drugs tried, used, and discarded during the last century of pharmacologic progress. What needs to be understood and incorporated into the modern definition of drug adversity is not the truism that "most drugs" or even "all drugs" are toxic (we have known this for a long time), but that all effects of drugs—good, bad, and indifferent—are examples of drug toxicity, a selective toxicity producing alterations in structure and function, which by some happy chance are useful to the sick man, or, by some misfortune, make matters worse for him (*17*).

Our new drugs are the products of a well-grounded scientific program that has led to the great positive achievements of modern therapeutics. The benefits must be weighed against the cost, which is far less than ever before; the benefits are incomparably greater. The concept that modern pharmacologic advance has left a new trail of disasters in its wake is simply untrue. What is true is that drug development has grown and expanded very rapidly, that reportage is better than ever, that observation is more acute, and that we no longer placidly accept adverse reactions of drugs. In some cases of old drug problems, matters are even becoming worse.

Unfortunately the layman views experimentation with drugs as a new, dangerous, and cold-blooded scientific pastime conceived by the Nazis, whereas in fact it is merely a safer, more public, and better controlled version of the natural, unwitting, inevitable, historic, and too-often-catastrophic drug experimentation in man that started with the witch doctor.

A great current danger is that legislation based on an inconsistent, puritanical, and illogical definition and lacking a historic view may well limit drug research and at the same time may aggravate old, and create new and serious, problems of drug adversity.

There is no aspect of drug experimentation on man that is not more ethically handled now than in the time of Hippocrates, Galen, or Withering—and now handled more safely. If a code is needed to define the ethical basis for drug research in man, it should be designed to protect man from mass disaster as well as to preserve the rights of the subjects of drug trials, and at the same time to foster progress in therapeutics. It should take into account past as well as current history—not merely thalidomide but penicillin and a host of other modern drugs—and it *must* have logic and consistency. It must recognize and weigh the accomplishments of pharmacology as well as unavoidable accidents and rare and unpredictable reactions to drugs.

If drug disasters have become less frequent, one cannot attribute the fact to legislation. All our outstanding modern achievements in pharmacotherapy preceded our new drug legislation; it is more logical to conclude that they result from the basic interest of the biomedical scientist in the health of the community and from his drive. It is a matter of medical science keeping its own house in order.

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Implant Biotelemetry and Microelectronics

Report on developments in implant telemetry, associated problems, and the potential of microelectronics

W. H. Ko and M. R. Neuman

Implant biotelemetry is a technique of biomedical instrumentation for conveying information from within the body of an unrestrained living organism to a remote location through a wireless transmission linkage. The essential blocks of such a system are shown in Fig. 1. The transducer or sensor converts the biologic parameters into electrical signals that can be processed by the conditioner. The signals are then transmitted by the radio transmitter to a remote receiver and recording or display facilities. The implanted transmitting unit, consisting of the transducer, conditioner, and radio transmitter, is located totally within the body of the organism under study. The location may be intracavitary, such as within the intestines, mouth, or bladder, or may be inside the internal as well as external surfaces of the body—subcutaneous or deep within the tissues. We now report some developments of telemetry systems to be used inside the body, after a brief review of the history and existing systems of biotelemetry.

Although radio transmission of analog signals has been known since 1844 (*1*) and frequency-modulation radio links were used to transmit pneumograms in 1948 (*2*), extensive development of biomedical telemetry techniques did not really get started until the transistor was discovered in 1948 and made

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available after 1954. The comparatively small size and power consumption of this new device made possible the construction of practical telemetry transmitters for implant measurement. Since then, the advances in solid-state devices and microelectronics have further enhanced the development of implant telemetry into a flourishing field of research in instrumentation (*3*).

In the late 1950's and early 1960's Mackay (*4*), Noller (*5*), Wolff (*6*), Zworykin (*7*), and others (*8*) developed active radio-transmitting units for use in the gastrointestinal tract and other cavities of the body. Subcutaneous and deep-body implantation of telemetry units was initiated recently by Essler (*9*), Ko (*10*), Mackay (*3*), Young (*11*), and others (*12*) to measure physiologic information in animals as well as humans; for a good historical review of these and other areas of biomedical telemetry see Caceres and Mackay (*3*). Surveys covering the current (1966) research in implant biotelemetry (*13*), as well as bibliographies on biotelemetry, are also available (*3*, *14*). Many types of physiologic signals have been telemetered; their characteristics have been summarized (*15*).

Present Implant-Telemetry Transmitters

In implanted telemetry systems the receiving units are generally standard and commercially available; if necessary, modification of the receiver can be made by routine engineering. Therefore nearly all research and design efforts are concentrated on the transmitting units, which must be designed to meet the special requirements of each experiment. The generalized criteria of an implant transmitter can be summarized: (i) small size and weight (less than a few percent of the subject's); (ii) minimum body reaction (packaged with nontoxic materials and with proper shape to reduce tissue reaction to the presence of the telemetry unit); (iii) high sensitivity (microvolts) and wide dynamic range (to handle signals ranging from microvolts to millivolts); (iv) good fidelity (signal frequency response from direct current to several kilohertz or higher); (v) low power consumption and long life; (vi) reliability, rigidity, and ease of handling; (vii) transmission range enabling free movement of the subject and the use of units with the same frequency at nearby locations without interference; (viii) compliance with regulations for radio transmission established by the Federal Communications Commission.

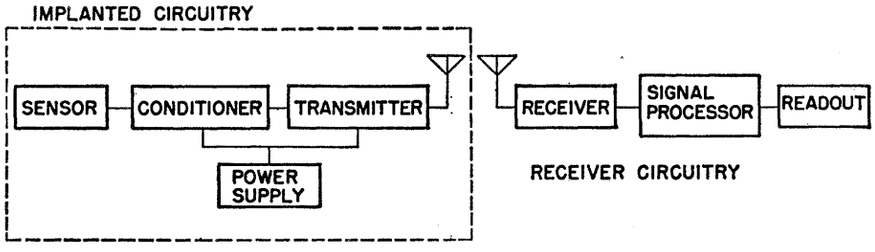


Fig. 1. Block diagram of a biotelemetry system.

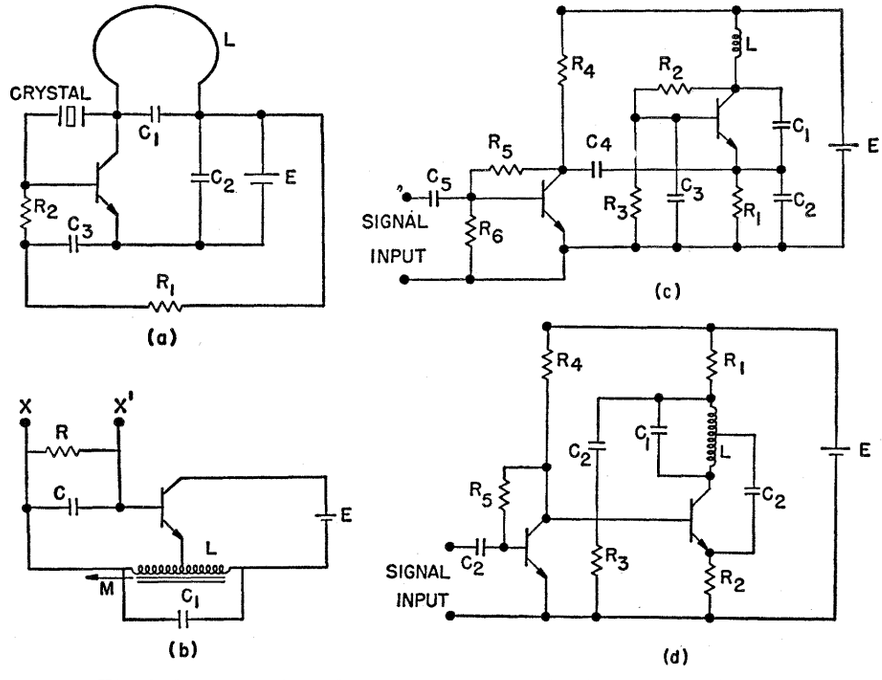


Fig. 2. Four popular telemetry transmitter circuits currently in use.

