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Y-1568

Instruments

MASTER

A MINIATURIZED RADIOTELEMETRY DEVICE
FOR MONITORING TEMPERATURES

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

E. W. Pipes

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the ATOMIC ENERGY COMMISSION under U. S. GOVERNMENT Contract W-7405 eng 26

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Instruments
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UNION CARBIDE CORPORATION
Nuclear Division

Y-12 PLANT

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ABSTRACT

Technological advancements in telemetry circuits and components, especially in the field of miniaturization, provide means of measuring variables under conditions which have formerly been considered impractical or impossible.

This report discusses the technical aspects of a biotelemetry system for measuring the temperature of a small mammal without the use of restraining wires, and a radiotelemetry system for measuring the temperature of a moving machine member or work-piece.

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SUMMARY

Various configurations of a miniature radio transmitter were fabricated and potted in medical silastic^(a) and implanted in rats to measure their body temperature by means of radiotelemetry.

This method of measuring body temperature allows biomedical studies to be made without handling or restraining the subjects during an experiment, and continuous monitoring without the presence of personnel is possible.

The telemetry system consisted of a miniature radio transmitter, a radio receiver, signal-shaping and noise-rejection circuits, and a temperature indicator and recorder. Several types of commercial telemetry receivers were tried in the experiments including an inexpensive "walkie-talkie" unit which was modified for the purpose. Signal-shaping and noise-rejection functions were implemented with standard solid-state logic circuits consisting of Schmitt triggers, monostable delay circuits, and operational amplifiers. In the prototype systems, both digital and analog-type temperature indicators were used. These instruments included a digital counter with a numerical indicator light display, a digital printer, an analog strip-chart recorder, and an analog panel meter. The strip-chart recorder and panel meter proved most practical for the visual use of information.

The transmitter, a modified Hartley blocking oscillator of the self-pulsing type, was powered by a miniature mercury cell. The device utilized a silicon transistor as the active element and a thermistor as the temperature sensor and timing element for pulse-frequency modulation.

For the machining experiments, the biotelemetry system was adapted, mainly by changes in the transmitter circuitry, to sense and record temperature changes on a moving machine-tool member and workpiece. Precise machining operations require that thermal expansion of the machine-tool members and workpieces be controlled. In the machining experiments, the temperature sensor was mounted directly on a workpiece being machined. The temperature of the moving workpiece was transmitted, analyzed, and recorded so that corrective action could be taken to control thermal expansion.

Among the advantages of the telemetering system in machining operations are: (1) that the small transmitter and sensor may be installed in relatively inaccessible moving parts of a machine, (2) the temperature is transmitted by wireless signal to the monitoring station, and (3) wires, slip rings, or other physical signal-coupling devices are eliminated from the moving workpiece or machine member.

(a) Dow Corning Elastomer Number 382.

Except for the transmitters, the radiotelemetry systems for the biological and machining experiments were the same. The transmitter used in the machining experiments utilized a tunnel-diode oscillator that was pulse-frequency modulated by a resistance-capacitance (RC) controlled, unijunction-diode, pulse-forming circuit. The resistive component of the unijunction RC control circuit is a temperature-sensitive thermistor which provides a frequency of modulating pulses that are proportional to the thermistor temperature.

These experiments have proven that radiotelemetry in biological and machining applications is practical and that good results can be obtained with standard commercial units or units that are made from modified existing circuits with off-the-shelf electronic components. The technical problems, associated mainly with the biological experiments, included: (1) difficulty in fabricating transmitters that were small enough to be implanted in small mammals, (2) obtaining very small power supplies which would sustain long experiments, and (3) obtaining uniformly received signals from a low-power transmitter in a free-ranging mammal. These problems were not so critical in machining applications; however, other problems were encountered: (1) machining requires transmitters that must withstand fairly high temperatures and high "G" forces, and (2) they must also be capable of operating in difficult machine shop environments.

These problems have been solved to a large extent, but improvements are continuing as new techniques and components become available. One major problem that is foreseen, but has not yet been studied, is the matter of obtaining miniature transducers suitable for sensing many biological parameters. Temperature has been selected purposely as the measured variable in the first experiment because it is easily sensed and measured with conventional transducers.

INTRODUCTION

Telemetry, the technique of measuring from a distance, is a long-established technology. Early applications utilized wires to transmit the electrical analog of measured values from a remote point of measurement to a convenient point of display, and many modern telemetry systems use this same principle in industrial measurement and supervisory control applications.

Radiotelemetry was developed in the early 1930's but, exclusive of radiosondes used for transmitting meteorological data,⁽¹⁾ commercial multichannel radiotelemetry systems were not marketed until the late 1940's. One of the first such systems supplied 40 telemetering channels on a microwave radio carrier.

The original meaning of radiotelemetry has widened to include the use of data transmission associated with control as well as measurement. During World War II there was an upsurge in the development and use of radiotelemetry for measurement and control in military operations. The density of data-transmission channels and hardware space limitations were not serious problems at that time and the equipment was fairly bulky.

