FINAL

MEDICAL AND BIOLOGICAL APPLICATIONS

OF

SPACE TELEMETRY

PREPARED BY:

Biosciences & Technology
Space & Life Systems Department
Hamilton Standard Division
United Aircraft Corporation
Windsor Locks, Connecticut

Under Contract
NASw 846

For

Office of Technology Utilization
National Aeronautics & Space Administration
Washington, D. C.

SPACE and LIFE SYSTEMS DEPARTMENT

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

MEDICAL AND BIOLOGICAL APPLICATIONS

OF

SPACE TELEMETRY

PREPARED BY:

Biosciences & Technology
Space & Life Systems Department
Hamilton Standard Division
United Aircraft Corporation
Windsor Locks, Connecticut

Under Contract
NASw 846
For

Office of Technology Utilization
National Aeronautics & Space Administration
Washington, D. C.

SPACE and LIFE SYSTEMS DEPARTMENT
Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

MEDICAL AND BIOLOGICAL APPLICATIONS OF SPACE TELEMETRY

CONTENTS

Preface

Biotelemetry -- Derived from three Greek words: bios = life; tele = far off, at a distance; and metron = measure

Biotelemetry is one of many areas in which the National Aeronautics & Space Administration has achieved major technological advances of great potential civilian use. Purpose of this document is to illustrate civilian uses of biotelemetry techniques developed for space applications, and to project and encourage the exploitation of these technological advances in the biological and medical fields.

In preparing this book, the authors have surveyed both the biotelemetry systems developed for or employed in the space effort, and the civilian biomedical applications to which these and related systems would seem to be applicable. This document is directed at the community of practitioners and research workers who may have need for biotelemetry systems but who may be unaware of the technological advances resulting from the space efforts in this field. Accordingly, it is organized with respect to application areas rather than to types of system components. Emphasis is placed on the functional requirements of the application rather than on engineering specification details of equipment developed by NASA.

Chapter one is an introductory chapter devoted to a general description of biotelemetry systems and their uses, and a comparison of space and non-space uses of biotelemetry. The next four chapters are devoted to the following application areas: Intensive Care, Telemetry in Surgery and Anesthesiology, Diagnostic Monitoring in Office Procedure, and Psychophysiological Research. Chapter Six discusses Telemetry Systems, Reduction to Practice with major emphasis on microminiaturization. The summary, chapter Seven, is followed by a glossary of terms, a partial list of suppliers and a selected bibliography.

Although every attempt has been made to describe space-related biotelemetry systems and their possible civilian applications, some omissions and errors have undoubtedly occurred. The list of manufacturers includes all of whom we are aware, but new companies are entering this field at a great rate; hence there is no claim for the completeness of this list.

ACKNOWLEDGMENTS

The United Aircraft Corporation wishes to thank the following individuals and groups for their contributions and assistance in preparing this document.

P.R. Amlinger, M.S.E.E., M.D.
Hamilton Standard Division
United Aircraft Corporation

M. L. Hansen, B.S.E.E.
Hamilton Standard Division
United Aircraft Corporation

D.R. Hitchcock, A.B.
Hamilton Standard Division
United Aircraft Corporation

S. Molnar, M.S.
Biomedical Engineering Consultant
Cambridge, Mass.

B. Robinson, Ph.D.
Stanford Medical School
Palo Alto, California

Sproul & Associates, Inc.
Biomedical Instrumentation Marketing Service
New York, N. Y.

D. Talbot, M.D.
American Medical Research Foundation
& Cox Memorial Institute
Dayton, Ohio

P. M. Wood, M. S.
Hamilton Standard Division
United Aircraft Corporation

Chapter I
Introduction

Biotelemetry, although broad in scope, is concise and clear in intent. It aspires to provide remote monitoring of important biological information. Three units are common to all systems: the transducer for actual measurement, the communication link that overcomes remoteness, and the data reproduction system for presenting the information to an observer. Apparent differences in aeronautic and civilian environments do not prevent applying much of what is learned in the space field to civilian uses.

What is Biotelemetry ?

Telemetry consists of performing measurements at a remote location and reproducing these measurements at some convenient location in a suitable form. The link connecting these locations may be an electrical circuit, a radio, a modulated light beam, a pneumatic or hydraulic line, or any other appropriate device. Telemetry systems may differ with respect to the nature of the measurements made, the distance between the points at which measurements are made and where they are reproduced, the kind of communication link employed, the form in which the measurements are reproduced, and the subsequent use of the data collected. What is characteristic of all telemetry systems is that the measurements are made at one point and reproduced elsewhere, and that there is some communication link connecting the two points. Biotelemetry differs from other telemetry applications only in that the thing which is measured is of biological significance. Most biotelemetry systems are designed to measure properties of a living organism; however, measurements of physical properties of the organism's environment may be of such biological significance as to warrant classifying them as biotelemetry.

Consideration of the definitions of biotelemetry systems reveals that no clear-cut differences between biotelemetry and other biometric devices exist. An EEG machine transmits voltage from the scalp of a subject through leads of several feet to an oscillograph where the measurements are accessible to visual inspecation. Yet this is not termed a biotelemetry system. Contrast this with a thermister inserted in an artery to provide blood temperature data from which blood flow estimates are made. Such a system employes leads as short as those of the EEG machine, but nevertheless is termed a biotelemetry system, since it makes blood temperature and flow information more accessible than other methods do. The decision to call some devices biotelemetry systems and to exclude others is often an arbitrary one. This decision tends to be influenced by considerations of the novelty of the system and the advantages it offers over conventional means of making the same or similar measurements.

D. R. Hitchcock, BS
Hamilton Standard Division
United Aircraft Corporation

Components of Biotelemetry Systems

It is convenient to think of biotelemetry systems as having three primary components: the transducer sensor which performs the measurements; the communication equipment which transmits this information from point of measurement to point of reproduction; and the data reproduction unit which reproduces the data for inspection or analysis. Figure 1 is a diagram of an idealized biotelemetry system.

The transducer, shown attached to the subject's arm, senses the values of the biological parameter and makes these values available for measurement. The term transducer ordinarily denotes a device which transforms energy in one form to energy in another form. Many biological transducers do operate by transforming heat, movement, pressure, etc., into electrical energy where the amount of electrical energy produced is a function of the amount of non-electrical energy present. Exceptions are those so-called transducers which are used to measure bioelectric phenomena. Electrodes used to detect potential differences, for instance, do not transform energy but, together with their associated amplifying equipment, they make it available for measurement. Consequently, they can be thought of as performing a function analogous to that of a sensing device which effects an energy transformation.

The communication equipment in Figure 1 consists of three elements: the data transmission device which receives energy from the transducer and transmits it, the communication link, and the data receiving unit. Most biotelemetry systems employ an electrical communication link, either wired or wireless. The data transmitter usually amplifies and modulates the signal received from the transducer before transmitting it to the data receiving unit. At the receiving unit, the signal is demodulated and often further amplified.

In Figure 1 the telemetered measurements are reproduced on a cathode ray tube, which is one of a large variety of data reproduction units that may be used. Almost any unit which generates a visual display may be used to exhibit the measurements in real time--that is, at the time at which they are received. Oscillographs and typewriters or other printing units that produce ink records provide not only real time visual display of the measurements, but also a permanent record of the data. Sometimes the data are analyzed and certain computed functions of it may be displayed instead of, or in addition to, the signal itself. For example, the signal obtained from a cardiac monitor measures the fluctuating potential obtained from one lead of an EKG, but it can be processed prior to presentation so that rate (beat to beat interval) and acceleration are computed and displayed. Also, the received signal need not be displayed in real time but can be stored on magnetic tape or some other suitable medium for subsequent display or analysis.

In a given biotelemetry system, the elements used to display, analyze and/or store the telemetered data are considered the data reproduction component of that system if there is only one such unit, and the data reproduction subsystem if there are more than one unit.

In surveying biotelemetry systems and their applications, it is convenient to focus on the transducers and the communication systems. These elements are of necessity tailored specifically for biomedical uses. Data reproduction units tend to differ little from those employed in other telemetry and non-telemetry data handling systems and information about them is readily available elsewhere.

Medical Uses of Biotelemetry

Inherent in the notion of telemetry is the concept of transmitting the measurements from an inaccessible location where they are made to a more accessible location where they are reproduced. A common condition of inaccessibility which dictates the use of telemetry involves remoteness of the object to be measured from the point at which the data is to be used, as in telemetry of physiological and performance measurements of astronauts to recording and display units on earth, or the location of tagged migrating birds. Telemetry may be employed also because the measurements must be made in a confined location where there is space only for the measuring unit and a small amount of data transmission equipment. Typical of applications in which the point of measurement is physically inaccessible in this sense are the measurement of pH in the stomach, or of temperature, respiration, cardiac rate, etc., of subjects in a hyperbaric chamber or a whole body pneumograph. A fetus is inaccessible in this same sense.