Compelled by the limitations on size and weight, most of the present transmitting units use one or two transistors to obtain transducer, conditioner, and transmitter functions. The radio-frequency carrier may be frequency-modulated continuous waves (CW), or modulated pulses. Amplitude modulation is not used because of the introduction of serious errors when relative motion between transmitter and receiver occurs. Review of the current literature indicates that most of the published transmitter circuits may be categorized into four groups; Fig. 2 shows four popular transmitter circuits selected from each group.

The circuit in Fig. 2a uses a piezoelectric crystal, as the feedback element in an oscillator, to achieve good carrier-frequency stability (*16*); it is widely used for animal tracking and narrow-band signal transmission over a range from 30 meters to several kilometers; both CW and pulsed operation can be obtained by varying the value of resistor R_1.

The circuit in Fig. 2b is a common-emitter Hartley-oscillator circuit (*4*); the transmitter is modulated by varying the rate of pulses of radio-frequency oscillations. It is popularly used to measure temperature, by replacement of the resistor R with a thermistor; pressure, by allowing pressure changes to move the core M; pH, by attaching suitable electrodes across the voltage input X; and other variables, by means of suitable transducers. Continuous-wave operation can be obtained by reducing the value of R.

The remaining two circuits of Fig. 2 are common-base oscillators: circuit 2c is a Colpitts circuit (*17*); circuit 2d is a Hartley circuit (*11*). Both use the voltage-sensitive emitter-to-base capacitance of the transistor to modulate the frequency of the carrier. These circuits, designed to transmit electrical signals such as electrocardiograms (ECG) and electromyograms (EMG), require

relatively wide bandwidths of several kilohertz. The signal's amplitude may vary from 50 microvolts to several millivolts, and the transmission range is usually from a few meters up to 30 meters at a power consumption of milliwatts.

The circuit of Fig. 2b represents the most desirable design approach, in which the transducer and conditioner are integrated into the components of the oscillator. The simplicity of the circuit and the small power drain (average current of a few microamperes in the pulsed mode) explain its success and popularity. However, one should note certain limitations or disadvantages for the pulsed mode of operation: (i) the large error that can be induced by voltage variations in the power supply; (ii) the interference generated over a wide frequency band because of the self-blocking pulsed-carrier mode of operation; and (iii) the relatively low carrier frequency required by the low collector current and common-emitter configuration if self-starting is required. These limitations may be relaxed when more complex circuits are used; the application of microelectronic techniques allows the small size and power requirements to be maintained even with the more complex circuits.

Single-Channel Telemetry Systems Developed

It is desirable to explore the possibility of using new solid-state electronic devices in biotelemetry to meet the general criteria and to obtain: (i) better performance, such as wider range of frequency (from direct current to 20 kilohertz) and better sensitivity (microvolts) without amplifier stages; and (ii) lower power consumption (microwatts) than yet achieved. Five models of single-channel telemetry transmitters using tunnel diodes as the main active components were developed at Case Institute of Technology: they are named transmitters K-1 to K-5 (Fig. 3). Models K-1, K-2, and K-5 are high-density packaged units using discrete circuit components. Model K-3 is a thin-film circuit, and model K-4 is a multiple-chip silicon integrated circuit. Frequency modulation of continuous carrier waves in the range 100 to 250 megahertz was selected as the modulation method because it best met the desired performance. The five models can be grouped into two types of design. In K-1 to K-3, the bias of the oscillatory tunnel diode was varied to achieve frequency modulation, while in K-4 and K-5 a varacap (voltage-controlled variable-capacitance diode) was used to vary the resonant frequency of the oscillatory tank circuit. Later we shall discuss models K-1 and K-5 in greater detail.

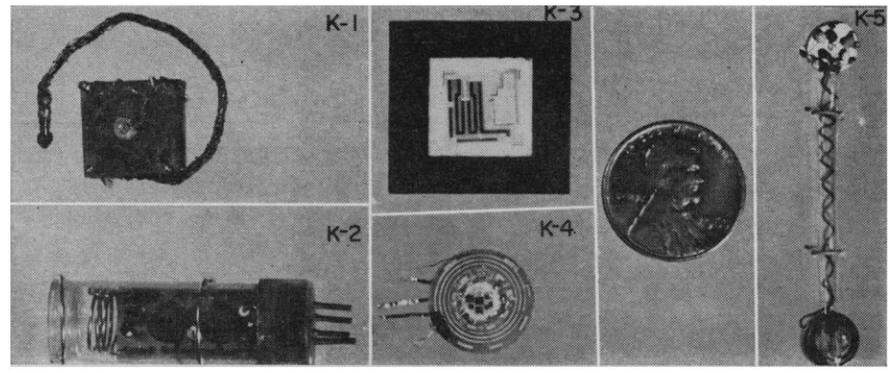


Fig. 3. Five transmitters.

Principle of Operation

Figure 4 shows the circuits used for the K-1 and K-5 transmitters, with a typical tunnel-diode I–V characteristic shown in Fig. 5. In section *bc* of this curve, the current decreases as voltage increases; therefore the alternating-current dynamic resistance is negative. When biased in this negative-resistance region, the tunnel diode may be used as an active device to generate oscillations. A negative-resistance tunnel-diode oscillator circuit, similar to the model K-1 telemetry transmitter, is shown in Fig. 6a; the direct-current source resistance R_b should be smaller than the value of diode negative resistance $-R_d$. The frequency of oscillation is determined by the resonant circuit $C'L'R'$ and the tunnel diode, where R' represents the total loss of the oscillation circuit, including radio-frequency radiation. The radio-frequency equivalent circuit of the oscillator is shown in Fig. 6b, where C is the combination of C' and the capacitance of the tunnel diode itself at the operating point. Because the values of R_d and C_d are a function of tunnel-diode direct-current bias, the frequency of oscillation varies with bias. Figure 6c illustrates the relations between frequency and bias, as well as frequency deviation and bias: if the modulating signal is applied to vary the bias of the tunnel diode, operating in the constant (df/dv) region, a high frequency-modulation index may be obtained; a frequency deviation (df/dv) from 50 to 500 kilohertz per millivolt, at a carrier frequency of 100 megahertz, was observed at the proper bias voltage. Although these high sensitivities are possible, the circuit of Fig. 6a presents the following difficulties in design: (i) it requires precision components; (ii) the power supply must be kept constant to within microvolts; (iii) the input impedance is low; and (iv) the gain and frequency are highly sensitive to temperature.