Activity in the radiotelemetry field accelerated again in the early 1950's due, mainly, to long-range missile developments and outer-space exploration programs. New problems that arose, and were solved to some extent, included: (1) requirements for hardware of minimum weight, (2) high packaging density and high reliability, and (3) optimum utilization of data-transmission channels. Solution of these problems was made easier by the advent of solid-state components and digital techniques of handling information. In addition to the usual measurements of environmental parameters, the space program made necessary the solution of another problem—radiotelemetry of biomedical parameters. Biotelemetry, a branch of biomedical electronics, is now a major field of technology. The National Aeronautics and Space Administration (NASA) has sponsored much of the research to solve these problems by providing grants and aid to universities and industry, and has made the information available through its Technical Utilization Reports⁽²⁾ and other publications.

Other growing areas of science such as oceanography—exemplified by Project Mohole—are making great demands on the technique of telemetry.⁽³⁾ At the same time, industry, aided by technological spinoff from government-sponsored research, is developing and applying telemetry for many new applications.⁽⁴⁾ So great has been the technological activity in modern telemetry for applications in space, oceanographic, biomedical, and industrial systems that the National Telemetering Conference, sponsored by various technical societies and industrial organizations, was organized in 1950 to serve as a forum for discussing and disseminating telemetering technology information. Proceedings of the yearly conferences are a prolific source of information on modern telemetering technology and applications.

No leveling off of the applications for telemetry is foreseen since it is apparent that any further advance in the use of data-acquisition systems and computers in industry and research, and particularly in biomedical systems, will require the capabilities of telemetry. Due to the potential industrial and biological applications of telemetry in the Y-12 Area, it seems appropriate that a thorough investigation and preparation be initiated that will extensively utilize this modern measurement and control technology. This has been the purpose behind the experiments that have been conducted in the areas of biotelemetry and radiotelemetry in industrial machining processes. The experiments began in April 1965 and are continuing at this date.

Use has been made of the electrical and electronics facilities in the Y-12 Area for implementing existing new radiotelemetry technology and some circuits and components have been synthesized into forms that hopefully will prove to be practical additions to telemetry technology. The purpose of this report is to discuss only the technical factors of radiotelemetry in the experiments; significance of the experiments relative to biology or machining is not considered. The Appendix to this report describes in greater detail some unique types of systems that have been devised for these experiments.

A most valuable part of the report may be the list of references cited. Telemetry has grown at such a rapid rate that many potential users are unaware of what is available and is being made available to them. The reference list, although not very exhaustive, will provide a good inroad to the field of telemetry technology.

EXPERIMENTS WITH THE TELEMETRY SYSTEMS

BIOTELEMETRY EXPERIMENTS

Purpose

The first objective in this project was to furnish personnel of the Oak Ridge National Laboratory Biology Division with a few miniature transmitters, powered by conventional mercury cells, that could be implanted in a rat to transmit its temperature without the use of restraining wires. Objectives beyond this stage were to: (1) extend the lifetime of a nonrechargeable cell by switching the cell on and off by external command; (2) recharge cells by radio frequency induction, or power the transmitter by other external means; (3) reduce the size of the transmitter so that it would be practical to implant it in a mouse; (4) adapt the transmitter for measuring other biological parameters; for example, strain, pH, or electrocardiography; (5) consolidate the prototype units into a functional laboratory system.

Description of the Study

A radiotelemetry system requires a radio transmitter, modulated by an analog of the measured value, a receiver, and means of recovering the transmitted information and displaying it in a form convenient for analysis or control. Many standard frequencies and modes of modulation are available for telemetry.^(5, 6) A frequency in the low citizens radio band (27.255 mc) was chosen because it is available for low-power experimentation, and inexpensive commercial radio receivers for this band are readily available. Although continuous-wave frequency modulation (FM/FM) seems to be the most popular mode at present for precise analog telemetering, a pulse-frequency modulation (PFM) mode was chosen because pulse transmission is relatively conservative of transmitter power and considerable experimental background material is available for work with this mode of biomedical telemetry.^(7, 8)

Several miniature transmitters were fabricated, utilizing Mallory RM625 mercury cells for the power supply. These transmitters were potted in medical silastic and run on life tests in a saline solution. As shown in Table 1, the power supply will run a transmitter continuously for more than 150 hours at an average transmitter pulse rate of 139 pulses per second. Only one transmitter failed due to the inleakage of saline solution through the silastic coating and this occurred because the transmitter was not properly coated.