Desire to isolate patients with contagious diseases and to minimize their contact with hospital attendants result in a kind of inaccessibility. A patient undergoing surgery is inaccessible to the extent that parts of his anatomy are draped, and these coverings cannot be removed during surgery to monitor physiological parameters. Patients in transit from one part of a hospital to another--for example, from surgery to the recovery room--are also inaccessible to conventional means of measuring physiologic parameters. Patients living at home are obviously inaccessible to the hospital staff.

Telemetry systems are sometimes used because they permit more frequent measurements than are economically feasible with the systems they replace. Heart rate measurements cannot economically be performed with great frequency by human attendants in a hospital. Here, although the patient is not literally physically inaccessible to the conventional measurement system--in this case, the human attendant--he can be said to be economically inaccessible because continuous or frequent measurements by conventional means are too costly.

A related set of economic advantages of telemetry deals with accuracy of measurements, the form in which measurements are reproduced, and accuracy of reproduction. Many conventional measurement devices are not very accurate. Usually measurements must be recorded in some permanent form, and the elimination of human transcription errors is a frequently cited advantage of telemetry systems that substitute for human attendants. Use of automatic data reproduction equipment permits recording of data in a wide variety of machine readable media. This means that measurements can economically be made accessible to automatic data storage and analysis devices.

NASA Contributions to Biotelemetry

The requirements of manned space travel have necessitated the development and use of several telemetry devices for monitoring of the physiological and behavioral parameters of astronauts.

During an actual space flight, the capacity of the pilot of the space vehicle to continue the mission and to perform the tasks required of him must be continuously assessed. Thus, during the U.S. Mercury program the body temperature, EKG, and respiration rate of the pilots were sensed and transmitted to the ground monitors. During this program, experiments were also performed on various procedures to measure blood pressure using an automatically inflatable cuff.

The purpose of this monitoring is clear: in the event of the pilot becoming seriously incapacitated, advanced warning of this could be detected on the ground and steps taken to terminate the mission.

There is a second important reason for NASA continued support of the development of biotelemetry devices: that is in the training of candidate astronauts to determine the limits of a man's tolerance to high stress situations. In context, the medical personnel are interested in the modes of change in cardiac function and other essential parameters, while the astronaut performs heavy physical tasks or is subjected to high-G loading.

Changes in cardiac accleration is frequently a parameter of considerable interest in these studies. It is obtained by relatively simple processing of the EKG as the latter is received by the display system.

In the performance of these tests it is imperative that (a) the subject be free of encumbering wires or connections, (b) the measurements be made continuously without interupting the experiment, and (c) the telemetry sensors be sufficiently small so as not to hamper or load the subject unduly.

The requirement that the sensors be small and lightweight, yet rugged, devices has lead NASA to support the development of several types of "integrated" telemetry devices based upon highly sophisticated techniques of circuit fabrication. In a typical integrated EKG transmitter (several of which will be discussed later), the electrodes, power source and signal generating circuits are all packed in a very small space and the whole device can be worn as a "button" attached to the skin.

In general, explanation of the use of telemetry in medical or clinical situations becomes attractive:

1. When a technically feasible system is available
2. The use of such a system either reduces the cost or improves the quality of care of the patient.
3. When the telemetry system permits the collection of new types of information.

The use of cardiac rate monitors, for example, make feasible the monitoring of several post-operative patients at one time. Rather than disturbing the patient at frequent intervals, it is now economically and technically feasible to provide each individual with a superficial device which senses and transmits his EKG to a central station. Once received at the central station, the signal is processed and the heart rate computed. If the heart rate exceeds or falls below present limits, an alarm is triggered to warn the nursing staff. If the rate stays within limits, no action is called for and no data displayed.

This rather simple example exhibits one important fact. The use of this system with its capability of continuously recording data would soon prove abortive were it not for the provision to process the results in some meaningful way. Failure to make such provision would soon lead to the observers being overwhelmed with records too bulky to handle usefully or effectively.

Chapter II
Practical Problems of the Use of Telemetry In Intensive Care Wards

The place of telemetry in intensive care wards is assured. By means of telemetry the status of the acutely ill patient can be constantly monitored and assessed. The introduction of this technology into clinical medicine will force increasing attention to the problems of "processing" the data so that ward personnel are not overwhelmed with the output of the system. The use of telemetry at the Cox Coronary Institute is discussed in this chapter.

Prior to considering any form of telemetry the physician should realize he is entering a field entirely different from medicine. From the operation of a standard EKG machine to the most sophisticated data acquisition system, the physician becomes increasingly dependent upon qualified technical people, upon his own knowledge of highly complex equipment, and upon interpretation and analysis of results of such a system.

With minimum training, the physician can operate the EKG machine, calling upon others only for the maintenance of the equipment. But as the system becomes more complex he must have competent technical assistance in the day to day operation of the equipment. However, he himself must be familiar with such things as frequency response, filtering, artifact, common mode rejection, impedance matching, amplifier gain, calibration and a host of other contributing factors which are alien to his training.

The additional information obtained by any form of telemetry is of value only if the individual is familiar with the contributing factors and limitations of the total system providing the information.

Applications of Telemetry In Intensive Care

Clinical experience in the past few years has demonstrated the need and the usefulness of the "Intensive Care Ward". Such units are predicated upon close observation of the patient and attempts at more frequent measurement of vital physiological, electrical, and biochemical variables. The rationale of such an approach was validated by the surgical recovery rooms, later medical and surgical Intensive Care Wards, and now the advent of Coronary Wards.

Thus, in dealing with intensive care patients, the physician is faced with the problem of monitoring a critically ill person for a short prolonged period of time. If this time increment is but hours, as in surgical recovery rooms, the standard methods of monitoring, such as the B.P. cuff manometer, rectal temperature, and observed respiration and pulse are adequate. However, if the patient requires longer periods

G. Douglas Talbott, M.D.
Director, Cox Coronary Heart Institute

of monitoring, biotelemetry becomes a necessity. It is apparent, that in the past, many of our commonly used measurements on critically ill patients have been of necessity casual and therefore empiric in nature. The rationale for obtaining blood pressure, pulse, respiration, and temperature every four hours is not predicated upon scientific rationale but is a result of tradition and as a convenience to the nursing staff and hospital routines.

Such presently time-sequenced measurements are intolerable, and near continuous or continuous measurements as offered by telemetry are mandatory.

Yet, biotelemetry remains in an infantile stage and is just emerging as a true scientific advance. Impetus to the application in civilian medical life of this field has occurred as a "spin-off" from the space program. Much of the instrumentation needed for the Mercury, Apollo, and Gemini programs has use in civilian medical and paramedical areas.

Telemetry is now beyond the conceptual stage, and although there are many difficulties and many problems yet to be solved, it is obvious that this represents a tool which makes the intensive care ward an ideal environment for the care of the critically ill patient.

An intensive care ward, such as a coronary ward, will of necessity encompass many physiological variables which can be measured and recorded simultaneously. For example the blood pressure, pulse, respiration, temperature, oximeter, and two point electrocardiogram can all be recorded at essentially a continuous rate. Inherent in these continuous measurements are two major problems; methodology and data handling.

Methodology

Blood pressure presents perhaps the most difficult problems of measurement. While it has been obvious to investigators for a long period of time that a telemetric approach to this variable is desirable, no universally satisfactory method has been achieved. The pressure cuff remains the standard form of measurement today. However, there are many new methods being tried. While the interfacing equipment between the transducers and the display units may vary depending on the use of hardwire, telemetry, or the number of variables measured; the sensor or transducer remains the difficult area of development. At the present time, the most promising method appears to be the forced-balance probe which can record a peripheral arterial pulse wave, and permit display of the systolic and diastolic digital waves. However, there are still many drawbacks and problems associated with this method.

The problem of exact placement over the arterial wall presents the major obstacle. Manually holding the probe circumvents some of this problem, but mechanical attachment to the wrist or the ankle is very unsatisfactory because of slippage and impingement on the arterial wall itself. This is true of all of the probe-balance systems which are currently under investigation. The finger plethysmograph represents another approach, but it requires a cycling-occlusive phenomena and involves the drawback of dealing with peripheral circulation. Thus, all of the influences relating to the change of peripheral resistance are brought into the problem. Temperature, position, and the autonomic nervous system may profoundly influence the values of arterial blood pressure displayed. Pulse wave velocity has been advocated as a measure of indirect blood pressure measurement, but there are many investigators who strongly believe that there cannot be an equilibration of blood pressure from this technique. When one considers the five major components that lead to blood pressure measurement (i.e. cardiac output, state of arterial wall, blood viscosity, blood volume, and peripheral resistance), one appreciates that the method of absolute blood pressure measurement utilizing pulse velocity is probably open to further question.

In an intensive care situation though we are still without an ideal telemetric method for the measurement of blood pressure. The probe-balance system, as developed by both General Electric and The DuPont Company, appears to be the most promising.

Respiration is generally measured by two approaches - that of a thermistor and impedence pneumograph. Previously the clinical value of measurement of respiratory rate, rhythm, and volume has been minimal; the use of telemetry should greatly enhance the value of such measurements. The quantitative relationship of respiration to anxiety, severe pain, drugs, or pathological pulmonary involvement such as cardiac failure, embolism, or atelectasis, may well be more closely defined. Effort is being expended to incorporate in a single sensor system, measurements of the electrical activity of the heart and of the respiratory system.