The improved K-5 model (Fig. 4) eliminates most of these difficulties. The

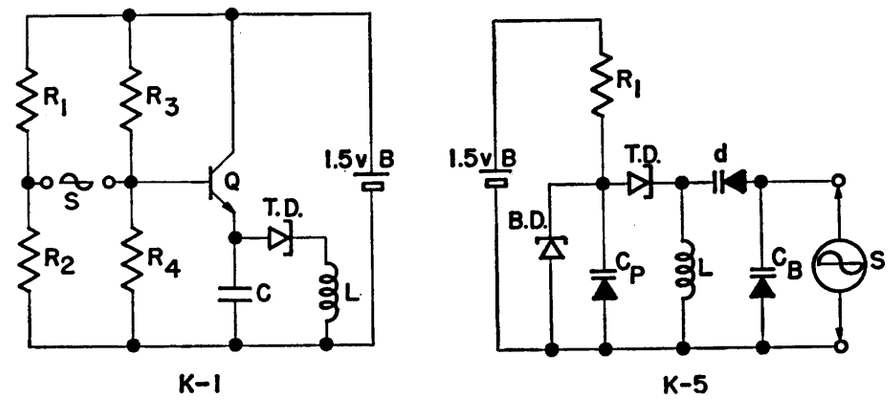


Fig. 4. The K-1 and K-5 transmitter circuits.

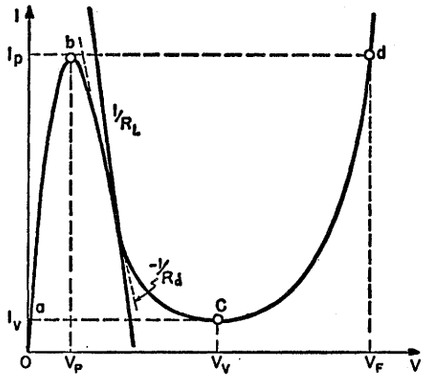


Fig. 5. A typical tunnel-diode I–V characteristic.

backward diode *BD* in this circuit is used to bias the tunnel-diode oscillator into a region where the frequency is not sensitive to direct-current voltage-bias variations. The alternating-current equivalent circuit of the K-5 oscillator can be reduced to the same as that shown in Fig. 6b. The frequency is determined by the coil L, the total loss R, and the combined capacitance $C = C_o + C_d$, where C_o is the capacitance of the tunnel diode and C_d, is that of the modulating varacap diode d (Fig. 4b). C_P and C_B are radio-frequency bypass capacitances. The input signal S varies the bias of the varacap diode d, thus controlling the capacitance C_d which, in turn, modulates the oscillator frequency. In this circuit the backward diode also functions as a temperature-stable voltage regulator; thus the frequency stability is greatly improved. The input impedance of this circuit is raised to the range of from 1 to 100 megohms. However, the modulation sensitivity (df/dv) is decreased about one order of magnitude; this condition may be improved considerably by the use of hypersensitive varacaps, special devices currently being fabricated in our laboratory (*18*).

The performance specifications of transmitters K-1 and K-5 are listed in Table 1; comparison shows that model K-1 has higher sensitivity, while the smaller K-5 has much better frequency and temperature stabilities and a much higher input impedance.

A comparison of EMG signals, recorded by standard wire techniques in current use and by wireless telemetry, is shown in the oscillographs of Fig. 7. The same pair of electrodes were connected to the telemetry system as were connected by wires to an amplifier and oscilloscope in a shielded room; simultaneous traces of the two signals are shown (Fig. 7), the top trace being the former and the lower trace being the latter. Figure 7A shows the two output traces with no input to the electrodes; note the pickup of 60-cycle noise from the power lines, which is present on the trace from the wire system but not evident on the trace from the wireless system. Figure 7, B and C, shows typical EMG signals simultaneously transmitted over the two systems.

Field-Test Results with K-5 Units

Model K-5 transmitters were implanted in animals to measure EMG and ECG; the input sensors were platinum or stainless-steel electrodes, either mounted one on each side of the transmitter package for EMG measurement, or extended through flexible cables to a remote location for ECG. The assembled transmitter was covered with a thin coating of acrylic or polystyrene for sealing, and then embedded in Dolph CO-1060 (*19*) hard epoxy or paraffin wax (melting at 65°C) to prevent body fluids from leaking in. Sometimes, ferrite powder was mixed with the epoxy to adjust the carrier frequency. The transmitter was finally encapsulated in

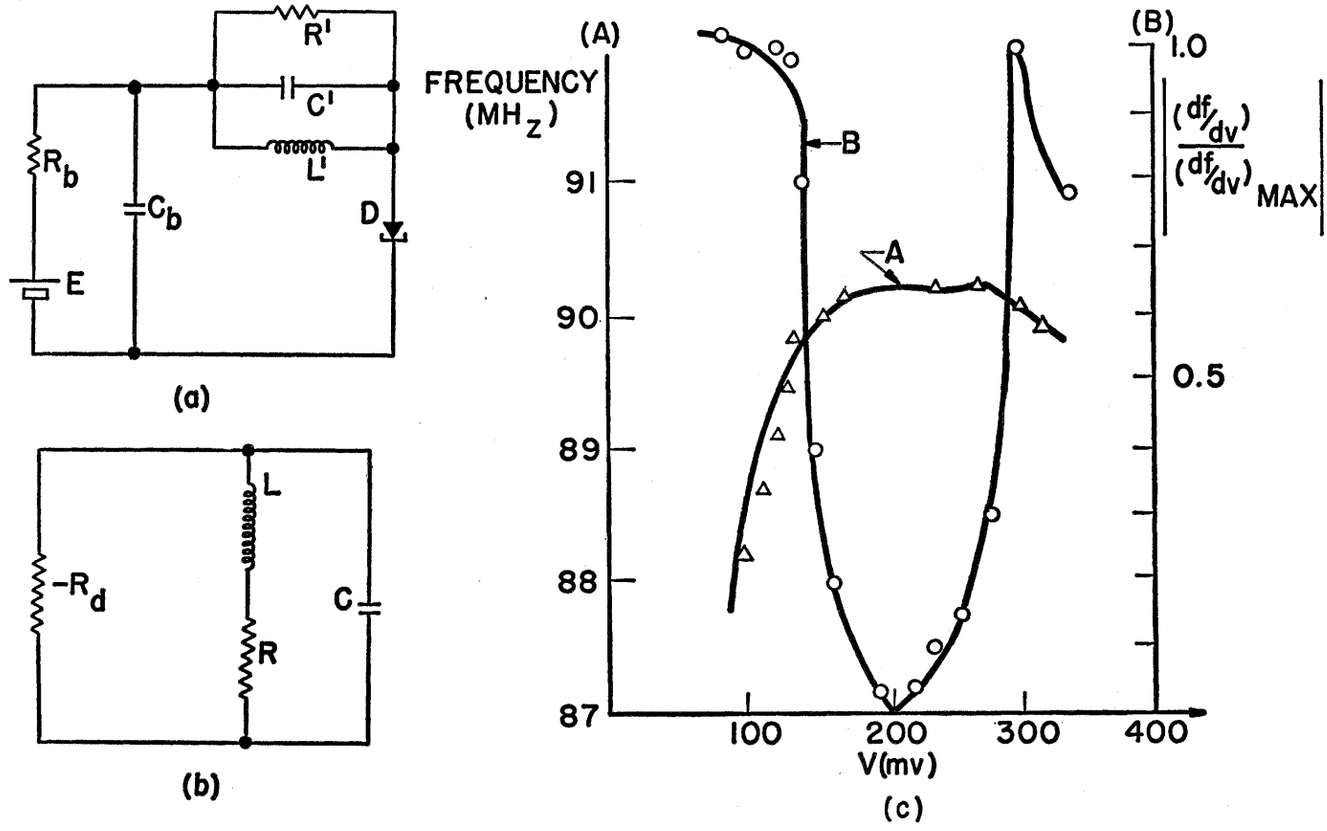


Fig. 6. Principle of operation of a tunnel-diode frequency-modulation oscillator: (a) circuit diagram, (b) alternating-current equivalent circuit, (c) oscillator frequency and frequency deviation as function of direct-current bias voltage.