Other experiments⁽⁹⁾ have evaluated the suitability of the silicones and other synthetic materials for biomedical implant material and have found that medical silastic incited less reaction than other materials tested, although leakage through silastic limited the operational lifetime of such high-impedance devices as crystal transducers. Fluid inleakage has not been a problem on devices operating for periods of

Table 1
LIFE TESTS OF SELF-PULSING TRANSMITTER WITH A
MALLORY-TYPE RM625 MERCURY CELL

Day	Time of Checks	Approximate Length of Time (hrs)	Pulses Per Second ⁽¹⁾
1	4:10 pm	8	138
2	9:00 am	25	135
2	4:10 pm	32	136
3			
4			
5	8:30 am	96	132
5	4:00 pm	104	140
6	8:30 am	120	135
7	11:00 am	147	140
8	9:30 am	168	140
9	8:15 am	193	107 ⁽²⁾

(1) Battery was at 1.34 volts at the start, giving 135 pulses per second at 70° F (room temperature).

(2) Battery down to 1.05 volts.

several weeks. Biology personnel have been furnished with samples so that tissue response to the silastic could be evaluated. These samples consisted of small pieces of silastic-coated wire that was cut to various lengths so that sample discrimination by X ray is possible.

Equipment for the transmitter life tests and calibration consisted of a communications receiver, an oscilloscope, an events-per-unit-time (Eput) counter, a hot plate, a beaker containing one-half liter of saline solution, and a mercury-glass thermometer. A diagrammatic representation of the setup is presented in Figure 1.

Figure 1. DIAGRAM OF THE ARRANGEMENT FOR TRANSMITTER LIFE TESTS AND CALIBRATION.

During the transmitter life tests, the AM communications receiver was tuned to the transmitter carrier frequency (~ 27 mc) and the headphone output was fed to the oscilloscope vertical input where received signals triggered the oscilloscope sweep

and was displayed on a time base for pulse amplitude and time measurements. After a time delay in the oscilloscope, the signal triggered the Eput counter where pulses were alternately totalized and displayed for one-second intervals on the numerical display lights. The nominal time between transmitter pulses was approximately seven milliseconds. The delay on the oscilloscope was set to inhibit any signal to the counter that might occur from zero to three milliseconds of time after the previously received signal. This adjustment improved the signal-to-noise ratio in direct proportion to the transmitter pulse frequency rate, verified by running a commutator-type drill motor near the receiver and switching the delay on and off. When the transmitter operated in the center of its calibrated range, about 75 percent of the random noise pulses were eliminated. Top linear temperature range is limited to 105° F when the noise-rejection delay is set to three milliseconds. This delay for random noise rejection was incorporated in the signal-conditioning circuits.

After the life tests were conducted, the power supplies were replaced and the transmitters repotted and calibrated. The calibration process consisted of immersing a transmitter in the saline solution, heating the solution to slowly drive its temperature over a range of 90 to 105° F, and recording the received pulses per second as a function of the temperature, as indicated on the thermometer in the saline solution. Results of the calibration for one transmitter, covering the probable temperature range of a rat, is shown in Figure 2.

A signal-conditioning and noise-rejection unit was fabricated from standard S-PAC^(b) logic modules (Figure 3), consisting of the following PAC's: low-voltage power supply, Schmitt trigger, delay multivibrator/pulse shaper, and an operational amplifier. This circuit provided the triggering, delay, pulse-standardization, and noise-rejection functions that were supplied by the oscilloscope on the previous calibration tests. In addition, the operational amplifier, connected as an integrating circuit, provided a DC output and scaling constant for recording the thermistor temperature. A block diagram of this unit is shown as a part of Figure 4.

The first operational experiment with the biotelemetry system was conducted in February 1966. ORNL Biology personnel implanted a miniature transmitter in a mature white rat. The instrument operated satisfactorily for eleven days before transmission became erratic because of low battery power. The unit had a volume of two cubic centimeters and weighed five grams. Figure 5 presents X-ray reproductions of the implanted transmitter. A diagrammatic representation of the experimental setup is shown in Figure 4. Several modes of temperature indication—loudspeaker, digital counter, digital printer, strip-chart recorder, and analog meter—were used in this first experiment in order to evaluate the advantages and disadvantages of each for the biotelemetry application.

(b) Computer Control Corporation.

Figure 2. TEMPERATURE CALIBRATION CURVE FOR A TYPICAL BIOTELEMETRY TRANSMITTER.

The audio indication does not seem to have much useful application in the pulse frequency range that was used, except for demonstration. The counter display is a most useful device for accurately monitoring temperature changes; however, it has the disadvantage that no permanent record is made. Some counters provide an output for presenting the information to a digital storage system. The digital printer provides a permanent record in discrete units of information, but the form is not suitable for quick analysis by personnel.

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Figure 3. SOME EQUIPMENT USED IN THE PROTOTYPE BIOTELEMETRY SYSTEM.

