modifiable via a signal-controlled FET. We have thus a unit pulsing at a "fundamental" frequency controlled by sensed temperature and which is periodically varied (modulated) as a function of a signal other than temperature say, the ECG-Complex. The total pulse-rate-modulated signal so produced is used to drive an fm oscillator which, in its quiescent state is biased beyond cutoff.

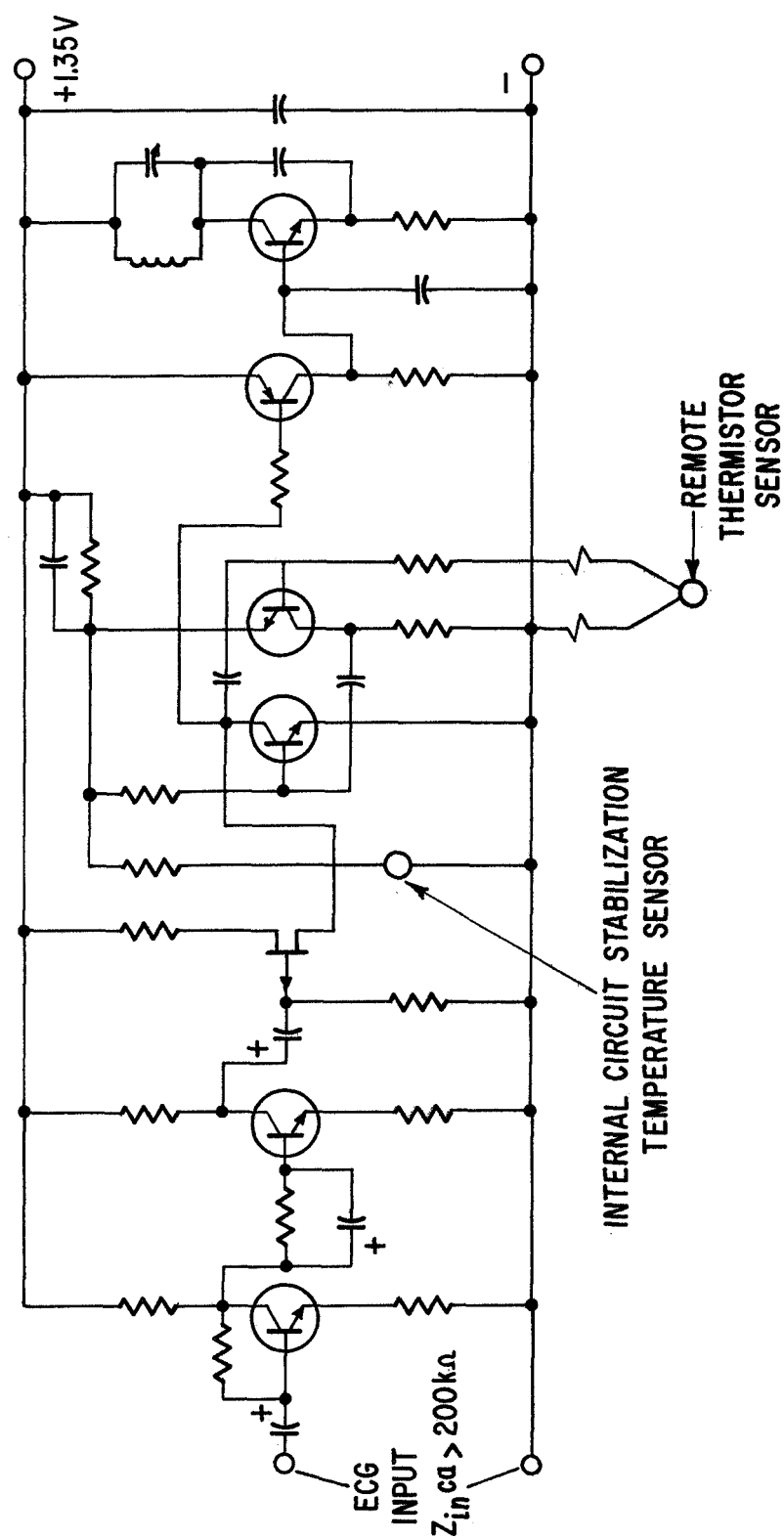


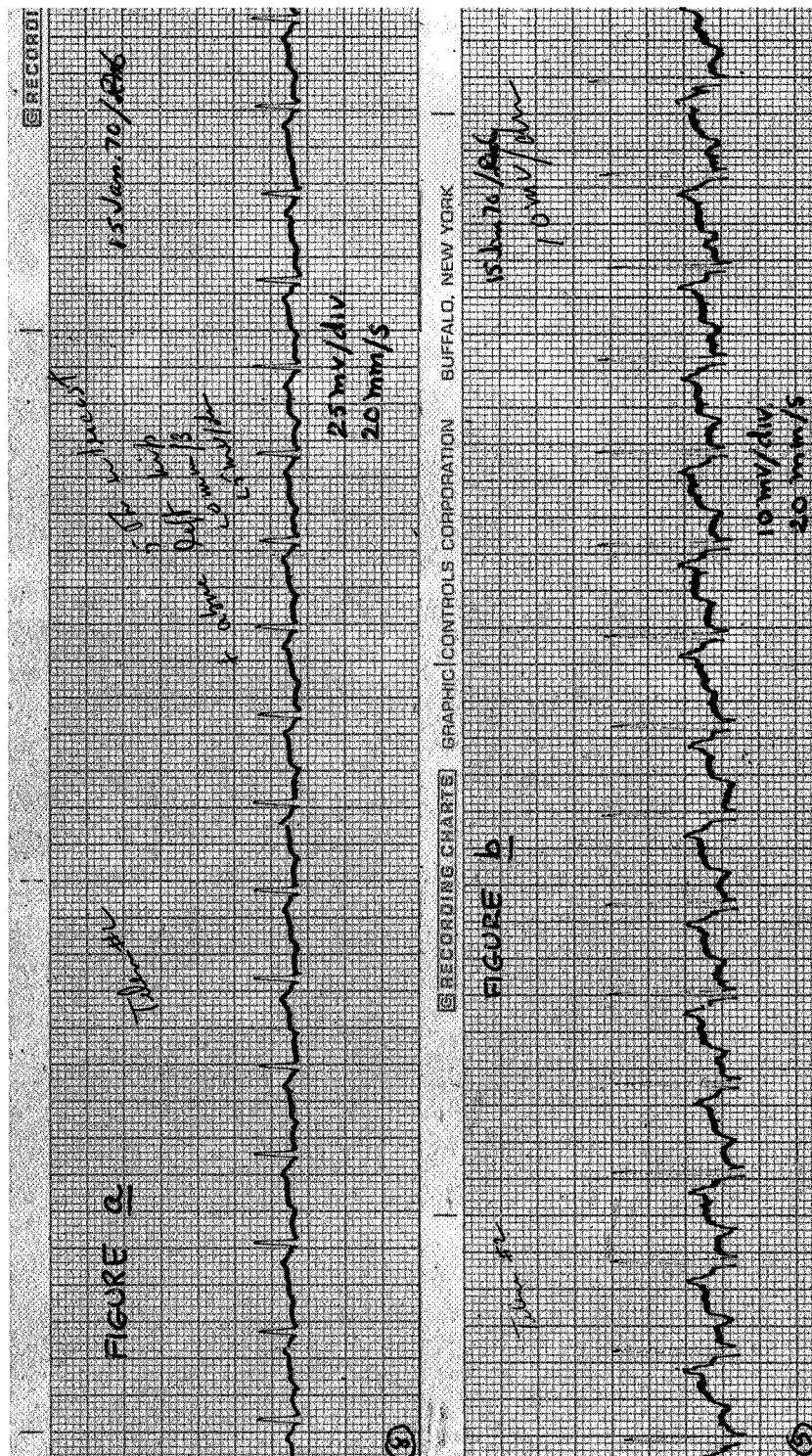
Fig. 1.3-1. Two-Channel Implant Circuit

The total system consumes ca. 20 μ a of current and has a computed operational, implanted lifetime of ca. 12,000 hours — well over a year. A typical ECG waveform transmitted via this system is illustrated in Figure 1.3.2. For the illustrated data, Beckman, surface-mounted electrodes were used. They were located at about the fifth intercostal space and just above the left hip.

The photograph of Figure 1.3-3 shows the packaging for this telemeter; also seen is the location of the covered aperture through which the telemeter tuning capacitor can be set for any frequency in the fm-broadcast band (88-108 MHz). The very short umbilical for the temperature sensor is appropriate for the particular unit shown; it can be any convenient length.

This unit has excellent performance characteristics. Its *system* band pass is as illustrated in Figure 1.3-4. The low-end, 3db-point is 0.28Hz and is 0.18Hz at the 6db point. The upper pass-band limit is determined primarily by the decoder low-pass filter characteristic. System output is linear in the range of zero to over 4000 μ V as illustrated by Figure 1.3-5. Temperature sensitivity is ca. 50Hz/ $^{\circ}$ C or 0.02 $^{\circ}$ C. Temperature differential between the telemeter circuitry and the thermistor sensor (at the end of the umbilical) are effectively eliminated as an error source through the use of built-in, circuit-temperature compensation.

The total unit weight, including power cell, encapsulation and umbilicals is 5.7 gms. The total unit volume is 4.5 cc.



ECG from dual channel telemeter surface mounted on human (RG), electrodes at 5th intercostal and just above left hip