Silastic 382 (*20*). The battery leads were coiled inside a Silastic tube (Dow Corning 372) which was connected to the battery package. The encapsulated transmitter weighed about 1.5 grams; it was 1.1 centimeters in diameter and 5 millimeters in thickness.

The power supply is usually packaged separately from the transmitter so as to keep the size and mass of the transmitter at a minimum; thus each can be located in a smaller place. The power supply can be in either of two forms: a mercury cell, or an induction-pickup circuit to convert energy in a radio-frequency field into direct-current power. For the former, a bistable, miniature, magnetically actuated switch was developed to spread the useful battery life over longer periods; the switch may be turned on or off by means of a direct-current magnetic field produced by a permanent magnet held as far as 15 centimeters from the switch. A complete K-5 transmitter, with battery, power supply, and magnetic switch, is shown in Fig. 8.

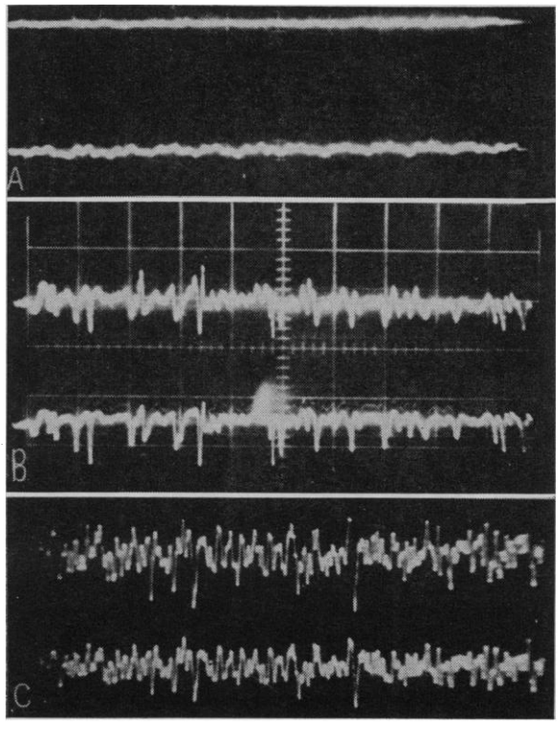
The radio-frequency-induction power-supply circuit and an actual unit are shown in Fig. 9. The overall package is a sphere, 1 centimeter in diameter, with three mutually perpendicular detector coils on its surface connected to the rectifier and filter circuits located within the sphere. When the detector is located in a cage, measuring 75 by 63 by 35 centimeters, having a coil wound around it driven by a 150-watt 1-megahertz power oscillator, sufficient power is produced to meet the requirement of 200 to 240 microwatts for the K-5 circuit. The power density within the cage is below the safe limit (10 milliwatts per square centimeter) set by government and industrial agencies (*21*).

Table 1. Performance of K-1 and K-5 transmitters. RF, radio frequency; S:N, signal-to-noise ratio.

Item	K-1	K-5
Size, less battery	1.3 × 1.3 × 0.4 cm	0.8-cm-diam. × 0.2 cm
Weight, less battery	1.7 g	0.44 g
Weight with battery	2.8 g (Mallory RM-400)	1.44 g (Mallory RM-320)
Power consumption	1.3 volts, 1.2 ma	0.2 volt, 1.2 ma
RF frequency (extensible to from 50 to 500 Mhz)	80–100 Mhz	100–250 Mhz
System noise (in shielded room at 1-kc bandwidth)	0.5 μv	3.5 μv (at 10-kΩ input)
Input sensitivity (6-db S:N)	1.0 μv	7.0 μv (10-kΩ input)
Dynamic range (limited by receiver)	2×10^3	10^3
Frequency response	0.01–20 khz	0.01–20 khz
Input impedance	5 to 8 kΩ	300 kΩ to several MΩ
Transmission range	5 μv at 3.66 m (with 10-cm lead)	5 μv at 1.22 to 2.44 m (without leads)
Carrier-frequency temperature stability	Poor	Better than 0.05%/°C

A series of 60 K-5 transmitters were surgically implanted in rabbits, rats, and mice after being sterilized by soaking in 70-percent ethyl alcohol for 1 hour; 24 of them were implanted directly in the right-rear quadriceps muscle of adult albino male rabbits weighing between 3 and 6 kilograms. Standard surgical techniques were used to secure the transmitter and sensor electrodes within a longitudinal incision in the muscle; the power supply was located subcutaneously near the transmitter.

Electromyographic signals were observed after the animal's recovery from the anesthesia (Fig. 10). Electrocardiographic signals from rats, rabbits, and mice were telemetered by implanting the transmitter and power supply subcutaneously dorsally at the base of the neck; wires connecting the transmitter to electrodes in the chest area were passed beneath the skin, and small incisions were made on the chest wall to suture the electrodes to the skeletal muscle fascia to prevent their migration. Typical ECG wave forms for rats,



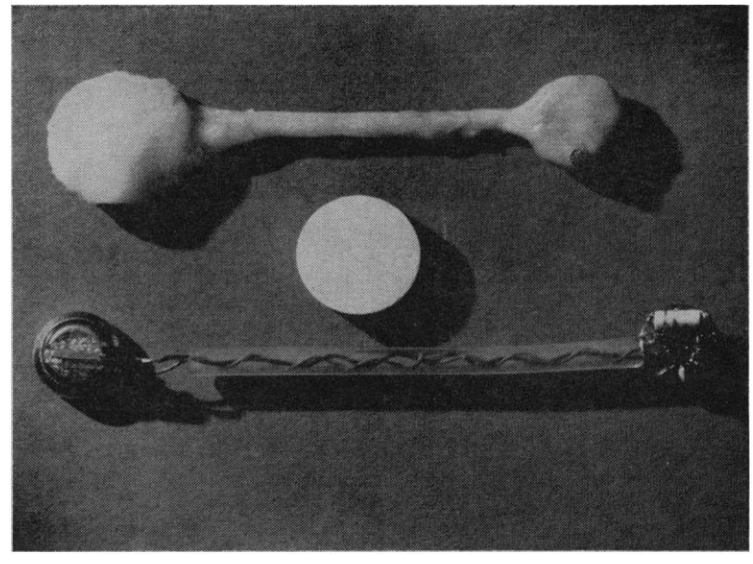


Fig. 7 (left). Comparison of electromyogram signals measured by wireless and wire systems: (A) no signal, (B and C) typical signals. The top trace is for the wireless system; the bottom, for the wire system. Fig. 8 (above). The K-5 transmitter (top), with mercury-cell power supply, compared to an aspirin tablet. Encapsulated in epoxy, with a Silastic surface layer, the transmitter is ready for implantation.