At present, available continuous measurement of body temperature is probably of little clinical value. However, if a continuous quantitative system capable of detecting minute changes in core temperature were available, such measurement might prove to be of much greater clinical value. It has been clearly established that the use of a thermistor to measure skin temperature, does not provide a true reflection of core temperature, but probably does provide a good indication of peripheral circulation and resistance. Patient comfort must also be considered. The rectal probe used in most telemetric systems is as unsatisfactory as the check pouch thermistor in terms of patient comfort. The most promising approach involves an infra-red system for measurement of the ear drum temperature. Animal experimentation has demonstrated that such a device does indeed measure true core temperature. It remains to be established whether core temperature, even if detected in a quantitative manner, will be of help in treating the accutely ill patient.

Of all the variables discussed, the one that has received the most telemetric effort in the past years has been the electrocardiogram. There are numerous systems involved with radio-transmission units, almost all using a two point test system.

Bulkiness, range, and weight have presented the major difficulties in these systems. Recently the United Aircraft Corporation has designed a small transmitter which has a great promise of meeting the above objections. (see picture of United Aircraft transmitter attached)

However, there are still problems; noise interference, limitation of range, and the fact that two point placement of electrodes has not been agreed upon, either in terms of location of the electrodes or the integrity of the signal, when compared with the standard electrocardiogram. The value of continuous electrocardiography during rest, exercise, and while pursuing daily activities, has been clearly established. The addition of monitored tape storage so that the patient can obtain continuous readings while away from the laboratory, bed, or office, and while in pursuit of his daily activities, represents a significant advance. Again, the development of this technique owes its success in a large part to the Space Program, where electrocardiographic tracings of the astronauts while in flight was mandatory.

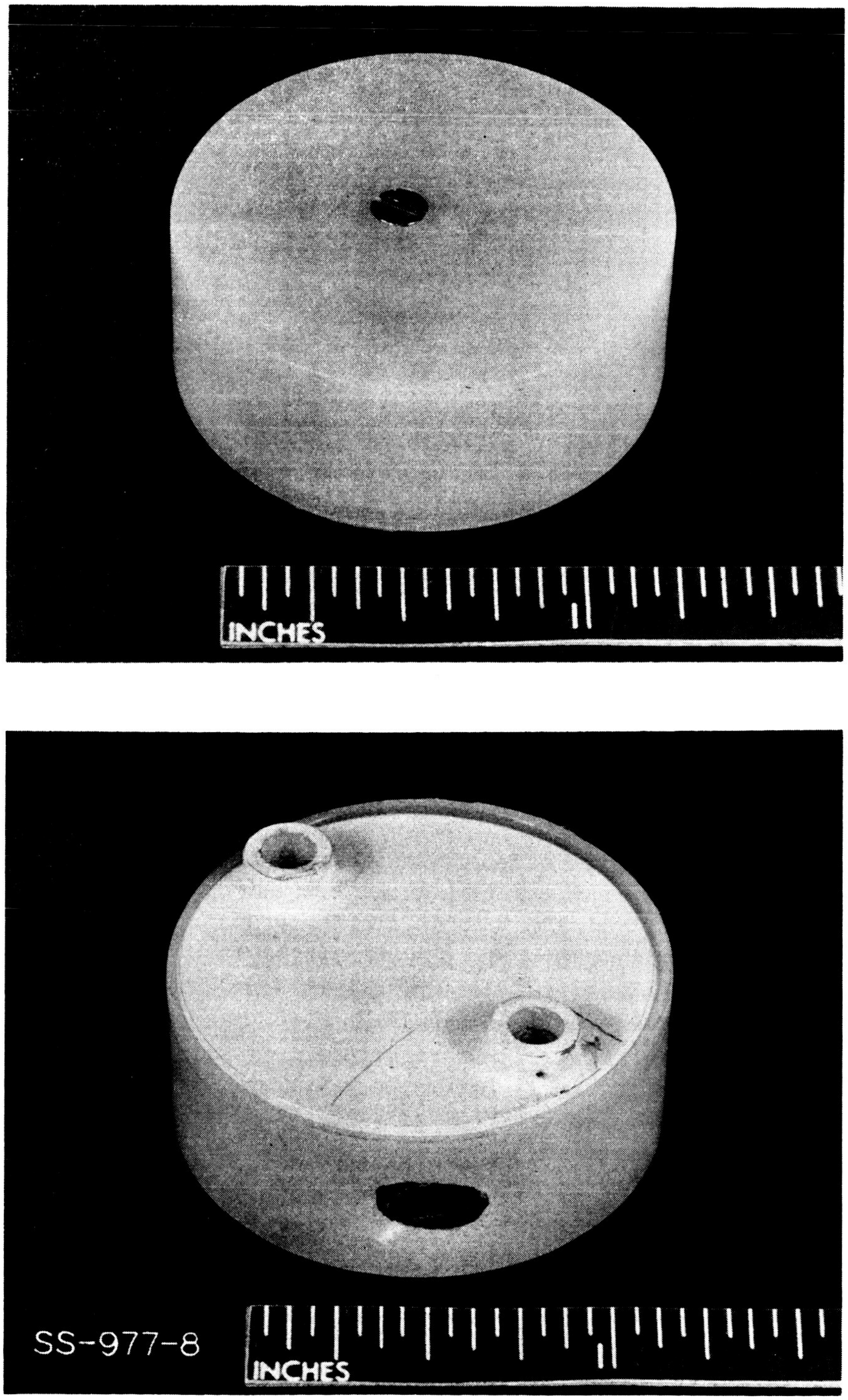
The use of the ear oximeter as a common measurement in an intensive ward has not yet been realized. However, one appreciates the need for such instrumentation, particularly in the cardiovascular patient.

Effort is also being expended toward a method for frequent measurement of cardiac output. This, of necessity, would involve dye methods using computerized equipment for read-outs of the dye concentration and consequent cardiac output rather than radio-active isotopes.

It is apparent from the foregoing discussions, that the ideal is a "bio-pack" whose characteristics would include no hardwire, a complete transmission unit which measures multiple physiological variables. Such a unit should be of light weight, compact, have considerable range, and yet be comfortable for the patient. A start in this ideal concept has been made by the Boeing Company and the Lear-Siegler Corporation which now has a contract from NASA to accomplish this. For an intensive care ward the information thus obtained could be displayed at a central console, where digital displays rather than analog signals would be under monitor control of a computer. Alarm systems, dependent on limits, could then be established. This would not only promote excellence in patient care but would also provide data for research through analytical characterization of given disease entities.

Data Handling

Thus all data handling of a telemetric system in an intensive care ward falls logically into two major categories; that of alarm and that of research concerning the variables measured. The former requires little sophistication beyond the establishment of alarm limits, recognition of false alarm situations, and appreciation of the problems and deficiencies of the measuring system. However, data collection for the purpose of



COMPACT EKG TELEMETRY UNIT

FIGURE 1

research presents major problems. Vast amounts of data are generated, and an intelligent pre-programmed technique of dealing with this data must be established. The need for brevity allows only an outline of how this research data can be handled.

This vast amount of physiological data for research purposes can only be handled effectively by computer techniques. Albeit, projects using computers, both analog, digital, as well as hybrid systems, have been installed in programs to read analogized data initially on physiological variables such as blood pressure, temperature, respiration and electrocardiographic records. It is important to point out that such programming must be performed by data teams composed of analysts with experience in biological data handling and computer programmers working with medical investigators. In successive steps, data processing in terms of a telemetric system in intensive ward, would be varied according to the investigator and the source of such data. However, one workable classification which has proved productive at an intensive care cardiovascular monitoring ward has encompassed six major steps.

1. Acquisition
2. Analysis
3. Symbolization or Mathematical Characterization
4. Correlation and Recognition of Patterns
5. Language Identification and Coding
6. Analysis and synthesis of a Mathematical Model

Repeated attempts at more precise analysis and synthesis are expected eventually and ideally to yield information sufficient to constructing a crude isomorphic analog or mechanical model of the physiological systems under study. Considering these steps in order:

1. Acquisition and data is acquired by telemetric methods of electronic monitoring of physiological variables on a continuous basis. Program is subject to alteration, as optimum intervals for sampling are determined. The band width of periodic variables will be determined by a spectral analysis of the variables and the band width of periodic variables will be determined by calculating the power density spectrums of the variables. These procedures will help determine sample rate for optimum results. The maximum quantification levels of each variable will be established by the sampling criteria.

2. Analysis of data will be accomplished by using mathematical procedures to explore the statistical functions of each of the variables. Proceeding from the simple to the increasingly complex means variances, standards deviations, distributions and probability density functions will be determined. Utilizing a dimensional block which characterized time variable and the individual response, time relationships will be explored in both the time variable and the time individual plane by those methods.