Like the counter, the printer may be used to furnish information to a data-acquisition system for storage or analysis by a computer. The strip-chart recorder, in conjunction with the analog meter, seems to be the best indicator combination for monitoring by individuals. The recorder provides a permanent record on which inflection points, maximums, minimums, and discontinuities in reference to time and amplitude are readily apparent. Since the charts are usually graduated in some multiple of ten, a scale conversion is required to read the temperature. The analog meter facilitates direct reading of temperature at any instant. A disadvantage of the chart recorder is that noise bursts and other disturbances are retained and sometimes make the chart information appear to be worse than it is. A biotelemetry strip-chart recording, showing daily cyclic variations in temperature of a mature rat, is shown in Figure 6.

Other implants of the first-generation transmitter were made and worked satisfactorily, except for one instance when a circuit opened up during the process of implanting. Second-generation improvements to the transmitter included replacing the Mallory RM625 mercury cell with a Mallory RM312 cell and adding a miniature dry-reed switch to make it possible to switch the transmitter on and off with an external magnetic source. Figure 7 presents a picture of such a miniature transmitter,

Figure 4. PROTOTYPE BIOTELEMETRY SYSTEM.

potted in medical silastic. Shown also are the component parts of the transmitter. The unit is three centimeters long, has a volume of less than one cubic centimeter, and weighs approximately 1.5 grams. Similar units have operated several weeks in biotelemetry experiments.

Although the composite system built of commercial units performed satisfactorily, it was desirable to simplify the total radiotelemetry system, both from a functional and from an equipment standpoint. Therefore, the next experimental efforts were directed toward consolidating the receiving, signal-conditioning, and display units, with emphasis on functional design and equipment economy. As a result, an inexpensive but completely adequate "walkie-talkie" citizens-band receiver of the superregenerative type (Figures 8 and 9) was modified to receive the transmitted pulse and provide an output for signal conditioning. The output stage of the receiver was modified to provide a pulse to the signal conditioner, the whole receiver was shielded, and input-output jacks for a coaxial cable were provided.

Also, the signal-conditioning circuits consisting of a Schmitt trigger, monostable delay, amplifiers, and level controls were fabricated on one 3 by 5-inch printed-circuit board, shown in Figure 10. The signal-conditioner printed-circuit board, its associated power supplies and calibration circuits, and an analog temperature display meter were mounted in the 8 by 8 by 10-inch cabinet shown in Figure 11.

(a) End View

(b) Oblique View

Figure 5. X RAY VIEWS OF IMPLANTED FIVE CUBIC CENTIMETER TRANSMITTER.

Figure 6. A BIOTELEMETRY ANALOG RECORDING OF A RAT'S TEMPERATURE.

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Figure 7. MAGNETICALLY SWITCHED MINIATURE TRANSMITTER.

A biotelemetry experiment, utilizing this type of equipment, was planned by the ORNL Biology personnel and demonstrated at the 17th annual meeting of the Animal Care Panel in September 1966.⁽¹⁰⁾ Transmitters of the magnetic-switching type, implanted in two rats for the demonstration, are still operating satisfactorily at this date. Figure 9 is a picture of the experimental setup, showing a rat (with implant) in his cage, modified "walkie-talkie" receiver with cage slipover-type receiving antenna, signal-conditioner and indicator-meter cabinet, and a strip-chart recorder.

Further refinements in hardware have been made and shop tested. These improvements include the consolidation of the total-receiving, signal-conditioning, indicating, and recording functions into one monitoring station. Three plug-in printed-circuit boards are used—one for the receiver, one for the signal conditioner, and one for the power supplies and associated equipment. Two types of receiver boards are used interchangeably and are identical except for the input stage. One receiver operates in the 27 mc citizens radioband, the other operates in the 88 to 108 mc FM broadcast band. Adjustments are available for receiver tuning over a narrow band

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Figure 8. "WALKIE-TALKIE" RECEIVER BEFORE AND AFTER MODIFICATION.

spread. The unit contains a built-in monitoring station calibrator. Few operator adjustments are necessary.

In addition to the refinements just described, a unique transmitter has been fabricated which is activated by a miniature thermal switch in series with the power supply. The switch is open above 92° F but closes when the temperature drops to 92° F. If this component is implanted in a warm-blooded mammal, a signal from the unit will indicate that the mammal has died. Refinements of this prototype unit may help solve

120443

Figure 9. DEMONSTRATION BIOTELEMETRY SYSTEM.

the problem of recovering deceased specimens from a colony of mice or rats, for example, before the evidence in the experiments is destroyed. The switch is available in either a normally open or normally closed configuration over a wide selection of temperature ranges. Many other possible uses for the device come to mind, such as a high or low-limit temperature monitor for intensive care.

This transmitter weighs approximately 1.5 grams and consists of a tunnel-diode, continuous-wave oscillator. To be of practical use in mouse or rat colonies, its size will need to be further reduced so that it can be implanted by cannula or other fast methods. A picture of the prototype device, not encapsulated, is presented in Figure 12 and a circuit diagram of the device in Figure 13.