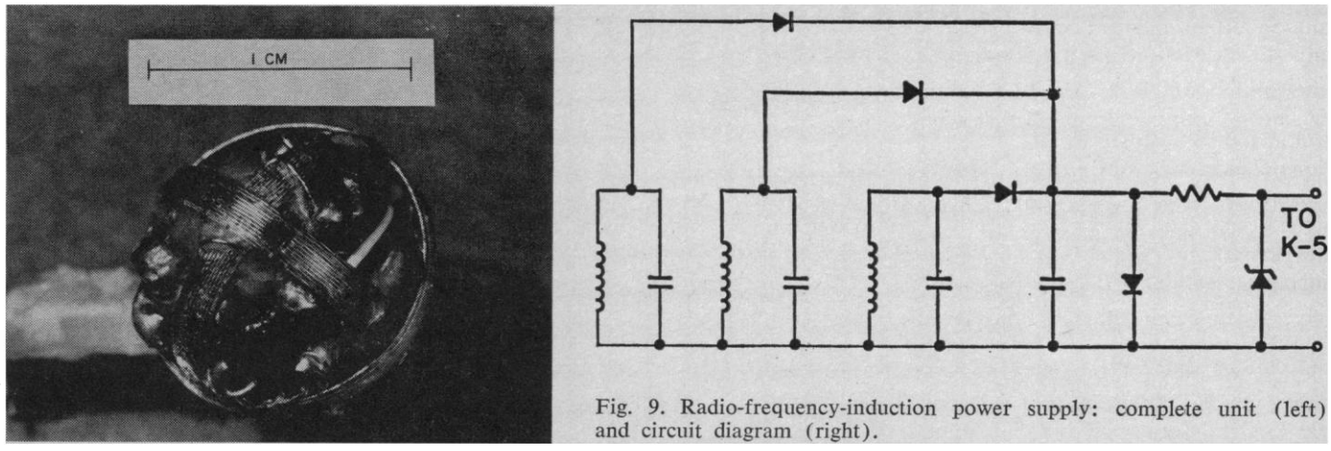
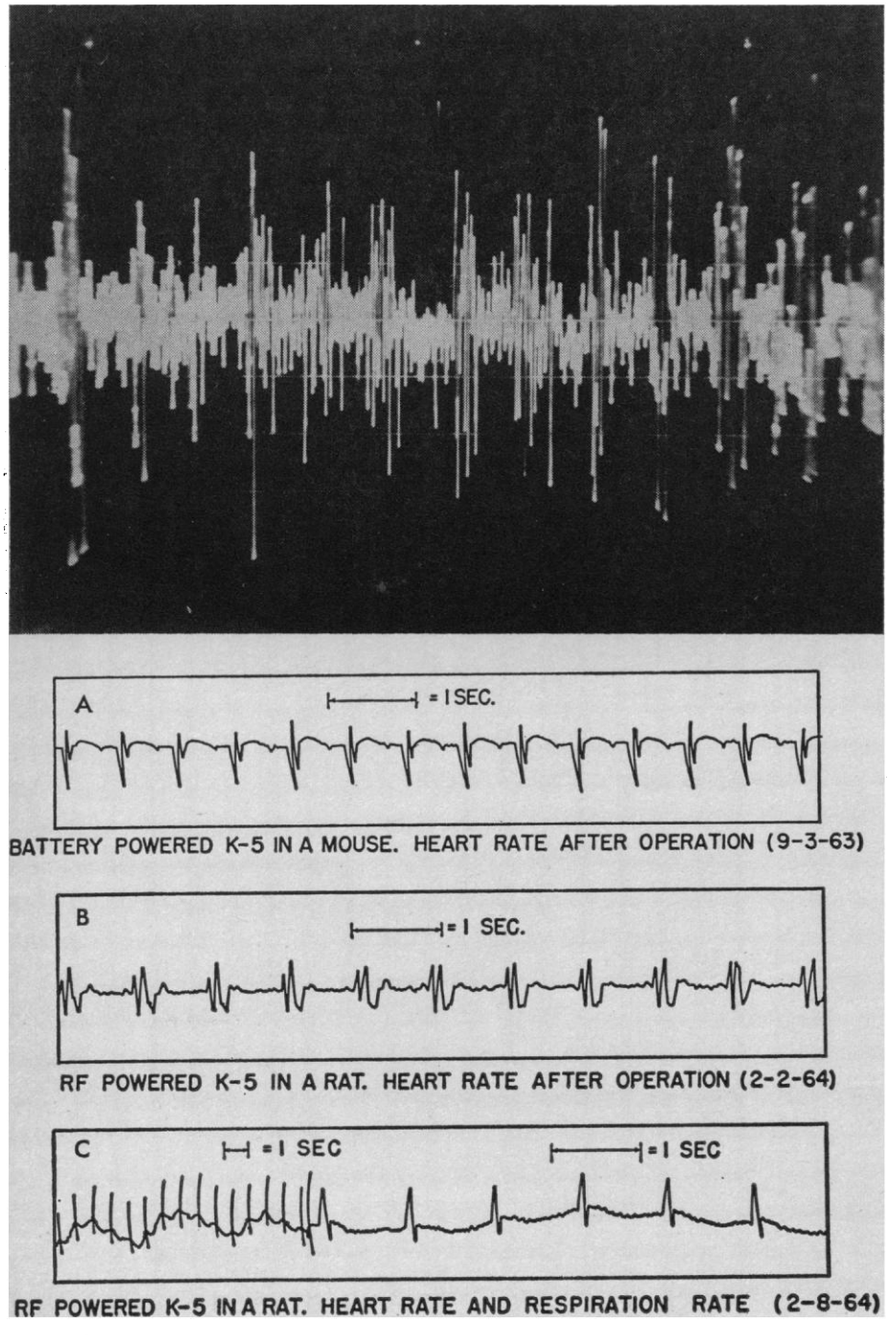


Fig. 9. Radio-frequency-induction power supply: complete unit (left) and circuit diagram (right).



by use of both battery- and radio-frequency-powered transmitters, are shown in Fig. 11; note that, for some electrode placements, respiration rate as well as ECG is obtained, the former appearing as periodic variations in the base line of the latter.

The life of battery-powered units is determined by the size of the battery; the maximum period of operation has been 10 days. However, when in later models a magnetic switch was built in the transmitter, the useful life of the battery was spread over a period of many weeks. When recovered after being implanted in animals for 4 months, transmitters have proved to be in good operating condition, given new batteries.

The life of the electronic circuits should be indefinite for radio-frequency-powered transmitters. A typical unit implanted in a rat has yielded good results for 100 days. Signals transmitted by radio-powered units are comparable in quality with signals from battery-powered units (Fig. 11). Figure 12 shows a section of the recorded heart rate of a mouse; these data are from telemetered ECG records taken over a 2-week period.