3. Symbolization or mathematical characterization of the variables will evolve what statistical functions are being explored. This evolution will lead toward the construction of a model. Prior to any valid attempts toward the construction of a biological model, a mathematical model must be constructed when varied forcing functions applied to the physiological variables the outputs will, of necessity, be commonly expressed in different terminology. To place in the construction of common denominators and to quantitate response, mathematical formulae theory appreciating the non-linear aspects of the biological systems must be utilized. These formulate in order that equations may be applied by systems to the construction of mathematical models. Lastly, of course, there must be correlation with the biological systems model.

4. Pattern recognition : With the aid of the computer, the mathematical characterization of physiological behavior can be roughly approximated to formulae of mechanical behavior. The foregoing will establish a repeated approximation close enough to constitute pattern recognition, analogization or synthesis of the mathematical model to represent the inner action of the closed loop system. Again, progress is made only by repeated trials. Formula and equations must be devised, compared with known counterparts and discarded or revised before satisfactory approximations can be achieved. The process computer is capable of making such comparisons. Ultimately and ideally the formulae presented in the mathematical model should yield information sufficient for the construction of the mechanical analog for the physiological systems. The differential here between classical clinical monitoring and its standard mathematical testing is used in compliment to classical bio-engineering techniques.

5. Language information: Any systems development program must have a formal information and language system. The language used in cardiovascular fields is informal, stylized and non-quantitative. Such expressions as Austin Flint murmurs, musical murmurs, water hammer pulse, grapefruit size tumors and arrhythmias are an example. While it is true that in the experienced physician these expressions have clinical connotations, their non-quantitative nature prevents precise communication particularly in the inter-disciplinarian sciences as well as the completed application. Therefore, there are two objectives to work toward:

1. To express cardiovascular phenomenon in machine language which is necessarily formal and precise.
2. To quantitate in terms of time and amplitude.

It is felt with such approach the jargon of the cardiovascular world can be more precise and consequently a more universally communicative media.

In summary, the use of telemetry in intensive care wards is assured. Time is the only element not assured, and this in turn is dependent largely upon further development in the mechanical and engineering aspects of the transducers and transmitters as well as the interfacing systems of display and data handling.

BIBLIOGRAPHY FOR TELEMETRY IN INTENSIVE CARE

Bean, M.A., Krahn, F. A., Anderson, B. L., and Hoshida, M.T.

Monitoring patients through electronics. Amer. J. Nursing 63: 65-59, April 1963.

Best, W.R.

The potential role of computers in medical practice, JAMA 182: 994-1000, Dec. 8, 1962

Cacares, C. A., et al

Computer extraction of electrocardiographic parameters, Circulation 25: 356-362, Feb. 1962.

Cacares, C. A.

Electrocardiographic analysis by a computer system. Arch. Intern. Med. 111: 196-202, Feb. 1963

Cacares, C. A.

How can the waveforms of a clinical electrocardiogram be measured automatically by a computer ? IRE Trans Biomed Electronics BME. 9: 21-22, Jan. 1962

Commilli, L., Pozzi, R., and Drago, G.

Remote heart stimulation by radio frequency for permanent rhythm control in the Morgagni-Adams-Stokes syndrome. Surgery 52: 765-776, Nov. 1962.

Farrier, R. M.

Problems of electronic patient-monitoring. Hospitals 37: 50-54, April 1, 1963

Furman, K. I., and Lupu, N.Z.

Cardiac monitoring and telemetering system. J. Appl. Physiol 18: 840-842, July 1963.

Geddes, L. A.

A bibliography of biological telemetry. Amer J. Med Electronics 1: 294-298, Oct-Dec 1962

Gibson, T. C., Thornton, W. E. , Algary, W. P., and Craig, E.

Telecardiographic device. New Eng. J. Med. 267: 1218-1224, 1962.

Hershberg, P.I., Kantrowitz, A., and Kass, E. J.

A postoperative pneumographic monitoring unit. Amer J. Med Electron 2: 207-211, July-Sept. 1963.

Holter, N. J.

New method for heart studies. Science 134: 1214-1220, Oct. 20, 1961

Ledley, R.S., and Lusted, L. B.

Biomedical electronics: potentialities and problems. Science 135: 198-201, Jan. 1961

Lepeschkin, E.

Electrocardiographic Instrumentation. Prog. Cardiov Dis 5: 498-520, March 1963.

McPetrie, J. S.

Telemetry applied to engineering and medicine. Nature (London) 199: 1047-1048, Sept. 14, 1963.

Pipberger, H. V., Stallman, F. W., Yano, K., and Draper, H. W.

Digital computer analysis of the normal and abnormal electrocardiogram. Progr. Cardiov. Dis 5: 378-392, Jan. 1963

Pipberger, H. V.

Use of computers in interpretation of electrocardiograms. Circulat Res 11:555-562, Sept 1962, Part Two.

Rentsch, W.

Electronic device for direct recording of a combined circulation-regulation test in daily practice. Amer J. Med Electron 1: 195-198, July-Sept. 1962.

Rikli, A. E., et al

Computer analysis of electrocardiographic measurements. Circulation 24: 643-649, Sept. 1961

Roach, C. J.

Data management, Clin Pharm Ther 3: 682-684, Sept-Oct. 1962.

Roach, C. J., Eilestad, M. H., and Lake, R. B.

Medical data processing and computer automated hospitals. Datamation, June 1962, pp. 25-28.

Schmitt, O. H.

Application of computers in cardiovascular disease. Circulat Res. 11: 505-514, Sept 1962, Part Two

Schoenfeld, R. L., and Eisenberg, L.

Multifunction instantaneous display counter. IRE Trans Biomed Electronics BME 9: 108-112, April 1962

Thompson, N. P.

Fourier analysis of the electrocardiographic function. Amer J. Med Electron. 1: 299-307, Oct-Dec. 1962

Tolles, W. W.

Telemetry in medical research and patient care. Progr. Cardiov Dis 5: 595-609, May 1963

Ueda, H., Ito, I., and Iio, M.

External measurement of cardiac output using radioisotopes by means of a digital readout device. Amer J. Med Electron 2: 229-238, July-Sept. 1963.

Chapter III
Telemetry in Surgery and Anesthesiology

Something of a dilemma has been created in surgery. Research and advanced techniques now allow operating in many marginal situations previously considered hopeless. In these cases, the surgeon and anesthesiologist are pressed to keep sufficiently informed of the patient's condition. Continuous monitoring and warning signals provided by biotelemetry are of ever increasing assistance. The synthetic environment common to astronautics and surgery may be the key to improved interchange of knowledge between these areas.

The Need for Telemetry in Surgery

Until a few years ago, continuous recording of physiological variables in the operating room was limited to the electroencephalograph and the electrocardiograph. These bioelectric potentials arise normally in the body's systems, and reveal at best, only gross malfunction. More recently, however, obtaining medical data from the surgical patient has been undergoing drastic change. No longer is continuous recording limited to the physiology laboratory and to smoked kymograph drums; electronic oscillographs and elaborate data acquisition and display systems have become standard practice in several surgical procedures and are even found in the wards.

This chapter examines reasons for the change in surgical monitoring techniques, showing the role that technological advancement in non-medical fields has played in bringing about the change. It relates the impact that space technology in particular has had and may have on the methods used to telemeter patient conditions during surgery. To discover some of the advances in surgical and anesthetic practices which may arise from space age technology, the need for improved patient monitoring is outlined and the history of surgical monitoring systems is traced.

It is not necessary here to investigate whether the medical need for new devices led to their invention, or whether existence of novel technology--sensors, circuits, materials or methods--made possible new medical procedures. Not only is a clear-cut answer unlikely, but it would be foolhardy to predict that earlier trends in the transfer of technology from field to field will continue unchanged. The fact is that there have been powerful factors urging progress in medicine and surgery simultaneously with the coming of the space age and a host of engineering advances. It would have been surprising had there been no transfer.

S. Molnar, M. S.
Biomedical Engineering Consultant
Cambridge, Massachusetts

Perhaps the strongest influence for change in surgical practice has come from other medical specialties. Public health and nutrition, pediatrics and geriatrics, immunology and cardiology have all contributed to a profound change in the make-up of the American people. There are more children and many more old people than ever before. Surgeons are now faced with problem patients that even a generation ago may not have lived long enough to be considered for surgical therapy. Despite development of new surgical techniques and anesthetic materials for these patients, they still constitue a poor risk group whose surgical and anesthetic mortality is likely to remain high.

When the "newer surgery", developed in response to the demographic change, is practiced, new surgical-physiological problems arise. Many of these problems need to be solved almost instantaneously in the operating room. Unfortunately, the very operations in which these problems are apt to arise are also the ones in which many of the usual clinical signs of anesthetic depth and patient conditions are confused or obliterated. Hypothermia, muscle relaxants and extra-corporeal circulation are among the new techniques used; each renders meaningless some of the traditional measures of patient welfare. The anesthesiologist, therefore, must rely for his information on data which comes from less accessible places. In short, he needs telemetry.