MACHINING EXPERIMENTS

Purpose

Success with the biotelemetry systems generated interest toward other in-plant applications of radiotelemetry. On lathe-type machine tools, the heat generated in

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Figure 10. CONSOLIDATED SIGNAL-CONDITIONING CIRCUITRY ON A PRINTED CIRCUIT BOARD.

rotating the spindle causes the spindle to expand or "grow" with the result that a one-to-one error occurs in the workpiece. It is desirable to either eliminate or compensate for this growth in precision machining. The Y-12 Fabrication Systems Development Department undertook a research study of this problem.⁽¹¹⁾ One of the objectives was to plot the spindle temperature just behind the faceplate as the spindle rotates. The biological telemetering system was adapted for this purpose.

Description of the Study

The transmitter for the experiments consisted of a tunnel-diode oscillator, operating in the 88 to 108 mc FM band, that is pulse-frequency modulated by a thermistor-controlled relaxation oscillator. Figure 14 shows some configurations of the transmitter construction and mounting. In each application, the transmitter and power supply (four mercury cells) are mounted in a mechanical adaptor for attaching to the machine. Radio-frequency energy is coupled by a probe from the transmitter tank coil to a circular antenna that rotates with the adaptor. Signals are radiated from this antenna to a concentric stationary antenna not shown in Figure 14.

For checking temperatures in deep holes, the adaptor includes an extender section, shown in Figure 14, to keep the transmitter near the point of measurement. The

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Figure 11. TEMPERATURE MONITORING STATION.

signal is coupled by way of a coaxial cable to a circular antenna at the end of the extender which, in some cases, is several feet long. Batteries for powering are mounted at the accessible end of the adaptor to allow for replacing them without disassembling the test arrangement.

A heat-conducting adhesive^(c) is used to attach the thermistor heat sensor to the surface to be measured. The sensor lead can be unplugged from the adaptor so that the adaptor can be removed for inspecting the measured area without disturbing the adhesive bond.

(c) Dow Corning Silastic 731 RTV.

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Figure 12. THERMALLY SWITCHED MINIATURE TRANSMITTER.

Figure 13. CIRCUIT ARRANGEMENT OF THE THERMALLY SWITCHED MINIATURE TRANSMITTER.

The first experiment with this system to investigate spindle growth was conducted in March 1966. The system consisted of a commercial FM broadcast receiver, a signal-conditioning circuit, and an analog strip-chart recorder for temperature indication. Results of the system operation were very satisfactory.

120449

Figure 14. VARIOUS CONFIGURATIONS OF MINIATURE RADIOTELEMETRY TRANSMITTERS USED IN MACHINING APPLICATIONS.

Several experiments have been conducted since then. A major improvement has been the fabrication of a printed-circuit-board receiver for operating in the 88 to 108 mc band. This component standardizes the receiving, signal-conditioning, and indicating portion of the radiotelemetry system so that the same monitoring station may be used with any transmitter in either the low citizens radio band or the FM broadcast band. By standardizing for economy and convenience of operation, the cost has been reduced to less than \$600 for a complete system, and an excellent quality of telemetered data has been preserved.

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CONCLUSIONS

Biotelemetry is now a reality, ready to be utilized on a large scale for science and medicine. Useful systems can be built from state-of-the-art technology and off-the-shelf electronic hardware.

Some pressing problems remain, such as: a need for production-type transducers, smaller or different type of power supplies, and further miniaturization of implant transmitters. A battery in the form of a thin cylinder would help.

It is expected that integrated circuit techniques, when applied earnestly to these problems, will result in many improvements, from both an operational and a cost standpoint.

Technological spinoff, such as for the machining experiments, is greatly enlarging the field of applications for telemetry, but much of the application is in the laboratory stage. There is beginning to be a need for more standardization of systems available for science and industry.

Some other possible uses for the miniature transmitters are: for sensing hot spots in high-voltage transformer windings and on large rotating electrical equipment; measuring from such high-voltage supplies as linear accelerators; measuring in explosive environments where a potted transmitter would not cause sparks as wired circuits might; measuring stresses in roadways and other locations where wires would be inconvenient; and providing a wireless radio tracer for tracing patterns of flow in liquid or gas systems.

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APPENDIX

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DESCRIPTION OF THE CIRCUITS

TRANSMITTERS

Self-Pulsing, 27-Megacycle Biotelemetry Transmitter

The transmitters used in the biotelemetry systems for transmitting temperatures were self-pulsing blocking oscillators of the modified Hartley type.⁽¹²⁾ Other investigators have used this circuit in a manner that allows the transistor collector-junction resistance to vary the transmitted pulse rate with the junction temperature change. However, in this study a thermistor in parallel with the junction resistance has been used, as suggested by Mackay,⁽¹³⁾ for the variable-leak resistor. This modification allows a better selection of pulse rate versus temperature and, therefore, better sensitivity and temperature-range selection. It also allows more flexibility in placing the sensing element to improve the time response for temperature changes. The circuit diagram is shown in Figure 15, and a pictorial layout in Figure 7.