The K series of transmitters proved undesirable for applications requiring long-term measurements of base-line variations: the drift of frequency with

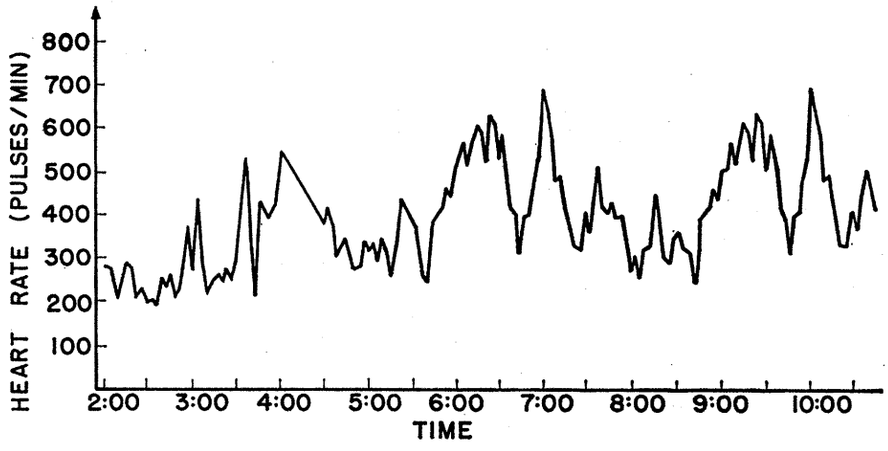
Fig. 10 (left above). Electromyogram signal telemetered from the right-rear quadriceps muscle of a rabbit walking freely. Fig. 11 (left). Electrocardiogram signals telemetered from rats by battery-powered transmitter (A), radio-frequency-powered transmitter (B), and radio-frequency-powered transmitter with electrodes placed in such a way as to pick up respiration rate as well as electrocardiogram as seen on the slow-speed trace (C).

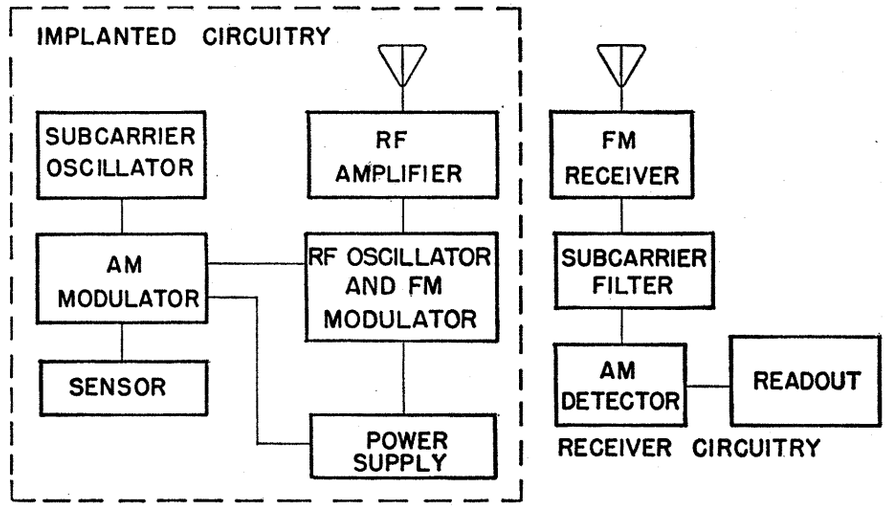
motion of the subject tended to mask any slow variations in the signal; and, if the telemetry system was stabilized by use of automatic frequency control at the receiver, the long-term variations could not be measured. For these reasons a telemetry system was designed using a subcarrier to provide the long-term accuracy (Fig. 13). A subcarrier oscillator is amplitude-modulated by the signal; the subcarrier then modulates the frequency of the carrier of the transmitter. A standard frequency-modulation receiver detects the main carrier, producing the amplitude-modulated subcarrier at its output. Amplitude-modulation detector circuits recover the signal from the subcarrier, and the signal is amplified and presented on the readout device.

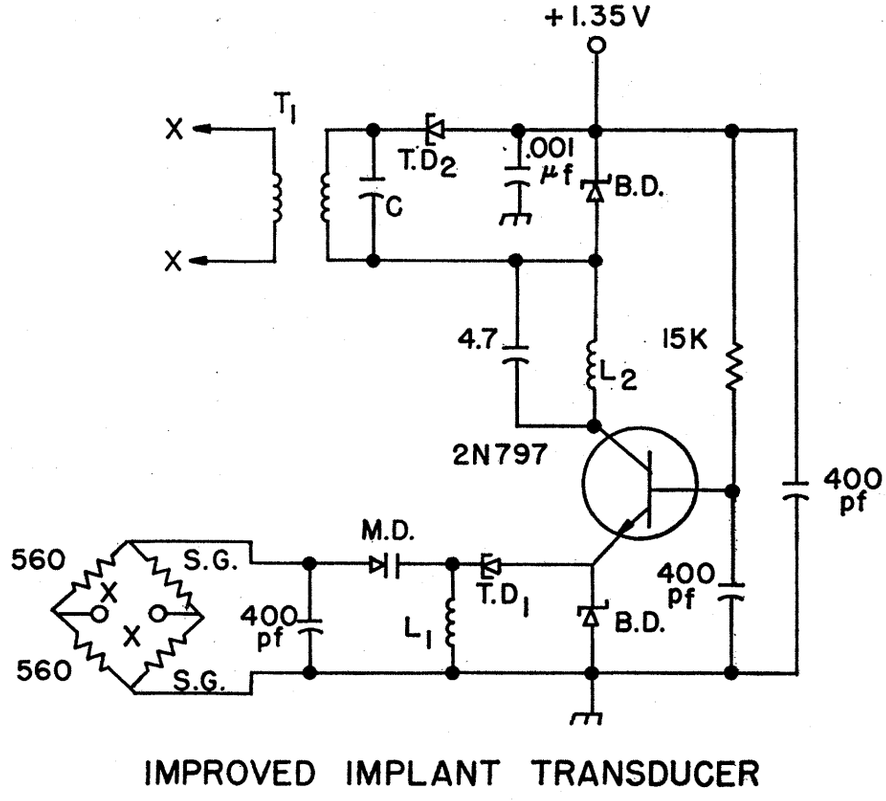
A subcarrier telemetry system was constructed to monitor intestinal pressures in dogs and monkeys (*22*); the implanted circuitry is illustrated in Fig. 14 (*23*). A tunnel-diode oscillator operating at a frequency of 22 kilohertz supplies power to a bridge circuit containing two strain gauges sutured to the animal's small intestine. The amplitude of the subcarrier at the output of the bridge is determined by the degree of balance of the bridge arms. This signal then is used to modulate the frequency of the K-5 type of carrier oscillator. The carrier-frequency transistor-amplifier stage boosts the level of the radio-frequency signal to give the transmitter greater range than it would have with just the K-5 circuit.

An example of the type of strain information that can thus be telemetered appears in Fig. 15. The strain gauges were attached to the small intestine of a dog, and the transmitter and power supply were mounted within the abdominal cavity. A record of the intestinal strain at the location of the strain gauges was made by a strip-chart recorder at the receiver. Figure 15 shows the effects of intravenous injection of atropine on the intestinal contractions while the animal remained under anesthesia.

Miniature electronic circuits capable of simultaneously telemetering two or







IMPROVED IMPLANT TRANSDUCER

Fig. 12 (top). Variations in the heart rate of a mouse, determined with an implanted K-5 transmitter. Fig. 13 (middle). Block diagram of a subcarrier telemetry system for measuring intestinal strain. Fig. 14 (bottom). Implanted circuitry of the subcarrier telemetry system for measuring intestinal strain.