Anesthesiology has been called "the specialty of emergencies"; for, when a level of light anesthesia is maintained and when adequate pulmonary alveolar ventilation can be provided, the criteria of patient welfare (reflex inhibition, blood pressure, and more rarely, blood oxygenation) are easily measured. In the patient undergoing the new surgery, however, these measures cannot be trusted and a larger number of more subtle physiological parameters must be used. Not all of these readings will be significant all the time. It takes practice and physiological insight to decide when to search for a certain value. If the information is conveniently displayed it will be used--in an emergency. The display to which the anesthesiologist can turn is the data reproduction subsystem associated with telemetry.

From the foregoing it might appear that physiological monitoring is being forced into the operating room, that it would be better for the patient if it were not needed, that it is useful only in extreme cases, and that the doctors would prefer not to have it. This is not so. Probably the most important aspect of operating room telemetry is that it can provide the surgical team with data that simply cannot be obtained in any other way . . . data that is as meaningful in a twenty-minute appendectomy as in a five-hour heart valve repair.

One significant difference between a surgical monitor system and an unaided anesthesiologist is the degree to which the electronic devices pay absolutely unswerving attention to their narrow task. In this sense their value is exactly in their unhumanity--their tirelessness, their singularity of purpose , and their freedom from distraction. Another and more important aspect of telemetry systems in surgery is their good memory--that is, the gathering of data throughout the operation makes it possible to infer the trend in the parameter measured, and to anticipate difficulties before they become acute. Thus, continuous monitoring can remove some of the emergency nature of anesthesiology and increase patient safety.

The monitor's role in surgery can be thus viewed as that of a quiet, patient assistant, but one that is not necessarily stupid. Systems developed over the next few years will probably watch the amount of anesthetic being administered, use their measurements to compute the dosage needed to restore or maintain physiological homeostasis at a given level of anesthesia, and even gently call the attention of the anesthesiologist to the drift of a parameter that would be insignificant were it not, for example, for the patient's particular pattern of childhood disease.

Before leaving the subject of the usefulness of telemetry systems to the surgeon and anesthesiologist, the physical layout and personnel of modern major surgery should be considered. Two extreme examples suffice.

In cardiac surgery using hypothermia, lung bypass and stoppage of the heart, there are several major pieces of equipment besides monitors in the operating room. At a minimum, these are a heat exchanger, a heart-lung machine, an internal-external defibrillator, an electrocautery apparatus, and means of metering and controlling several gas flows. Nearby must be a device for measuring blood loss, an autoclave, a source of suction, oxygen and anesthetic gases, hot and cold water sources, and an instrument and suture cabinet. In addition to this array of devices there are people: the several surgeons, the anesthesiologist, the surgical nurses and the heart-lung machine operator. So far no monitoring.

It would not do, in this case, to have only the anesthesiologist aware of changes in patient condition. He is a busy man and an unnoticed clinical sign may spell failure. Besides, the surgeon may need to alter his protocol depending on the immediate state of the patient. The heart-lung machine operator, during at least part of the procedure, must be kept current on blood pressure, temperature, flow, and oxygenation.

The solution to the problems imposed by the complexity and magnitude of cardiac surgery is to increase the amount of equipment and personnel a little more, but in doing so to provide and disseminate the information needed to consolidate efforts of the surgical team. A monitoring system with suitable displays can give to each person only those facts which he needs; and may, with a well-trained monitor operator, call attention to a seemingly anomalous value.

In proton beam surgery, in which heavy atomic particles are directed at brain defects, there is no scalpel, no blood. Yet monitoring, perhaps even wireless telemetry, is required. Here the patient is usually conscious and immobilized, perhaps lightly medicated, but there is no one in the room with him. The surgical team consists of the neurosurgeons, sometimes a neurologist and a nurse, and the operators of the cyclotron which provides the proton beam. An irradiation may take over an hour. Up-to-date information on the patient's physiological responses can be had only by telemetry. Using telemetry, all concerned persons, no matter how remote from the operating room, can have the immediate facts they need.

Another benefit of surgical monitoring is its place in research. The availability of continuous quantitative data taken during surgery may allow the revision of procedures so that lesser insults are imposed upon the patient's physiology. The deeper the study of physiological feedbacks, the more it is realized that any perturbation of the homeostatic mechanisms will have far-reaching effects. Today, these effects are often unpredictable in detail, but it is thought that continued research can eventually reveal ways in which anesthesia and surgical intervention can be employed more safely.

Growth of Telemetry in Surgery

That surgical monitoring has a heritage going back to industry no one today seems to doubt. Actually tracing the lineage is all but impossible. Within the hospital, the first instance in which a multichannel recorder was rolled down the hall from the research laboratory to the operating room is not recorded; to this day, though, one of the most popular surgical monitor systems is sold interchangeably as a system for phsyiological research. Up to this decade, then, the surgical telemetry system was chiefly distinguished from its identical twin, the research polygraph, by having wheels.

By mid-1960 one important conceptual advance was evident: patient connections were made in the operating room and wired into ducts which led to an adjoining monitor room. There the signals were amplified, processed and returned, via wire, to the displays mounted off the floor of the operating room. This saved space, lessened clutter, required fewer people in the operating room and provided all that was required of a surgical monitor.

More recent advances in surgical monitoring systems, almost without exception, have used circuits and devices borrowed from other fields, principally military and space electronics. In rough order of their introduction to the field, these are seen in the most recent installations:

large-screen oscilloscopes
military-type connectors
servo-control of electrocautery
analog computation
etched-circuitry using transistors
elaborate switching for channel
selection and automatic calibration
digital displays
magnetic tape recording

Perhaps use of wireless telemetry in surgery can be considered a conceptual advance. Its use is justified on the basis of its freedom from electrical interference, lack of clutter, and the fact that the patient's electrocardiogram can be observed continuously from before induction of anesthesia, through surgery, to the return of the patient to his room. It is finding favor among pediatric surgeons.

Employment of wireless telemetry in obstetrics makes possible recordings of combined fetal and maternal electrocardiographs free from electrical interference and free from all but extreme muscle potentials. This is often difficult with conventional wire recorders. The wireless system, built with microvolt sensitivity, uses abdominal electrodes to enhance the fetal signal relative to the maternal. It usually can be used through the delivery, serving as an indicator of fetal distress.

The surgical monitoring field today is analogous to that of scientific magnetic tape recording in 1950. There is great dependence upon the user to invent or discover applications of existing devices and methods. Systems rather than components characterize the technology. Unusually fine liaison must exist between user and manufacturer. As tape recording was then, patient monitoring is now--a new field capable of changing with amazing rapidity and ready for infusion of new ideas. Introduction of surgical telemetry in a hospital cannot be thought of as simply the installation of a new device but rather as the first step in a new technology. Systems of 1964 are, in general, but an experimental phase in a new medical-technical age.

Surgical Telemetry and Space Life Sciences

Engineering techniques and devices now employed in the most up-to-date surgical monitor systems are not new or radical. They have been used for years in the development of airframes, engines and missiles. Most are found in the process industries: chemical plants, petroleum refineries and paper mills. Indeed, their use in these industrial fields is for the same general purpose as in the operating room. They aid in determining the history and status of complex process, and often make predictions and control the process.

For economic and sociologic reasons dealing with dissemination of technology, only recently have some of the simplest devices, common in the process industries, found their way into medical monitoring. Yet it is clear that transfers of technology from engineering to the life sciences is occurring at an increasing rate. It can reasonably be predicted that transfers from life science research and development for space use to non-space applications will be even more rapid.

The analogy between the surgical situation and manned spacecraft can be carried far. The high number of observers per subject has been mentioned as a similarity, but there are other more subtle ones which give clues as to the devices which may be forthcoming from space medicine. Chief difference, alluded to previously, is that astronauts are healthy individuals exposed to a hostile environment, whereas the surgical patient is an ill person in as felicitous surroundings as can be managed.

Both the astronaut and the surgical patient, in general, live in a synthetic atmosphere. If it were possible comfortably and continuously to monitor the constituents of both the inhaled and exhaled gases, much would be known of the pulmonary function of the subject. A device, developed in part at the School of Aerospace Medicine, Brooks Air Force Base, Texas, senses the oxygen content of the gas which surrounds it. This device has been used in face masks, helmets and spacecraft. Similar devices are also available. Monitoring of carbon dioxide and anesthetic gases would be useful.

Although direct measurement of blood pressure is frequently used in surgery, a reliable, accurate, indirect method would often be preferred. This need is consistent with that of the Manned Spacecraft Program, so that developments made under its auspices will find quick acceptance in general medical practice. In the same vein, both space and clinical medicine have need for improved blood flow meters. Knowledge of local blood flow would not only tell the body's response to psychological and physical stress but would also give an indication of vascular lesions and emboli.

Another realm in which space program developments may be of use in surgical telemetry systems deals with displays. Already one form of alarm-limit display developed for the X-15 program is available for hospital use. As time goes on, and as manned lunar landings are more nearly approached, it is not unlikely that methods of processing and displaying physiological data will be developed that are far better than those presently found in surgery.