Figure 15. CIRCUIT ARRANGEMENT OF THE SELF-PULSING BIO-TELEMETRY TRANSMITTER.

Oscillator frequency is determined by the LC constant of the resonant tank, consisting of the antenna coil, L , (Figure 15) parallel with the circuit and coil-distributed capacity, C_d . As the circuit oscillates, positive swings of voltage, coupled to the transistor base through C_1 , cause emitter-to-base current flow. On negative swings of voltage to the base, a charge is trapped on C_1 and begins to leak off through the collector junction and thermistor in parallel. Since the 2N2925 collector-to-base

resistance at cut off is approximately 50 megohms, its effect in the RC time constant can be neglected when paralleled by the 100 K thermistor, so that the time constant is determined by $R_1 C_1$.

If the $R_1 C_1$ time constant is short enough to allow C_1 to discharge during portions of the RF cycle when the transistor base is not being driven positive with respect to the emitter, the net bias on the base of Q_1 will remain proportional to the voltage across the oscillator tank circuit, and continuous oscillation will result. However, when the $R_1 C_1$ time constant is long compared to the LCd period of the tank circuit, the charge on C_1 will increase over a number of RF cycles until Q_1 is biased to cut off and oscillation ceases. During the off time the charge on C_1 leaks down across thermistor R_1 until Q_1 again conducts and transitions from cut off to saturation and oscillation begins again.

As this pulsing continues, the off time depends on the $R_1 C_1$ time constant. The on time, when battery energy is expended, depends on the number of RF cycle excursions into the transistor saturation region required to charge C_1 to the transistor cut off. This action, in turn, is determined mainly by C_1 , with the on time increasing about linearly with the C_1 capacity. Figure 16 presents a simplified representation of the pulsing cycle. The resistance of Thermistor R_1 varies inversely with the temperature; therefore, the pulse-repetition rate varies directly with the thermistor temperature

Figure 16. SELF-PULSING OSCILLATOR WAVE FORMS.

and a count or averaging of pulses per unit of time yields the measured temperature information.

Requirements in the design of the transmitter for biotelemetry are to: (1) furnish the necessary radiated power by using a power supply that is large enough and an efficient circuit, (2) fabricate components in a minimum package, (3) conserve the power-supply energy by using a low pulse rate (high C_1) and narrow pulse width (low C_1), and (4) provide good temperature resolution by utilizing a fast pulse rate (low C_1) and high-resistance thermistor. Because of conflicts in the requirements, trade offs must be made for optimization. Experiments, so far, have required less than a milliwatt of radiated power. C_1 has been selected to work with a standard 100 K thermistor to give a pulse frequency rate of approximately 140 pulses per second at the ambient room temperature. This adjustment allows a counter to resolve about 0.5° F when counting pulses for one second intervals, giving a resolution of better than one percent. More strict attention to the optimization of transmitter performance by manipulating the design parameters will be required as further miniaturization is attempted.

Transmitter components are identified in the circuit diagram of Figure 15. The first switch (SW1) is optional and may be locked on or off by an external magnetic field. The other switch (SW2) is also optional and is a thermally operated miniature switch, available in a normally open or closed configuration. A wide selection of temperature ranges and operating points is available. The switch will activate the transmitter on high or low-temperature limits, and if so used, SW1 would not be used or would only be used for testing. One disadvantage of these miniature thermal switches is that they have a wide make-break differential zone and are, therefore, only useful for sensing in one direction when used in biomedical applications. For one-direction temperature sensing, they are fairly precise. The main advantage of using either SW1 or SW2 is to conserve the transmitter power supply.

Thermally Activated Biotelemetry Transmitter

The purpose of the thermally activated transmitter for biological use is to indicate when a rat has died. This provision is accomplished with a simple continuous-wave oscillator which is switched on by a miniature thermally operated switch when the rat's temperature drops to 92° F. A picture of the prototype unit is shown in Figure 12.

In order to minimize the number and size of the components, a series-type tunnel-diode oscillator (Figure 13) has been used.⁽¹⁴⁾ The frequency of this oscillator will drift some with temperature and voltage. A miniature dry-reed switch has been used without the locking magnet in parallel with the thermal switch so that, if necessary, the transmitter can be periodically switched on and the receiver adjusted to its frequency. The band width of the citizens band receiver that was used for monitoring the unit was broad enough that no problem with frequency drift occurred on the prototype unit.

The transmitter utilizes a 1N3712 tunnel diode, having a peak-point current of one milliamperere for the active element. When the transmitter is switched on, the anode of the 1N3712 is biased at approximately 130 millivolts, putting its quiescent operating point in the negative-conductance region of the characteristic operating curve. This provision allows continuous oscillation at a frequency determined by the negative conductance of the tunnel diode, the parallel resistance combination of R_1 and R_2 , and the LC tank circuit constant. Capacitance, C , consists of the distributed capacity of the circuit and the coil and junction capacity of the tunnel diode. The radiating tank coil, L , consists of 25 turns of Size 39 wire wound on a Plexiglas tube, into which the tunnel diode was fitted.