Fig. 15. Record of the intestinal strain monitored by a subcarrier telemetry system implanted in a dog; note reaction to an injection of atropine.

more channels of information are also needed for biomedical instrumentation systems. To meet this need, a six-channel frequency modulation–frequency modulation, frequency-division, multiplex system has been designed and built to monitor such physiologic parameters as body temperature, respiration rate, pulse rate, and muscle spasms (*24*). Tunnel-diode subcarrier oscillators are frequency-modulated by transducers for each channel; a block diagram of the system appears in Fig. 16. The system was clinically evaluated in the metabolic ward of Highland View Hospital, Cleveland, Ohio. The transmitter package, measuring 1.5 by 6.3 by 6.3 centimeters and weighing 15 grams, was surface-mounted on a quadraplegic patient. The six-channel unit consumed 7 milliamperes at 9.0 volts. Transducers to measure two surface temperatures, one internal temperature, respiration rate, body position, and heart rate were attached to each channel of the transmitter, and receiving and recording equipment was placed in an adjoining room. Continuous data were recorded over 26-day periods of operation, with satisfactory operation of the telemetry system (*24*). Figure 17 shows the heart rate and ear temperature of a person for 19 hours after a meal, averaged over a period of 2 weeks, as measured by this telemetry system.

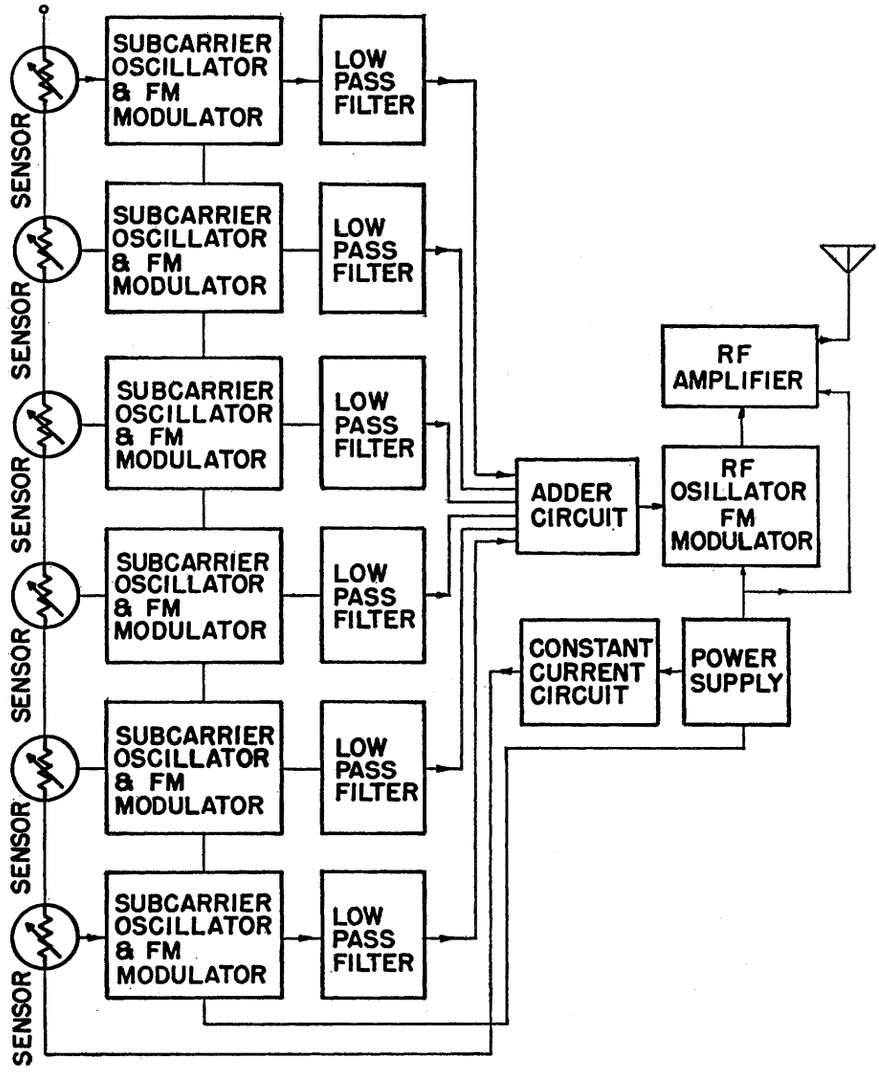


Fig. 16. Block diagram of a six-channel telemetry system.

An integrated-circuit, implantable, time-sharing multiplex system, now under development, will be able to transmit all physiologic measurements that currently can be telemetered on single-channel units; it is estimated that the ten-channel transmitter, without power supply, will occupy a volume of less than 16.4 cubic centimeters and weigh less than 30 grams. The unit can be powered by radio power or by a storage battery chargeable by radio power.

Problems Associated With Implant Telemetry

Although the initial experiments with implanted telemetry have proved the great promise of this technique, they have also revealed many serious problems that must be resolved before the full impact can be realized; the problems, which are now being studied at research centers for biomedical engineering (*25*), concern such things as:

1) Body reaction to electronic packages attached on the surface, injected, or implanted: scattered information exists, but more details are necessary because of the close interaction between body and instruments.

2) Power supply of electronic circuits: when the circuit is miniaturized, the power supply becomes the major part of the system in volume and weight. Required are either circuits with much lower consumptions of power, or some way to convert physiologic energy into electrical energy.

3) Size and weight standards: the body reaction is believed to be affected by the size, weight, and surface conditions of the electronic circuits. Some quantitative standard should be established for implant size and weight, normalized to body size and weight.

4) Circuit simplicity and reliability: because size and reliability are of pri-

mary concern, circuits should be as simple as possible. Special circuits and devices will be needed for biomedical applications; reliability and ease of operation of the instruments should be maximized.

5) Transducers and special electronic devices: miniature transducers are needed to match the telemetry systems to expand the type of measurement that can be made. Special electronic devices for implant telemetry may be developed to simplify the circuitry.

6) Effective cooperation between life scientists and physical scientists or engineers: since it is essential for scientists and engineers of several disciplines to work together in the application of electronics to biomedical problems, close cooperation and effective communication are essential.

Potentials of Microelectronics in Implant Instrumentation

The solutions to many of the problems mentioned in the previous section may be made easier through the application of microelectronics—extremely small electronic circuits or systems. The technology has now been developed to the extent that circuits containing a few hundred component parts may approach the component density of cells in the human brain. Microcircuits also prove to be much more reliable than equivalent circuits constructed from discrete components (*26*). The telemetry systems that we have reported used only primitive techniques in microelectronics; improvement by an order of magnitude is possible with advanced technology.

The manyfold reduction in size and mass (with much higher reliability) of microelectronic systems from their conventional counterparts makes it possible to incorporate entire implant systems into very small packages. Furthermore, because of the reduction in size, components may be duplicated to ensure extreme reliability. Besides telemetering units, complex instrumentation systems for biomedical research that one could not implant in the past may become technically realizable; such systems not only can serve useful instrumentational functions but also will provide better clinical techniques and tools for research.

Implant electronics may also be used for the electrical stimulation of biologic systems (*27*); a remotely controlled circuit for stimulating heart, bladder, nerve, or limb muscle is illustrated in Fig. 18; preliminary tests of the unit on the bench yield favorable results. The external transmitter supplies radio-frequency power to the implant circuitry; this power is converted to direct current to power the electronic circuit. The radio-frequency waves are also amplitude-modulated with the desired wave form of the stimulating signal. This modulating envelope is detected and amplified by the implant circuitry and then applied to the stimulating electrodes. A K-5 transmitter is incorporated in the implanted unit to telemeter the current, applied to the stimulating electrodes, back to the external monitor receiver; this feedback information can then be used to control the wave shape of the stimulating signal, modulated on the carrier amplitude, to obtain the desired effect.