It may be in the processing of physiological data that the greatest advance will be made. There is presently under way a Space Administration sponsored program* which plans to examine the correlations among a variety of physiological parameters.

* The PIAPACS System being developed by the Lear-Siegler Corporation

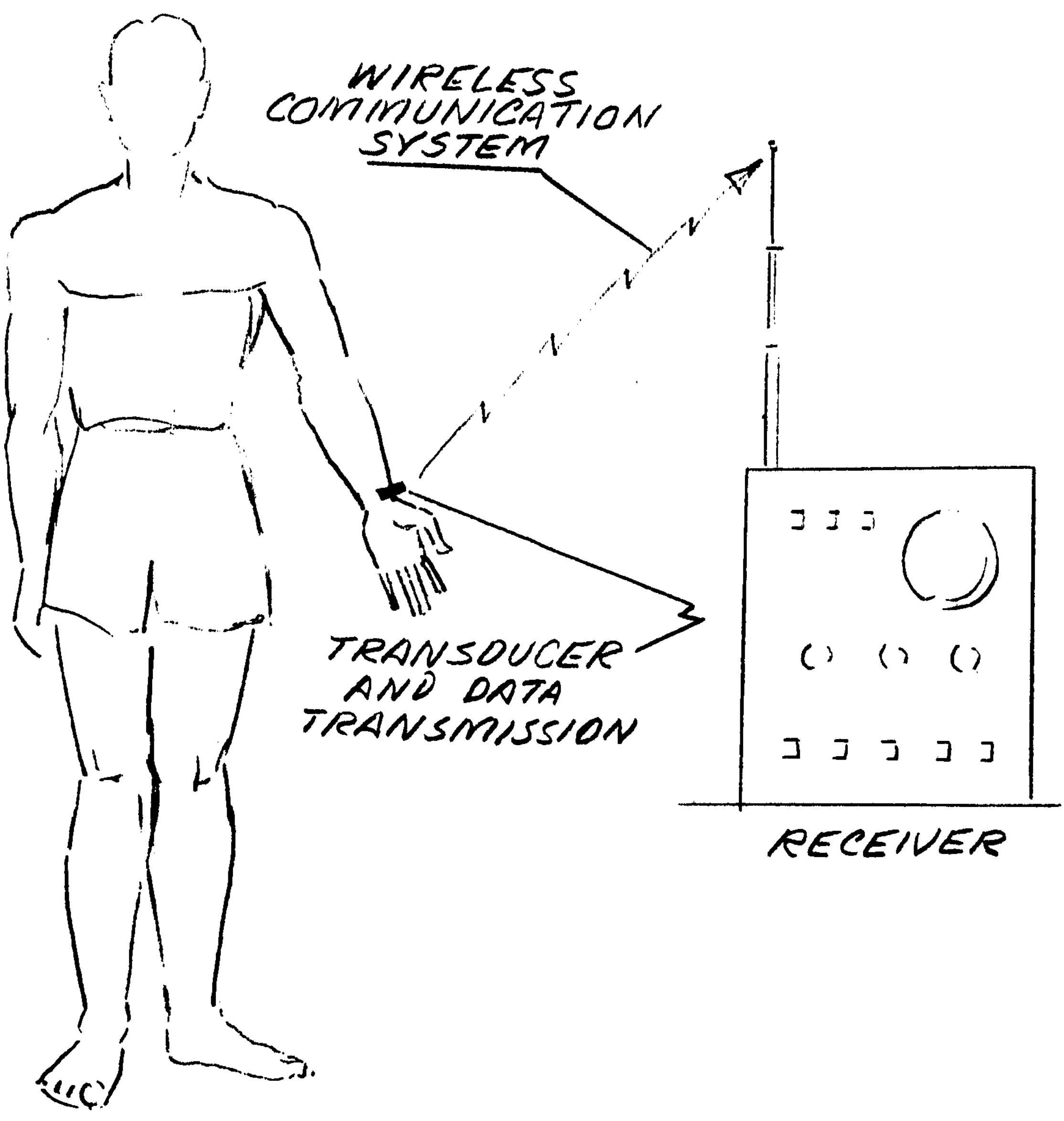


FIG 1 IDEALIZED TELEMETRY SYSTEM

Once these correlations are known, it is thought that a computer can be used to "mix" incoming data so as to provide a composite indication of astronaut condition. This would have the obvious advantage of quick apprehension by earth-based medical personnel and would make remedial action more timely.

One can envision a similar device in a surgical setting. This would make it possible to combine data from diverse sources (the patient's history of allergies, for example, coupled with a currently observed reaction to a drug) and allow further correlations to be made and reported in the event that an incipient alarming condition arises. From here it is but a small step to the automatic and almost instantaneous recognition of syndromes and combinations of syndromes. Such a system can logically seek out the evidence it needs for its appraisal of the situation, issue a timely report on patient condition and, in effect, learn by having its output confirmed or contradicted.

These monitoring computers might even be used in "closed loop" feedback systems that make possible automatic control of anesthesia depth, blood volume and blood pressure; automatic overdose monitors which take account of cumulative effects; and medication recorder-controllers which administer dosages in accordance with elimination rates. All these could serve to free the anesthesiologist for his most significant task-watching the patient and not the machine.

Chapter IV
Diagnostic Monitoring in Office Procedure

Biotelemetry as the electrical transmission of biological data for the preservation of life has been classified according to its functional conditions in monitoring normal life in normal or in abnormal environment, and abnormal life in normal environment. However, such groupings may be overlapping. Although this chapter is concerned mainly with the observation of normal life in office procedures, where the environment can be called normal, it still requires dealing with (usually) normal life under some unusual conditions.

Continuous Monitoring of Basic Parameters

Heart beat and respiration observations are basic, easily available and reliable parameters for the control of life, and therefore are often used to trigger an alarm system indicating danger. In all cases of particular stress they must be observed carefully, and possibly continuously. Until the advent of electronic monitoring systems this had been done manually, often requiring the full time of a person trained in and equipped with valuable skill and many years of experience. Vital functions often change rapidly and unpredictably, and not only in severe cases. Since moments can sometimes decide between life and death, immediate medical action is required. Hence, the observation must be continuous, at least for the critical hours; and the longer it can be continued the more valuable it is. When done manually, this is a waste of nursing talents and money which cries for automatic equipment. However, it should be made clear that the machine cannot replace the human being. It can only support him, taking over routine work and freeing the human being for more intelligent work.

During minor operations in the hospital as well as in the doctor's office, continuous information on the heart's activities is most desirable. Usually in these operations no person is specifically assigned the task of performing the anesthesia and continuously watching the patient. Here, as in severe cases, the heart's electrical potentials provide valuable information. The EKG or ECG has been used for more than half a century as a diagnostic and, recently, a monitoring tool. The changing waveshape is now a familiar picture. Because the heart potentials are not directly accessible, they are picked up at different points on the body. To minimize the differences in waveforms arising from different electrode positioning, a number of standard positions have been agreed upon, such as between left arm and right arm, leg and arm.

A host of books deal with the diagnosis of the EKG, which has become a standard and indispensable tool in the hands of the skilled cardiologist. Since the EKG reflects

P.R. Amlinger MSEE, MD
Hamilton Standard Division
United Aircraft Corporation

primarily the changing heart potentials, it is unsurpassed for the diagnosis of electrical disturbances. It aids tremendously in the diagnosis of many heart disorders of acute and chronic nature. EKG recorders, on the market for many years, are increasing in perfection, ease of handling and even transportation. Perhaps the main reason why the EKG has not found more use as a monitoring instrument is the wiring which runs from the patient to the electronic machine. In most cases this poses severe restrictions on the patient's freedom of movement and on activity of the medical personnel. Hence, the logical solution is a wireless transmitter, miniaturized to reduce inconvenience to the patient--miniature not only in weight and size but also in power consumption for long carefree operation and elimination of electrical hazards.

A basic question is: what is the vital information desired from such an EKG? Momentary changes in the heart rate are the easily and quickly observable indicators of imminent danger. A small transmitter, positioned on the patient's chest close to the heart and self-sustained by a miniature battery will give the needed electrical information, even with electrodes just protruding from the miniature case. The wave-shape need not be directly comparable with one on the standard EKG signal configurations.

What follows is a discussion of the general principles used in such wireless transmission. Keep in mind that part of the biological telemetry using VHF (very high frequency) circuitry is also common to older lead-connected systems.

Biotelemetry Principles

In a telemetry system, signals picked up at two points on the skin must be modified for radio transmission. This is accomplished by a signal conditioner circuit. In this circuit the electrical signal is first amplified to lift it out of the noise level. The inputs have very small signal strength; usually in the millivolt range for heart potentials and in the microvolt range for brain potentials at the scalp. Noise, random electrical activity covering a wide frequency spectrum, can be 60-cycle noise from power lines or muscle noise due to muscle activity, etc. Such noise often mixes with the physiological signal, grossly distorting it. Noise is encountered practically everywhere with the exception of specially shielded locations. For this reason it is standard practice to use a differential amplifier with high common mode rejection in the input stage.