- Recorder at 25 mv/div. & 20 mm/s
- Recorder at 10 mv/div. & 20 mm/s

Fig. 1.3-2. Telemetered ECG via Two-Channel Unit

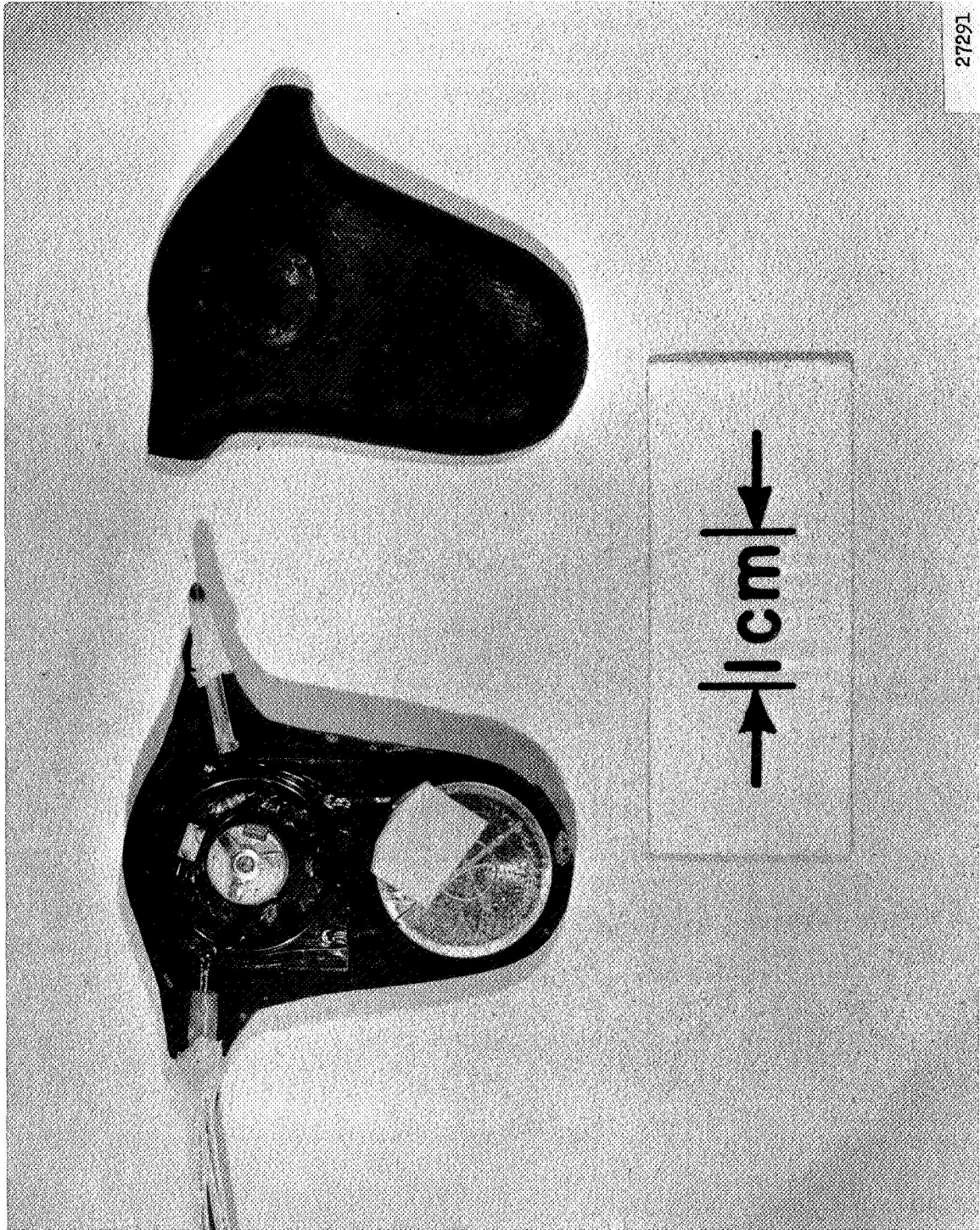


Fig. 1.3-3. Two Channel Unit

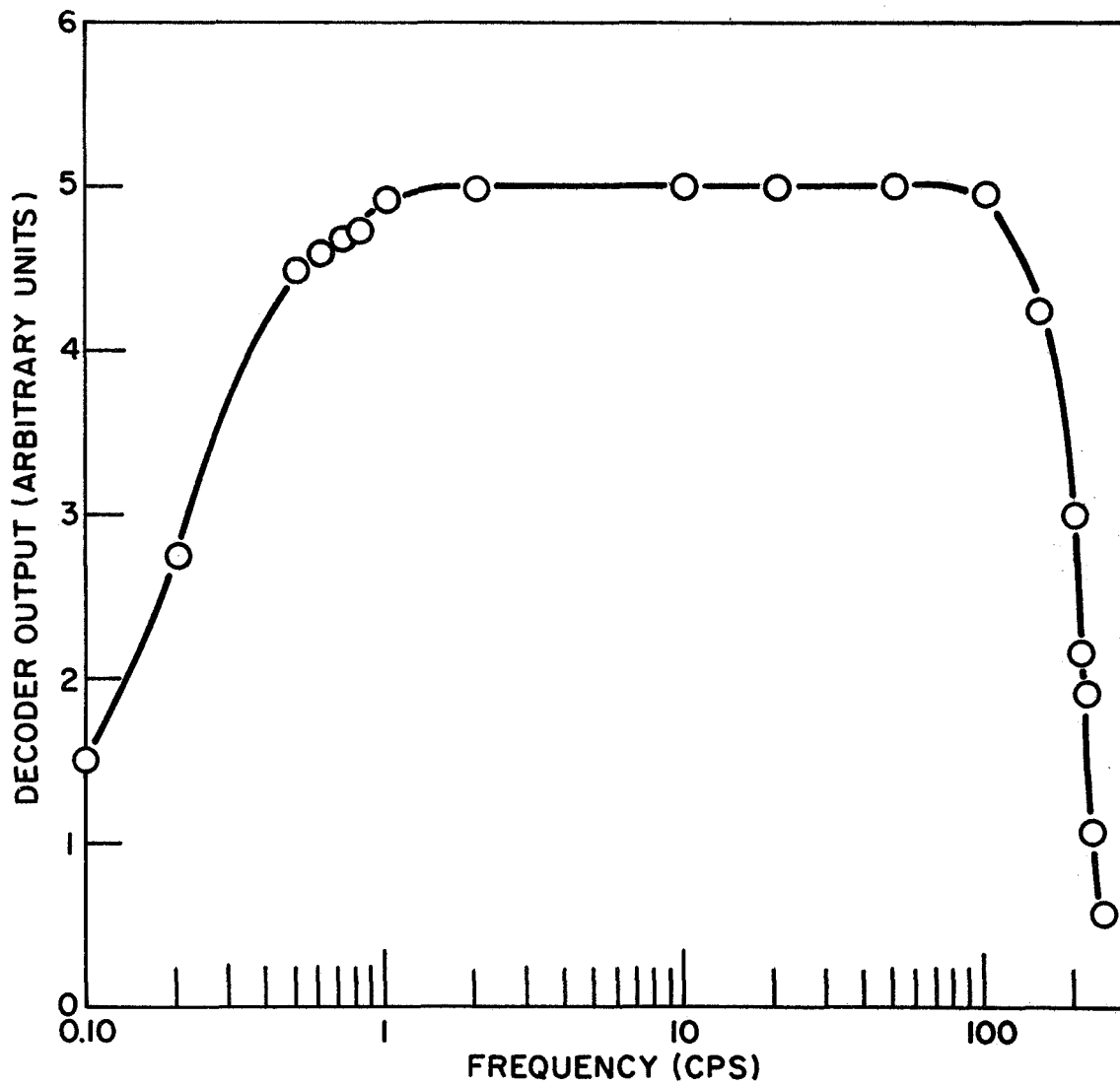


Fig. 1.3-4. Two Channel System, ECG Bandpass

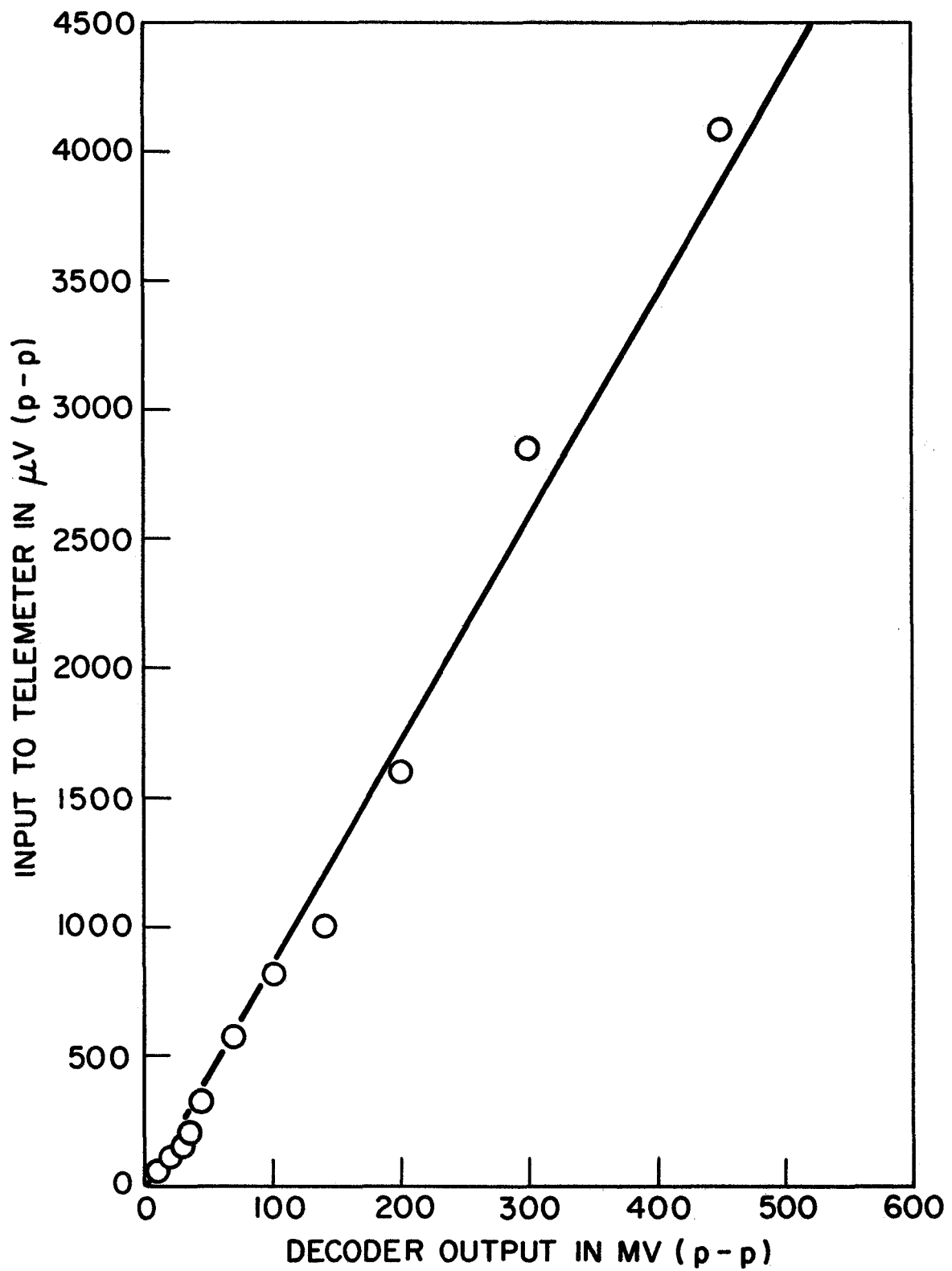


Fig. 1.3-5. Dual Channel Telemeter Input vs. Decoder Output

1.4 References for Section 1.0

- (1-1) Goodman, R. M., "Simultaneous, Multi-Parameter Data from Implantable Telemeters", Digest of the 7th Int'l Conf. Med. and Brd. Engrg, Stockholm, Sweden, August 1967, 87.
- (1-2) Gibson, R. J., Goodman, R. M. and Isquith, I. R., "Space Related Biological and Instrumentation Studies", FIRL Report A-B2299-1, March 1967.
- (1-3) Gibson, R. J. and Goodman, R. M., "Space Related Biological and Instrumentation Studies", FIRL Report A-B2299-2. March 1967-March 1968.
- (1-4) Gibson, R. J. and Goodman, R. M., "Space Related Biological and Instrumentation Studies", FIRL Report A-B229903, March 1968-March 1969.

2.0 IMPLANTABLE TRANSDUCERS

In the period reported here, work continued on the development of miniature, implantable, long-life pH electrodes. Effort was also expended on related reference electrodes.

As noted in the preceeding section of this report, effort was also initiated on the application of piezo-junction pressure sensors in conjunction with our telemetric implants.

2.1 The pH Electrode

Electrode impedance, which is related to its area, is an important consideration when electronic circuits fed by it do not present an extremely high (an infinite) impedance load to the sensor. This situation obtains for both the glass and the iridium electrodes.⁽²⁻¹⁾