This is just one example of the many types of closed-loop implant systems that are made possible by the application of microelectronics.

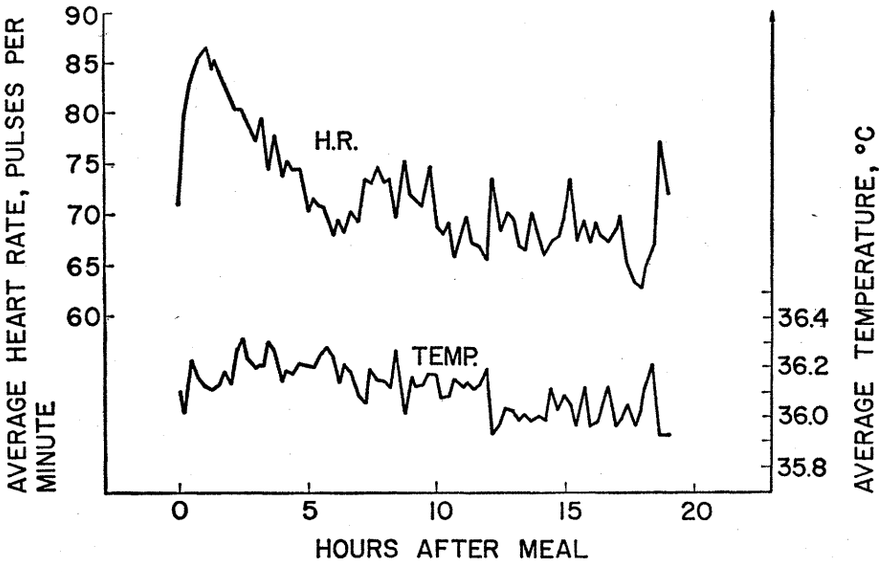


Fig. 17. Average heart rate and ear temperature of a human, as monitored by the six-channel telemetry system for 19 hours after each meal; data were averaged over a period of 2 weeks.

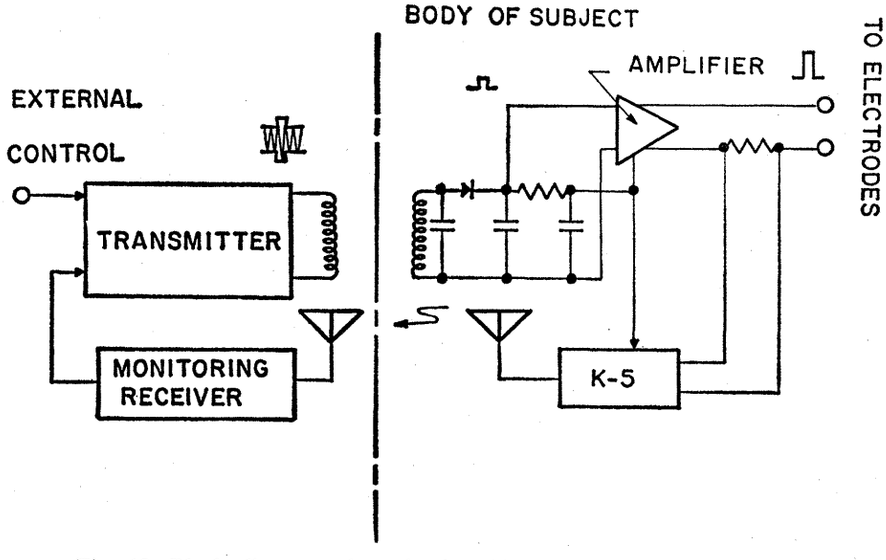


Fig. 18. Block diagram of an implantable electrical-stimulator system.

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28. We thank the Veterans' Rehabilitation Administration, NASA, and the National Institute of General Medical Sciences for support and guidance.

NEWS AND COMMENT

The National Academy of Sciences: Profile of an Institution (II)

At 9:30 a.m. on 24 April 1950, the 87th annual meeting of the National Academy of Sciences was called to order by President Alfred Newton Richards. When the meeting ended the next day, vengeance had been exacted in a vendetta seething since World War II. As a consequence, though it is doubtful the members had this outcome in mind, the Academy entered a period of growth and activity unprecedented in its long and drowsy history.

The meeting, attended by 201 of a membership then totaling 461, opened with a brief business session at which Richards went through the formality of announcing what the members already knew: He had notified the Council of the Academy that in June, upon completing a 4-year term, he would leave office. J. Robert Oppenheimer offered a resolution of appreciation for the retiring president, who, in his 74 years, had distinguished himself as a pharmacologist and research administrator. The resolution was adopted. Various items of routine business followed. Notice was given of the deaths of five members since the last meeting, and appointments were made to a number of committees. Invitations had been received for the Academy to send representatives to various scholarly and ceremonial proceedings. It was announced that a member would attend the 10th International Ornithological Congress in Sweden; "greetings" would be dispatched for the installation of a new president at Geneva College, in Beaver Falls, Pennsylvania. And so forth. At 9:50 a.m., the business meeting was adjourned. Scholarly proceedings were scheduled for the rest of the day, but it is doubtful that scholarship was uppermost in the minds of many members. Rather, it is likely they were thinking of the following morning, when the Academy would vote on Richards' successor.

Now, since decorum characterizes the Academy's proceedings, and the academicians are not the stuff of which juntas and coups are easily made, elections of Academy officers are usually placid, predestined affairs at which the Council, upon recommendation of a nominating committee, serves up one candidate per office. In preparation for Richards' retirement, the decision-making apparatus of the Academy had produced a candidate of the most sterling distinction, Harvard president James Bryant Conant, whose attainments as a chemist had brought him Academy membership in 1929 at the unusually early age of 36. At the beginning of World War II, along with his fellow academicians, Vannevar Bush, president of the Carnegie Institution of Washington, Frank Jewett, president both of Bell Laboratories and of the Academy, and Karl Compton, president of M.I.T., Conant had led the mobilization of the scientific community and had played a key part in establishing the Manhattan Project. During the war, as chairman of the National Defense Research Committee, he was second only to Bush in the far-flung military research enterprise that came under the Office of Scientific Research and Development (OSRD). Following the war, the highest levels of government regularly sought his counsel on the new complexities of military technology, strategy, and international diplomacy.

In the long history of the Academy, one would have had to go back to the great physicist and Smithsonian secretary Joseph Henry to find an individual of comparable scientific stature, political *savoir faire*, administrative experience, and dedication to the public service. In fact, it is possible that the Academy elders coveted Conant's lustrous reputation more than Conant coveted the Academy presidency. He had taken little part in Academy affairs. There may have been a good reason, but he was not present for the election meeting, and he was so heavily engaged with duties in Cambridge and Washington that it is likely that he would have followed tradition and viewed the Academy presidency as mainly an honorific position. Nevertheless, the presence of his name on the ballot established the fact that he was willing to take it.

However, at the instigation of Conant's fellow chemists, the rank and file of the academicians present were not willing to give it to him.

The motivations for what transpired on that day 17 years ago are now difficult to discern. The minutes record