Pulsed Tunnel-Diode Transmitter

The miniature transmitter used for experiments in machining was a series-type tunnel-diode oscillator pulsed by a unijunction relaxation oscillator. The transmitter operates in the FM broadcast band. The active element of the oscillator is a one-milliamperere tunnel diode (1N3712) powered by a 1.35-volt mercury cell. The relaxation oscillator is controlled by an RC network consisting of Thermistors R_1 and R_2 in parallel, and Capacitor C_1 . The relaxation oscillator frequency modulates the oscillator; however, the bias on the tunnel-diode anode may be set so that the circuit does not oscillate until pulsed by the relaxation oscillator, which then turns the oscillator on and sweeps it through a frequency excursion.

An explanation of the circuit (Figure 17) is as follows: The tunnel-diode oscillator consists of Battery B_1 , Tank Coil L , Tunnel-Diode TD, and Resistors R_4 , R_5 , and R_6 . The frequency of oscillation varies directly with the negative-conductance characteristic of the tunnel diode and can be changed by moving the tunnel-diode operating point to different negative-conductance points on the characteristic curve. This alteration is achieved by adjusting the potentiometer, R_4 .

Normal operation is to leave the circuit oscillating at 101 megacycles between relaxation-oscillator pulses. When a pulse from the relaxation oscillator appears at the anode of the tunnel diode, the increase in bias shifts the operating point to one of less negative conductance, thereby decreasing the frequency. As the pulse from the relaxation oscillator ramps down, the gradual decrease in the tunnel-diode bias gives a frequency excursion of the carrier back to the original quiescent frequency. This frequency excursion is detected as a pulse on either an FM or AM radio receiver. The number of these events per second depends upon the thermistor temperature. Two thermistors are parallel to prevent thermistor self destruction at the higher machine temperatures. The two have a total of 50 K resistance at room temperature.

Operation of the relaxation oscillator is as follows: The thermistors and Capacitor C_1 are across Batteries B_1 and B_2 (about 5 volts). As C_1 charges through the thermistors, the emitter of Q_1 , the unijunction diode, will increase in voltage until it reaches the unijunction breakover or conduction point. At this time, C_1 discharges

Figure 17. CIRCUIT ARRANGEMENT OF A PULSED TUNNEL-DIODE TRANSMITTER.

through R_3 and through the C_2 - R_6 combination. The resulting drop across R_6 provides the oscillator-frequency changing bias. R_3 , C_2 , and R_6 determine the discharge rate of C_1 and, therefore, determine the steepness of the detected FM carrier envelope. C_1 recharges at a rate depending upon the resistance of the thermistors and the cycle is repeated; therefore, the output pulse rate is directly proportional to the thermistor temperature.

This circuit has operated continuously on machines for 168 hours before having the batteries replaced. A switch could be provided for transmitter use on intermittent machining operations.

RECEIVERS

The required radio-transmission range for the experiments was less than three feet, but some trouble in signal reception was encountered due to the directional radiation properties of the miniature transmitter tank coils. The super-regenerative-type receiver worked best to solve the directional problem. A Knight-Kit^(d) C-100 citizens band transceiver was modified for use in the experiments. A functional block diagram of the receiver, indicating the portions modified, is given in Figure 18.

(d) Knight Electronics Corporation Type C-100 Transceiver Kit.

Figure 18. RADIOTELEMETRY RECEIVER.

At the output of the receiver, the audio transformer was disconnected and two additional RC-coupled power stages were added to make a total of three power amplifiers. All three amplifiers were referenced to -6 volts bias, rather than ground, to allow for a greater signal swing. An output jack was provided for feeding the signal to the signal conditioner.

The front end of the receiver was modified to accept the loop antennas used in the experiments. The front end of some receivers was also modified to receive carriers in the FM broadcast band (88 to 108 mc) so that they could be used to receive signals from the pulsed tunnel-diode oscillators used in the machining experiments. The modification consisted of replacing the converter-stage collector inductor (L2) with one of fewer turns (3.3 turns of Size 18 wire) and paralleling the inductor with a trimmer capacitor having a range of 3 to 17 pf. The transmitter portion of the receiver was disconnected. Power for the receiver is furnished by a common power supply that also powers the signal-conditioning circuits.

Audio quality of the receiver would not be good because of the saturation and limiting the amplifier stages, but it works very well for receiving and demodulating the pulsed telemetry carrier. Distance of reliable reception from the miniature transmitters is 25 feet or more.

SIGNAL CONDITIONERS AND INDICATORS

The signal-conditioning circuits consist of standard amplifiers, digital logic circuits, and a commercial operational amplifier. (15, 16) These items were fabricated on a 3 by 5-inch printed-circuit board (Figure 10); a power supply for the unit was fabricated on another printed-circuit board. A circuit diagram of the signal conditioner, temperature indicator, and associated power supplies is shown in Figure 19.