⁽²⁻²⁾ ⁽²⁻³⁾ Circuit input impedances much greater than 100M Ω are easily obtained on the bench using electrometer tubes or MOSFET's. Such impedance levels are more difficult to attain in implants, particularly when available voltage levels are very low.

For these reasons we wish the electrode design to embody as low an internal impedance as possible. Since the electrode impedance is related to the inverse of the electrode area, we must increase the area as much as possible without unduly increasing the outside dimensions. One approach is to form a wire of flat, rectangular cross-section rather than round. In addition, a long wire can be wound

as a helix, retaining the same length as a straight rod and with only a modest increase in diameter (See Figure 2.1-1). A helix has the advantage over a large diameter, solid cylinder in that the inner surface

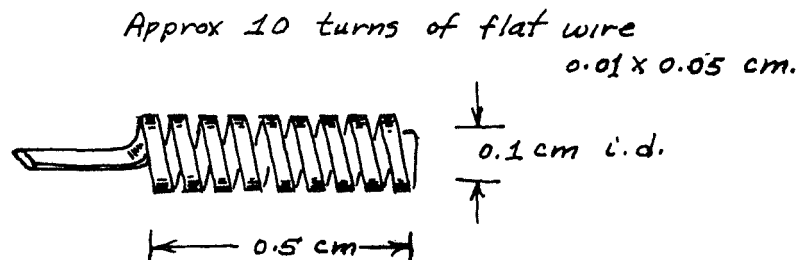


Fig. 2.1-1. Proposed Electrode Design for Iridium

becomes available and is open to circulation. A typical rod electrode may be fabricated from .025cm (.010 inches) diameter wire, 0.5cm long and have a surface area of ca. $.039\text{cm}^2$. A flat wire (electrode) of rectangular cross section 0.01 X 0.05cm will have the same cross-sectional area as a round rod .025cm in diameter, but will have an exposed area of $.060\text{cm}^2$ to a nominal length of 0.5cm. This arrangement permits an area improvement of X 1.53. If a long piece of this flat wire is formed into a helix of about ten turns with an internal diameter of 0.1cm and an outside diameter of 0.12cm, the length of wire required will be about 3.46cm or 6.91 times the 0.5cm length. This provides another factor of X 6.91 in area. The total increase in area is then 10.57 or one order of magnitude. The exposed area of the resultant helix is 0.41cm^2 .