The signal input electrodes are each connected to a separate amplifier stage. These amplifiers are carefully balanced so that they give equal amplification over a wide range of environmental changes. A signal like noise appearing at both inputs (common to both, therefore called common mode) will be the same, though amplified, at both outputs. However, the potential difference seen by the input electrodes due to physiological activity appears as an amplified difference between the outputs.

Differential amplification with high common mode rejection is standard practice in wireless as well as in lead systems. In wireless systems the low frequency biological signal is then used to modulate an oscillator operating at some radio frequency instead of directly driving the signal display device after sufficient amplification. Biological signals are mostly in the range of a fraction of a cycle to several hundred cycles per second.

Modulation is a standard radio technique, and many circuits and different kinds of modulation are in use. Generally, an oscillator generates a sinusoidal carrier frequency wave with constant magnitude and frequency. Frequency is usually in the megacycle range. In AM (Amplitude Modulation), the low frequency signal produced by the slow physiological potential changes is impressed upon the carrier so that the carrier amplitude varies from cycle to cycle with this low frequency. In FM (Frequency Modulation), the carrier amplitude is kept constant and its frequency varies, increasing and decreasing with the changing physiological wave. Particular advantage of FM is low sensitivity to noise and other artifacts superimposed on the modulated carrier in the transmission. There are many good and simple transistor oscillator circuits in use. Most recently, tunnel diodes and oscillators have been attracting attention due to their simplicity, low power requirements, and ease of modulation. A more complex method of modulation is pulse modulation. Here, however, is not the place to deal with systems aspects, carriers and subcarriers, and various modulation and encoding techniques employed in this method.

After modulation, the signal is amplified and transmitted. Detecting the radiated signal is rather simple as it is in no way different in principle from an AM or FM radio signal. Hence, a standard receiver with the appropriate frequency range and detector can be used. For AM, an AM detector is used, with local oscillator, and intermediate and audio frequency amplifiers. In FM, the modulated carrier wave is clipped at the top and bottom to get rid of the superimposed artefacts. The resulting constant amplitude wave is then fed into a discriminator, where the frequency changes are transformed back to the original biological potential changes. The clipping accounts for FM's high freedom from interference and its superiority over AM.

The next important step in the signal processing is the display. This review will not deal with modern computer data handling techniques, such as data reduction, storage, retrieval, analog to digital conversion and evaluation, but will restrict itself to momentary, simple signal evaluation. A simple signal evaluation can use the common cathode-ray oscilloscope for optical display. A pen recorder for conservation of the data or even magnetic tape storage is hardly required in this application. A simple counter with a numerical display of the heart rate, possibly in connection with an optical or acoustical warning system, is sufficient.

Other Measurements

In analogy to the age-old stethoscope, a microphone can be used to pick up the heart's sound and transform it to electrical signals. This signal can then be processed as described above, resulting in a phonocardiogram. In this case, the signal pick-up is called a transducer as distinguished from a sensor for original electrical signals. True fidelity of the heart's sound requires a good low frequency microphone and good overload protection. However, when only the heart rate or its rate of change is required--and this is the dominant factor in our application and in fetal heart monitoring--a very simple system with restricted frequency response will give the necessary information.

Another important parameter is the respiration activity. Several methods are used. Straingages in a band around the chest respond to circumference changes with the respiratory movements. However, these are often inconvenient and the patient may shift to abdominal breathing. Impedance pneumographs use two electrodes positioned on opposite sides of the chest. These electrodes are electrically in the load circuit of an oscillator. They sense the lungs' impedance changes with breathing due to the difference in air volume, and thus modulate the oscillator frequency. A thermistor, whose resistivity changes with temperature, has been placed in the air stream in front of the mouth, with a movable diaphragm to monitor respiration.

Ideally, one would like to use a single transducer for both cardiac as well as respiratory information. There is such a device. Essence of its operation is the change with respiration in the height of the heart's QRS complex, particularly the "R" wave. This is used to monitor respiration rate and possibly respiration volume.

A physiological parameter of great significance is the systolic and diastolic blood pressure. For a century or more, the medical profession has used to great advantage the Riva Rocci method. In this method an inflatable cuff slung around the upper arm is connected to a mercury column. With the changing pressure, an upper and lower value is obtained for the reappearance and disappearance of the arterial pulse sound in the elbow area. Electronic systems have been designed analogous to this mechanical method, requiring the inflation of the occlusion cuff by the patient in certain intervals, or even using an automated system attached to a fingercup. Another method tries to measure blood pressure by slight compression of the vessel, possibly pressed against a bony background. This uses the dislocations of a pressure transducer by the pulse wave instead of the occlusion method. In contrast to such surface transducers are implantable ones, using a partly occlusive cuff slung around the individual blood vessel. These require surgical action and therefore are hardly applicable for office use. A simpler internal transducer is a very tiny pressure type implanted temporarily into the blood vessel like an injection needle.

Changes in the skin's electrical resistance--the Galvanic Skin Response (GSR) --are considered valuable information though obviously too complicated for the use under discussion. Body temperature may be measured in the axilla, or in the rectum. Recently an infrared sensing device positioned close to the eardrum has been proposed. This area follows the temperature changes in the brain's hypothalamus region much more accurately than does a more distant point.

In all applications complexity and cost of the equipment must be weighed carefully against the desired information to allow the most reasonable compromise. In this respect, the heart rate indication is considered the most valuable of all. Second may be respiration rate or blood pressure. Though pressure is a consequence of or at least associated with heart rate changes, it adds vital information about the circulatory system's performance.

Most important in such monitoring systems is the automatic alarm that enables the operating surgeon and other medical personnel to concentrate on their specialized functions. This is the concept of the monitoring system in office procedures. Hence, true fidelity or exact reproduction of the electrical wave shape is not required. This is an extremely important factor in cost reduction.

Further Applications

A simple, but nonetheless vital control and alarm system designed specifically for minor surgery could be a blessing in many other situations, as in dentistry where a timely signal could warn of potentially lethal events, and particularly in pediatric operations, even the most simple ones. Application in fetal heart monitoring in labor, pre- and postnatal, has already been mentioned. In such cases, the electronic control and automatic alarm system would allow the physician to concentrate completely on his primary work, yet give early indication of danger. Such warning may require an interruption of the operation and the immediate administration of life saving medication or other procedures.

Cardiac and possibly respiration monitoring should also play a vital role in emergency wards, particularly when a sudden influx of a large number of patients may cause severe limitations due to a lack of personnel.

Biotelemetry for Diagnosis and Research

A simple, miniaturized and self-sustained cardiac transmitter used for diagnostic purposes could find wide application in individual patient examinations. In spite of the EKG, the old fashioned stethoscope has retained an important role in the auscultation of the heart and lung, and in blood pressure measurements. However, it restricts the medical examination to incomplete, spotty information while the patient is at rest or at some time after an endurance test. A wireless cardiac monitor attached to the patient's chest would give a continuous picture of the heart's changing activity during all phases of stress--information which has been unobtainable so far. Never before has the examining physician been able to watch the changes of the heart's acoustical and electrical activity continuously during physical stress. The superiority of wireless telemetry is here fully evident. Little definite information has been collected concerning the momentary changes in the heart's electrical and mechanical activities and blood pressure during all times of stress. Therefore it is not possible to predict the effect of this additional information with respect to diagnosis, therapy and prophylaxis.

No known, simple, reliable, superficially applied blood pressure monitor has yet been developed. The problem is primarily that of the transducer. Physiological transducers, representing the input stage of all information, may be the most vital and urgent problem in biological measurements. The problem of fidelity begins with the transducer or sensor. The most sophisticated and faithful electronic equipment can only reproduce the picture as it is presented by the transducer at input. Many considerations govern the design and application of a transducer; mechanical considerations like weight or size cause possible interference with physiological activities or inconvenience to the patient, electrical factors like loading effects due to impedance levels and frequency spectrum responses must also be considered.

Additional parameters could be monitored during minor surgery or in similar situations. Items such as the brain's electrical potentials would be of valuable assistance. This review has been limited to the simple, most important, but vital information sources.

Chapter V
Telemetry and Telestimulation in Psychophysiology

The development of miniaturized circuitry, with resulting savings in space and power, has greatly extended the range of applicability of telestimulation to experimental psychophysiology. In wireless telemetry, biological information in the form of electrical signals is transmitted to a receiving unit; in telestimulation, electric stimuli are transmitted by wireless to the central nervous system of animals (primates) carrying small implanted stimulator devices.

The subject is thus able to move freely but is electromagnetically coupled to a source of stimulation which is used to elicit behavioral responses.

Telestimulator systems can be used in conjunction with telemetry devices, so that physiological responses of subjects receiving electric stimulation of the brain can be remotely observed.

In this chapter, three such telestimulator-telemetry systems are discussed. The first of these are the MARK I and II systems developed by the General Electric Company. The third system is under construction by the United Aircraft Corporation with support from NASA.

System characteristics, psychophysiological applications, space applications, and possible medical uses for such systems are discussed in the chapter.