As may be noted from the circuit diagram, signal from the telemetry receiver is fed to an adjustable amplifier where the pulse-amplitude discrimination level is set.

Figure 19. SIGNAL-CONDITIONER AND TEMPERATURE-INDICATOR CIRCUITS.

Signals from the input amplifier are applied to a Schmitt-trigger circuit to standardize the signal amplitude and shape a steep wave front for triggering. The leading edge of the Schmitt-trigger output is differentiated and applied to trigger a monostable delay circuit which passes the pulse to the offset amplifier but will not accept any other pulses until it has reset. This delay feature is used for excluding random noise pulses that fall outside the normal pulse-time period. The offset amplifier operates between limits of -6 volts and some adjustable positive voltage so that the pulse amplitude to the integrator is constant but may be offset for integrator balance and indicator-scale zeroing. A potentiometer in parallel with the integrator-feedback capacitors provides for indicator-scale calibration.

The offset and scale-calibration adjustments are inside the monitor cabinet and not normally available for operator adjustment; a check and range-shifting circuit is provided for use by an operator. In the calibrate mode, a 120-cycle full-wave rectified and unfiltered voltage is fed to the signal conditioner and serves as a standard reference for calibrating. With a calibrated 10-turn potentiometer, meter add constants may be inserted to cover any desired temperature range, as indicated on a transmitter calibration curve (Figure 2).

A zero to 200-microampere full-scale indicator meter is used in the monitor with a jack in series to provide output for a recording microammeter. If it is desired to use a standard 50-millivolt full-scale recorder, a 250-ohm precision resistor would be installed across the jack terminals.

REFERENCES

- (1) MacNichol, E. F., Jr.; "Special Data Transmission Systems", Electronic Time Measurements, Collective Vol 20, pp 408-409; Ed by B. Chance, et al; McGraw-Hill Book Company, Inc, New York (1949).
- (2) "Medical and Biological Applications of Space Telemetry", Technology Utilization Report, NASA SP-5023; National Aeronautics and Space Administration, Washington, DC; July 1965.
- (3) "Telemetry's New Frontier - Oceanography", Proceedings of the National Telemetering Conference (collective papers), pp (4-1-1)-(4-7-7); Los Angeles; June 1964.
- (4) Hoepfner, C. H.; "Industrial Radio Telemetry", IEE Spectrum, 3, pp 89-93; October 1966.
- (5) Marcus, Jean; "Standards for Telemetry", Radio Remote Control and Telemetry and Their Application to Missiles, pp 245-249; Pergamon Press, New York (1966).
- (6) "Modulation", Reference Data for Radio Engineers, Fourth Edition, pp 527-548; Ed by H. P. Westman; American Book-Stratford Press, New York (1949).
- (7) Mackay, S. and Jacobson, Bertil; "Pill Telemeters from Digestive Tract", Electronics, 31, pp 51-53 (1958).
- (8) Lonsdale, E., Dunmire, I., and Brown, S.; "A Transistorized Self-Pulsing Oscillator for Telemetry", Proceedings of the National Telemetering Conference, pp (2-1-1)-(2-1-5); Los Angeles; June 1964.
- (9) Cholvin, N. R.; "Development and Operation of Chronically Implanted Electronic Devices with Their Effects in Experimental Animals", IRE International Convention Record, Part 9, pp 79-87; Institute of Radio Engineers, New York; March 1962.
- (10) Darden, E. B., Jr., Serrano, L. J., and Harris, L. W., Jr.; A Subcutaneous Implant for Telemetering Body Temperature of Small Mammals; Unpublished Paper Presented at the 17th Annual Meeting, Animal Care Panel; Chicago; September 1966.
- (11) Whitten, L. G. and Lewis, T. G.; Machining and Measurement to Submicron Tolerances, Y-KE-204 (Revised); Union Carbide Corporation-Nuclear Division, Y-12 Plant, Oak Ridge, Tennessee; September 8, 1966.

- (12) "Radar Electronic Fundamentals", War Department Technical Manual TM11-456, pp 219-222; June 1944.
- (13) Mackay, R. S.; "Telemetry from within the Body of Animals and Man: Endoradiosondes", Biomedical Telemetry, p 181; Ed by C. A. Caceres; Academic Press, New York (1965).
- (14) "Oscillators", GE Tunnel Diode Manual, First Edition, pp 33-40; General Electric Company, Semiconductor Products Department; Syracuse, New York (1961).
- (15) "Digital Circuits", GE Transistor Manual, Seventh Edition, pp 199-200; Ed by J. F. Cleary, General Electric Company, Semiconductor Products Department; Syracuse, New York (1964).
- (16) "Switching Circuits", Selected Semiconductor Circuits, NAVSHIPS 93484, pp (6-55)-(6-56), pp (6-63)-(6-65); Bureau of Ships, Department of the Navy; Washington (1960).