The iridium electrode is reported to require a current of less than $0.1 \times 10^{-6} \text{ A/cm}^2$ (2-1) to prevent polarization. The potential difference is on the order of 0.1 volts between the electrode and an Ag-AgCl reference electrodes for several pH numbers. Thus an internal resistance factor can be expressed as $0.1 \text{ volt}/0.1 \times 10^{-6} \text{ A/cm}^2$ or 10^6 ohm-cm^2 . If this value is divided by the electrode area, one obtains a value for the required load impedance to permit limitation of current drain to $0.1 \mu\text{A/cm}^2$. The helical electrode described above would thus require at least $10^6 \text{ ohm-cm}^2/0.41 \text{ cm}^2$, or $2.5 \text{ M}\Omega$ of load to limit the current drain as desired. On comparison, the straight rod electrode requires $25 \text{ M}\Omega$. We anticipate no difficulty in obtaining telemeter input circuit impedances on the order of $2.5 \text{ M}\Omega$.

Other electrode configurations, which result in increased available surface area, are possible. A spiral electrode of approximately 0.5cm diameter, made of flat (.01 X .05cm) wire with about ten turns, has very nearly the same surface area as the helical configuration (See Figure 2.1-2).

In the design of these electrodes it is necessary to consider factors in addition to active area. For example, the overall dimensions must be small, the configuration rugged and all materials compatible with tissue and body fluids. Sylgard silastic, polyethylene tubing and FIRL modified paraffin have all performed excellently in long-term exposure *in vivo*. With regard to necessary cement materials, Epo-tec #201 has been proved to be the most desirable of the many materials

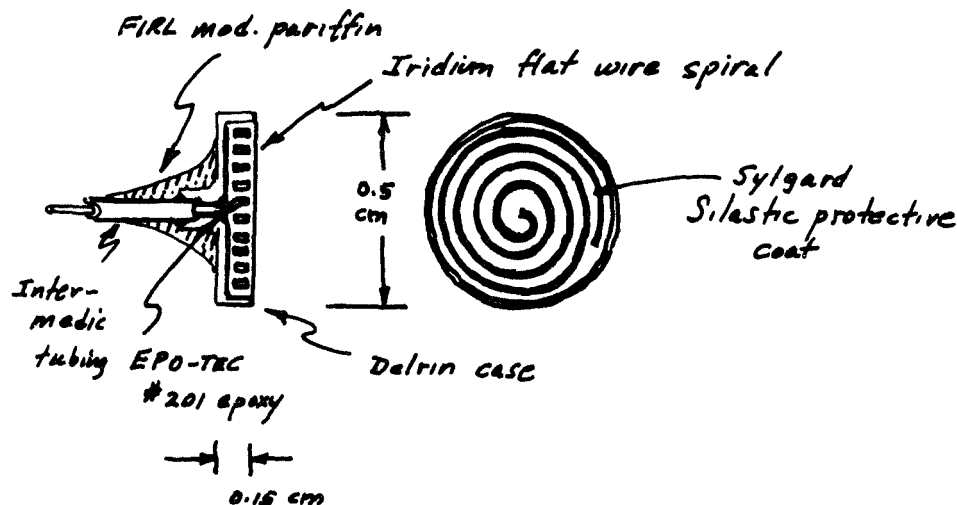


Fig. 2.1-2. Proposed Spiral Iridium Electrode

tested. *In vitro* tests over several thousands of hours, wherein these cements were exposed directly to physiological saline, were carried out. In the proposed designs, exposure of cemented surfaces to body fluids has been minimized.

A pair of test electrodes, iridium-wire rod (.010" diam.) sealed in glass and an Ag-AgCl reference electrode protected with a Sylgard* coating were retested after several months of dry storage. Their performance is illustrated in Figure 2.1-3. The electrodes were rinsed in distilled water prior to each pH measurement, placed in a buffer solution of appropriate pH and allowed to stabilize for six minutes. The pH was measured with a Beckman pH meter, using the millivolt scale. Many

*Dow-Corning #184 Potting Resin.

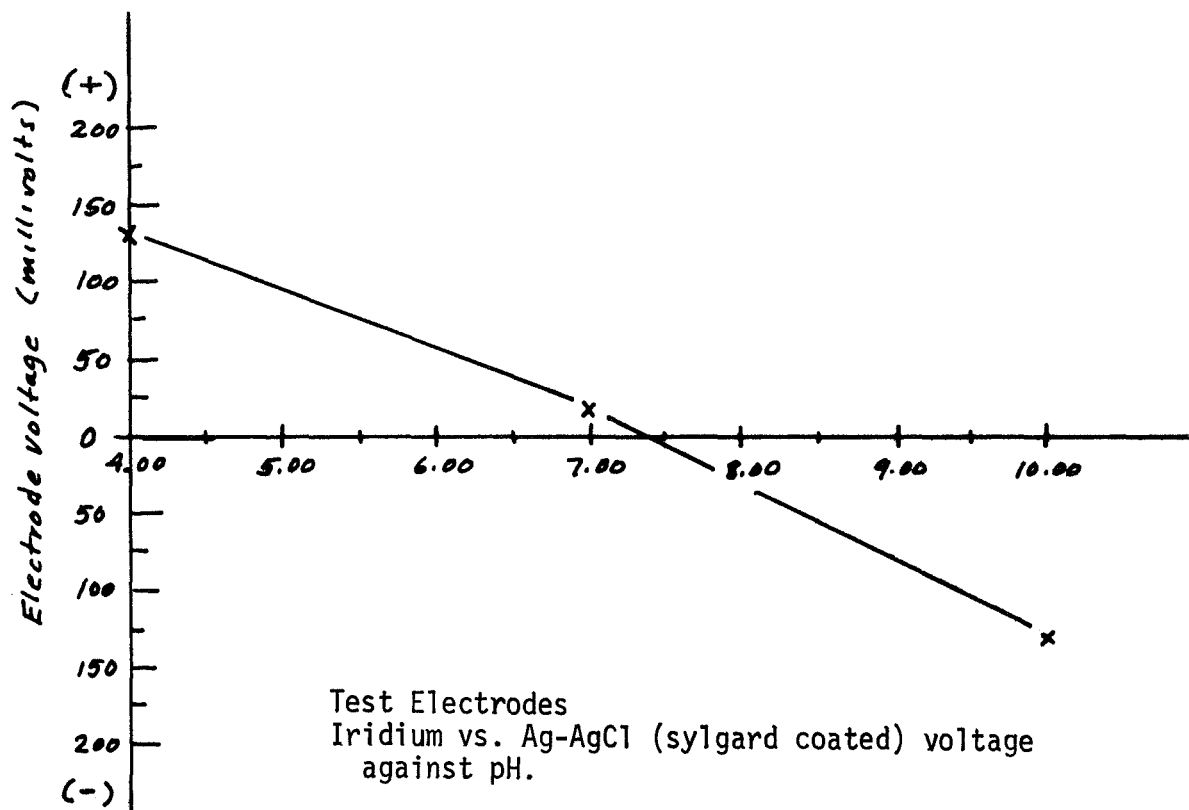


Fig. 2.1-3. pH Electrode, Output vs. pH Units

replications over the illustrated pH range gave similar results. We believe that the stabilization time required (about 3 minutes) is due in considerable part to the time required for the Sylgard electrode-coating to come into equilibrium with the solution. A coating, thinner than that used, is expected to equilibrate more rapidly. The coating used was about 0.002 inches thick tapering to a thickness of about 0.010 inches (top to bottom) and ending in a small droplet. A method has been devised to reduce the size of this droplet to negligible proportions. At present however, it serves as an excellent protective "bumper".

Several proposed electrode configurations are shown in Figures 2.1-4 and -5. In these figures the electrode rod itself may be of Ag-AgCl for the reference electrode and Iridium for the pH electrode. A pair, consisting of one of each is required for pH measurement. The figures show the electrode rod as a single cylinder. This can easily be replaced with the flat wire helix discussed earlier with little or no change in the remaining construction. The designs shown are influenced by the desire for mechanical protection of the electrode rod itself. The method of sealing this wire into the telemeter body or to the umbilical has been proven by tests with stainless steel electrodes used for ECG pickup. Figure 2.1-4 is intended for sensing pH remote from the telemeter itself and the length of umbilical is not limited by circuit constraints. For application such as in the stomach or intestine, the electrode could be mounted directly in the telemeter body on opposite sides or edges of the telemeter. The projection of the electrode from the side of the telemeter is not critical and it may even be recessed into the telemeter body with some slight additional effort in construction. The whole design has been simplified insofar as possible and no dimensions are critical. Figure 2.1-2 shows a design incorporating a flat wire spiral. This design is not as satisfactory as those in Figures 2.1-4 and -5 because it utilizes Delrin as a body material instead of glass. Delrin, however, is the best of many plastic materials in our experience for this kind of application. It is highly impervious to chemical attack and as far as is known, relatively inert with respect to tissue reaction.

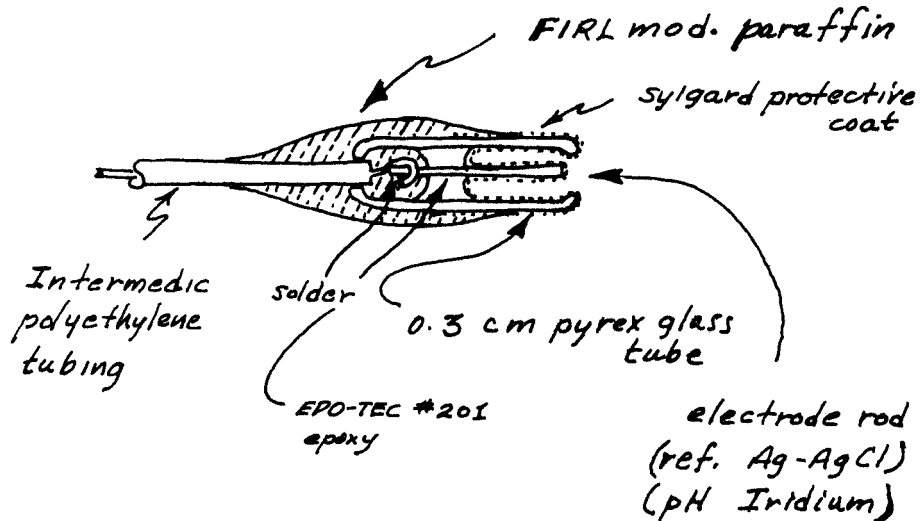


Fig. 2.1-4. Proposed Umbilical pH Electrode

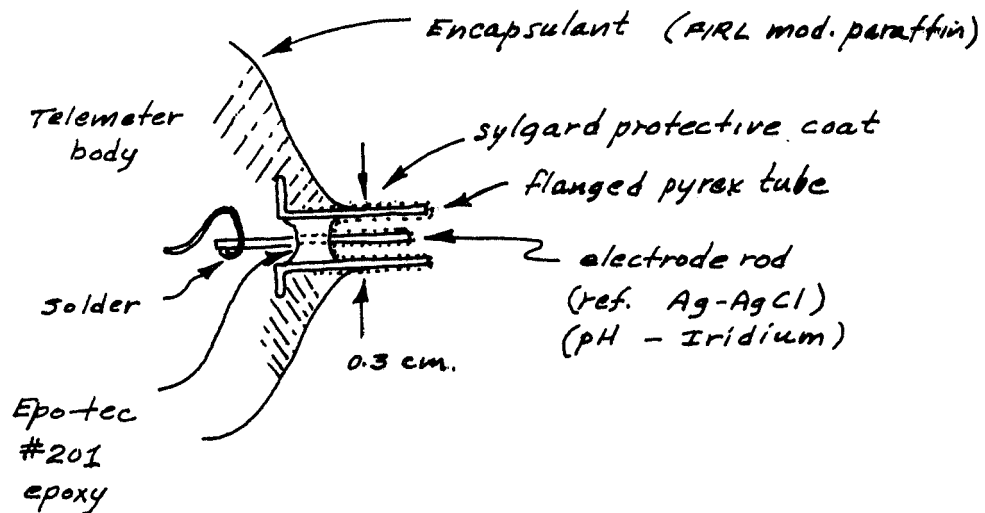


Fig. 2.1-5. Proposed pH Electrode in Telemeter Body

A thin coating of silastic or FIRL mod. paraffin over all the exposed surface could effectively seal the Delrin from tissue and body fluids. Glass could be substituted at an increase in construction complexity.

2.2 Reference and Other Electrodes

During the last five years a large variety of electrodes have become commercially available. These fall into several categories: pH electrodes, reference electrodes and electrodes specific to various metallic ions. As yet, none of these commercially available units are suitable for long-term implantation *in vivo* — either directly wired, or for use in conjunction with implanted telemetric devices.

The available pH electrode of the smallest size is the Beckman, Model EC-10, catheter electrode. The tip of this unit is on the order of 2mm, tapering sharply to 4mm in diameter. It is a conventional glass electrode sensitive only to the hydrogen-ion concentration. It is normally mounted in a catheter and the length of the electrode itself is about 1-2 cm. This dimension alone makes the unit less desirable for implant purposes. The important feature of the electrode is its special coating (not identified in available literature) which makes it stable for some period of time when immersed in blood or other body fluids. The coating is said to prevent blood coagulation. However, the coating is not permanent and is useful for periods up to about 100 hours (*in vivo*). The coating is evidently renewable by the factory. An equivalently serious disadvantage of the electrode is its extremely high impedance. It is on the order of 10,000M Ω at 25°C and probably somewhat lower at

body temperature (37°C). Little information has been published by the manufacturer regarding the electrode's time constant.

Silver — silver chloride electrodes are being produced in a wide range of sizes and by a number of manufacturers. Two such sources are Biometrics* and InVivo Metrics**, both in California and both offering electrodes identical in size, shape and performance characteristics. These electrodes are porous, molded silver-silver chloride. Units are also supplied which are modified with platinum-black to enhance response to ac and to reduce so-called ac polarization impedance.

Costs for the units are modest and availability includes both rods and pellets. Representative units have been procured and they will be checked for stability, impedance, etc. If the purchased units prove to be as stable as our laboratory — fabricated ones, we plan to substitute them for our own reference electrodes.

Published interelectrode bias potentials are in the range of 5-125 μ V. Selected pairs may be better after stabilization. Drift is said to be less than 16 μ V/24hrs. This figure is somewhat high, but may prove to be a short term datum. Our own electrodes have shown smaller drifts for periods of several days.

Two organizations appear to lead the commercial field in the manufacture of electrode systems for the detection of pH and other anions

*Biometrics, Inc., 2123 S. Sante Fe Ave., Santa Ana, Calif. 92705

**In Vivo Systems, 10709 Venice Blvd., Los Angeles, Calif. 90034

and cations: Instrumentation Laboratory* and Orion Research, Inc.**.

Instrumentation Laboratory produces a 3mm diameter glass stomach-electrode to be used with a separate reference electrode. No data is available on stability. The electrode incorporates a sealed-in, Ag-AgCl half-cell. It is probably subject to contamination drift after short exposures as is the usual glass electrode; because of its very small size, it also has an extremely high impedance. I. L. also offers a combination glass electrode/reference electrode with both half-cells Ag-AgCl, with the reference electrode 1mm above the glass membrane. The diameter of this pair is only 5mm. The reference half of the electrode requires filling with electrolyte; a porous plug limits the required leakage to about 1 μ l/hour. This arrangement precludes its application as an implant.

The Orion Company supplies electrodes for the detection of sulfide ion activity, calcium ion activity, cyanide ion activity, chloride ion activity and divalent cation activity. While these electrodes are new and permit the measurement of various ions of biological interest, they are totally unsuitable for *in vivo* or implantable measurement — even with extensive modification. Several of these units require frequent refilling and the others require frequent recalibration against standard solutions.

To date, no commercially available electrode has been found (except the simple Ag-AgCl) which is suitable or particularly helpful

*Instrumentation Laboratory, Inc., 9 Galen St., Watertown, Mass. 02172

**Orion Research, Inc., 11 Blackstone St., Cambridge, Mass. 02139

in reaching our goal of an implantable, long-life, stable electrode suitable for implantation and processing via telemetry. It is incumbent upon us to continue to monitor the industrial and research literature for innovations and improvements in electrodes to ensure that no progress in the field has been overlooked.

In the literature, two useful papers have come to our attention. The first by R. K. Kaminski (2-4) is a review of the basic electrochemistry of ion-selective electrodes. The paper is practical and also includes a comprehensive U.S. listing of related electrode manufacturers. The field is rapidly changing and in the last six months about 15 new anion or cation electrodes have been introduced to the market. The second paper, by S. Rush, et al (2-5) contains valuable information on the calculation of spreading resistance and electrode capacitance. These calculations are indirectly applicable for any small electrode system. The authors also treat the problem of glass leakage resistance — important in *any* high impedance electrode system.

2.3 References for Section 2.0

- (2-1) Ives, D. J. G. and Janz, G. J.; *Reference Electrodes, Theory and Practice*; Academic Press, Publ. N.Y. 1961.
- (2-2) Perley, G. A. and Godshalk, J. B.; U.S. Patent No. 2416949, March 4, 1947; British Patent No. 567,722 June 10, 1942.
- (2-3) Gibson, R. J. and Goodman, R. M.; Annual Report A-B2299-3; "Space Related Biological and Instrumentation Studies"; March 1968-March 1969; Vol. 1; NASA Contract NSR 39-005-018.
- (2-4) Kamenski, R. K.; "The Basics of Ion-Selective Electrodes; Instrumentation Technology, Sept. 1969, 41-45.
- (2-5) Rush, S., Lepeschkin, E. and Brookes, H. O.; "Electrical and Thermal Properties of Double Barreled Ultra Microelectrodes"; IEEE Trans. on Biomed. Engrg; Vol. BME-15:2; April 1968.

3.0 MATERIALS

3.1 Electrode Materials

The search for materials which will tolerate body fluids for extended periods of time still continues. Material function covers three main categories: cements, protective coatings and construction.

For cements, our previous report (A-B2299-3) discloses an exhaustive listing of those tested along with grades of performance. Those found best in that reported study continue to give good service and no change in the original evaluation is suggested. The Epo-Tec #201, clear epoxy cement has withstood many hundreds of hours of additional testing. It has tolerated both distilled water and normal saline solution. For a stonger mechanical joint, the 1C Hysol, filled epoxy at a 5:1 resin/hardner ratio has proved to be very good.

As a perfective coating, the silicone solvent, evaporative coating (Dow-Corning #630) has also continued to perform well in as-going tests. No change in adhesion has been noted over many months of immersion in distilled water or physiological saline. Another protective coating used in the FIRL-Modified-Paraffin developed previously under this contract. This highly impermeable material is extremely useful as an insulating and protective coating for leads and electrode parts which are to be sealed against body moisture. Samples of this modified paraffin have been sent (on request) to a number of researchers throughout the country.

A critical characteristic of the two protective materials discussed above, in addition to their non-permeability, is the formation of a bond to glass, metal and other surfaces. This excellent bond does not permit creepage of the liquid environment through the interface at the bond. Such creepage is the primary cause of bond failure in a majority of adhesives tested. Bond destruction initiates with a film of moisture creepage at the edge of the interface. It progresses slowly throughout the interface and finally produces complete bond failure. The creepage film is extremely thin and produces interference colors in the layer at the interface. It is important to note that even if a mechanical bond is maintained by locking the adhesive into local mechanical irregularities, the creepage film will destroy the *sealing* qualities of the band and finally permit fluids to penetrate the original seal. It is clear from these observations that mechanical adhesion is not a sufficient test for the quality of a sealing band.

3.2 Encapsulation Materials

Two materials are of interest: syntactic foams and the FIRL-Modified-Paraffin.

We decided, early in the report period, that intimate coating of electronic components with modified paraffin should be eliminated as a protective process. This is important for several reasons. In the first place, coated components are difficult to see and when they are to be replaced or repaired, the procedure becomes most difficult to carry out successfully. Secondly, the paraffin has a relatively large dielectric constant and when in contact with the tuned circuits of the implant causes changes in excess of 1.5% of the transmitted carrier frequency.

In addition to the problems noted above, we found that when micropower transmitter tuned-circuits are surrounded very closely with a conducting medium (saline solution) the circuit is severely loaded - often to the point where oscillation can no longer be sustained. An improved load match is attained if the conducting medium is kept a small distance from the tuned circuits. This results in a minimum tuned circuit frequency shaft on immersion and a much improved radiated signal. The separation problem was solved with the use of syntactic epoxy foam which is loaded with silicon spheres of small diameter. This foam is extremely rugged, very light and has a low dielectric constant.

It permits the fabrication of circuit enclosures which both protects the fragile circuits and provides low dielectric constant separation from the conducting saline environment. This enclosure is glued closed with a few drops of a cyanoacrylate adhesive. It is then *overcoated* with The FIRL-Modified-Paraffin mix. In combination. These arrangements maintain the circuitry free of the effects of implantation. If repair is necessary, or if the power cell is to be replaced, the foam enclosure is easily opened and easily resealed.

4.0 COOPERATION WITH THE RESEARCH COMMUNITY

During this reporting period we have had informative discussions with many research makers and in a number of cases, have been able to assist them with information, materials recommendations and/or design data - all of which are the results of developments generated under this contract. This dissemination of information and technique has been accomplished at no cost the this contract.

Dr. Charles Lyon, Research Professor of Botany at Dartmouth College and one of the Biosatellite experimenters, has become interested in the effects of magnetic fields on plants. This interest has apparently been stimulated by his experience with the Biostellite program. In response to his query, we have advised him concerning the production of a "null" field and have lent him two sets of expendable shielding cylinders as developed in our studies.

Dr. Irwin R. Isquith, Biology Department, Farleigh Dickenson Univeristy, during his association with us as a Participating Scientist, became interested in bio-magnetic studies relating to protozoa. He has been carrying out a number of studies on the orientation of paramecium and a membrane permeability of paramecium .

We were able to assist him in this work through technical discussions concerning the production of magnetic fields and in experiment design.

The Max Plank Institute fur Verhaltens Physiologie in Munich has requested that we construct for them a system for temperature telemetry from small animals, for biological rhythm studies. In its basic concepts, the system is similar to that evolved for Dr. C. S. Pittendrigh, then at Princeton University. It was supplied to them at no cost to this contract.

A study is currently in progress, with the Institute for Rehabilitation of New York University (Dr. Theobald Reich), as to the possibilities for telemetering blood flow from the major vessels by combining their dc magnetic field flow meter with the implantable systems developed here. The ultimate goal for the study is to obtain the blood flow to and from the important vascular beds under conditions of no restraint and zero-g. A proposal for this work is presently being revised for resubmission to the NASA Experiment Survey Program.

Sample, but useful quantities of the FIRL-Modified-Paraffin have been sent to a number of other researchers.

5.0 PAPERS PRESENTED, PUBLISHED OR IN PREPARATION

A monograph titled: Monograph on Magnetic Fields for Life Scientists" has been written and volume II to our last annual report (A-B2299-3). Twenty five copies were delivered to the NASA and a partial list of other recipients follows:

Dr. Bernard Sigel, Dean, Womens Medical College, Phila. Pa.

Dr. Dietrick Beicher, U.S. Naval Aviation Medical Center
Pensacola, Fla.

Dr. John H. Busser, Executive Secretary, BIAC, American
Institute of Biological Sciences

Dr. Sidney Galler, Assistant Secretary of Science, Smithsonian
Institution, Washington, D.C.

Dr. Howard Baldwin, Sensory Systems Laboratory, Tuscon, Ariz.

Dr. Irwin R. Isquith, Biology Dept., Farleigh Dickenson Univ.,
Teaneck, N. J.

Dr. Charles Lyon, Dept. of Biological Sciences, Dartmouth
College, Hanover, N. H.

Dr. Harvey Fisher, Chairman, Dept. of Zoology, Southern Ill.
Univ., Carbindale, Ill.

Favorable comment has been expressed by a number of recipients. Steps are underway to accomplish monograph availability to all members of the biological community who desire it.

An abstract, "Protozoan Growth in an Attenuated Magnetic Field", by I. R. Isquith (Farleigh Dickenson University) and R. J. Gibson (FIRL) has been published (and read by title in the journal of Protozoology, Vol. 16 (supplement), page 21, 1969

A paper "Protozoan Growth in an Attenuated Magnetic Field" is in preparation by I. R. Isquith and R. J. Gibson.

A short paper on FIRL-Modified-Paraffin is in preparation by R. J. Gibson and R. M. Goodman.

A paper entitled "Biotelemetry" will be presented by R. M. Goodman at the 25 February 1970 meeting of IEEE Professional Group on Engineering in Medicine and Biology.

A paper on fm/fm, multichannel, implantable telemetry is in preparation by R. M. Goodman.

A paper on dual channel, implantable telemetry for chronic studies is in preparation by R. M. Goodman.