Introduction *

One of the most quietly dramatic developments of the past several decades has been the steadily successful application of technological advances, from whatever discipline, to the enduring problems of brain organization and function. The neurological researcher, like many of the physicists of the past half century, has been fueled by the belief that his area of science is one of truly basic significance,

*Footnote: This discussion is intended for persons not professionally engaged in psychophysiological research. As is customary in such a presentation, documentation of many statements by reference to the literature has been kept to an absolute minimum. The author sincerely hopes no injustice results. The general bibliography appended at the end of the volume will guide the interested reader to the original contributions.

B. Robinson, Ph.d.
Stanford Medical School
Palo Alto, California

in the sense of forming a direct road to man's most fundamental philosophic concerns. Just as a determination of the fine structural organization and function of the atom has long seemed to reward the physical scientist with powerful conceptual tools for grasping much about nature of the universe, and with knowledge not divorced from profound philosophical import, so those research workers concerned with the brain have felt that a final disclosure, a final unraveling of the fine structure and function of the nervous system should yield rewards as rich or richer.

For man's brain is at the root of every fact, every aesthetic judgement, every theory, every emotion. Unless we take the position that the brain of homo sapiens is final and complete--that it transmits data without distortion, stores all the information necessary for a complete understanding of the universe and itself, and generates ideas and concepts without ambiguity or error--we must conclude that the brain in some way limits or transforms the world for us. It follows, therefore, that a greater understanding of the brain is necessary for a more complete and clear understanding of the world.

Understanding a phenomenon, and controlling a phenomenon, are like the two sides of a coin. Without the one, there is seldom the other--they are inseparably related. Brain research is carried out predominantly by people who are motivated by a desire to understand man in the interest of aiding him by medical procedures. Yet, for ethical and other reasons, control of man through an understanding and control of the brain has not been fully considered and discussed by the scientific community, in spite of the fact that the very understanding that is so ardently desired will largely bring with it the ability to control man by the manipulation of his brain.

Immediately, there may spring to the mind of the horrified reader the picture of a malign power reaching into the brains of men and turning them to evil purposes, or at any rate manipulating them toward certain goals. In the broader view, we have seen this come true again and again in the misuse of education and propaganda. Yet there are desirable and acceptable forms of control of humans by each other. To give two illustrations: First, experience has so far indicated that the techniques now possessed for treating mental illness are quite ineffective. The methods are not efficient, are too time consuming, and require too high a doctor-patient ratio. How the mentally ill could benefit from well directed manipulation of their behavior. Second, the advent of the space age with the imminence of space flight and exploration by primates, either human or subhuman, has promised to present qualitatively and quantitatively greater challenges to the adaptive capacities of the exploring organism than it has heretofore faced in its terrestrial environment. Here again, manipulation of specific behavior patterns might be beneficial or even life-saving.

The purpose of this paper is to review, concisely and clearly, the techniques currently available for remote brain stimulation and recording. The emphasis will be consistently on general principles; the reader interested in the details can utilize the bibliography for access to the literature. The possible uses of these techniques will then be discussed. A large part of this discussion is frankly speculative. It is a discussion that projects into the future, for the field is barely new-born. Yet, in an age when the future is barely realized before becoming obsolete, such a projection may have its justification.

Definition

At first glance, the word "teletechniques" seems self-explanatory. Teletechniques are wireless techniques, i.e. the experimenter and his subject are coupled solely by electromagnetic fields. However, there are different degrees of remoteness, different levels of circuit sophistication, different power requirements -- all dependent on the experiment at hand. A teleunit remote enough and otherwise sufficient for one experiment may be unsatisfactory for other.

If such techniques are to rise above the level of laboratory curiosities, they must satisfy stringent requirements. Indeed, the romance of the word "remote" has so intrigued many in the field that all other considerations have often been sacrificed in the design of equipment--with the result that, except for the capacity for remote operation, the equipment offered little usefulness, since it usually lacked flexibility, or reliability, or life span, or some other essential feature. Only within the past several years has it been possible to design telestimulators and recorders which are not only as good as, but in many ways better than, conventional equipment, despite being fully remote in operation. But these are complex matters, and will be discussed below.

For the moment, let us present our objectives clearly, even if by so doing we also reveal our shortcomings. We may take as our definition of "tele-equipment" equipment such that the subject is a function of the experimenter, although the experimenter is not a function of the subject, except as predetermined by experimental conditions. Also, it may be noted that to perfect and employ remote equipment successfully requires an adequate level of competence in the following areas: circuit design, fabrication, antenna coupling, power supply, behavioral localization, behavioral relevance, and surgical implantation techniques.

Circuit Design

It is important to realize the close and often conflicting relationship that exists between adequate circuit sophistication on the one hand and the required limitations of volume, mass and power on the other. What is easy, even trite, in conventional equipment may become a major design problem in the development of tele-equipment, since the necessity to restrict size and power may dictate novel arrangements. At times, conventional circuits, e.g. triggers, pulse generations, amplifiers, output regulators, etc., must be redesigned without benefit of certain components, or with certain components restricted to a narrow and often incovenient range of values.

Basically, what is desired is sophisticated circuitry in a configuration of small mass and small volume. Yet sophistication demands electrical power, and power and mass-volume are usually inversely related. Design strategy, then, becomes a logistic problem, demanding an accurate knowledge of the current state of the art in combination with an overview of what is biologically requisite in the use of tele-equipment. Successful design is thus often a matter of choice between available compromises. These compromises cannot be wisely devised unless a basic policy provides guide-lines by defining the ideal equipment for the projected use.

In the present discussion, we envision the equipment as being used primarily to control and to manipulate the behavior of primates in natural or artificial environments--in situations relating to adaptive, or emotional, or social, or survival-in-space behaviors. It is desirable also to record neural and autonomic variables during such behavior. Above all else, the equipment must operate for long periods of time over great distances. It must be flexible and reliable. It should be inconspicuous--if possible, completely concealed. These design goals cannot be met completely, but a surprising amount of progress has been made toward achieving them. What follows herewith indicates the developments with which the author has been directly concerned. The techniques described are but representative of several of the many approaches that could be taken.

Reference will be made to three telestimulator-telemetry systems. The Mark I and Mark II systems were developed by General Electric Co. in collaboration with the author and other members of the Laboratory of Psychology of the National Institute of Mental Health (1,2). These are telestimulators, fully remotely controlled, and powered by solar cell supply. The unit has so far been attached to the skull of the experimental animal (M. mulatta), but other arrangements are possible. The third system, the U.A.C. system, is under collaborative development by the United Aircraft Corporation, the author, and H.E. Rosvold, and is sponsored by the National Aeronautics and Space Administration (3). It is a highly complex telemetry-telestimulation system, multichannel and fully remotely controlled, and powered by energy radiated from an external source.

Telestimulation

Little new is required in the telestimulator that is not present in a conventional stimulator. A stimulating wave form must be generated. Experience has shown that a rectangular DC pulse is quite suitable for evoking behavioral changes. Second, the pulse must be delivered in a train to the brain; and the parameters of pulse duration, pulse repetition rate, train duration, and pulse current must be variable within usual limits by remote control. Early attempts usually employed a mere triggering of pre-set parameters with perhaps the length of the train remotely controlled (4). Other investigators(5), however, did achieve control of other parameters using transistorized units. In the GE Mark I, only pulse current was manually controlled; in the GE Mark II, a unit powered by solar cells, all parameters of stimulation are remotely controlled.

Two problems of particular importance in telestimulators are the duty cycle and the output regulation. The compactness of the finished circuit restricts heat dissipation; and this, rather than electronic recovery time (as is usually the case), becomes the limiting factor on the duty cycle. Experience has shown that duty cycles of 0.05 - 0.1 are generally adequate. The GE Mark I and II exhibit duty cycles 0.05 at full power and 0.15 at reduced power. Likewise, the U.A.C. unit is being designed to operate at a duty cycle of 0.1 at full power.

Output regulation is, if anything, more important in telestimulation than in conventional stimulation, since there is no way to monitor the current entering the brain accurately except by utilizing a precious telemetry channel, which may not be desirable. Impedances of macro-electrodes may vary greatly, depending on the metal and the amount of current passed. Simple high-impedance outputs cannot be used, since the power supply, whether from batteries or from electromagnetic fields, is necessarily of low voltage, and the voltage available is generally no greater than that needed to supply the greatest specified pulse current through the largest anticipated electrode impedance. For example, to drive 2 ma through a 10 kilohm electrode requires 20 volts. High-impedance output regulation would require approximately 200 volts, an impracticable voltage. Therefore, electronic active regulation with feedback circuits has been employed. Regulation to better than 3% over the entire expected electrode impedance range was obtained on GE Mark I and Mark II, and hopefully will be obtained in the U.A.C. unit.

Thus, there exist or are under development units featuring remotely controlled stimulation parameters, adequate duty cycles, and excellent output regulation. The U.A.C. will provide other features not usual in conventional equipment: biphasic stimulation pulses, bi-electrode simultaneous stimulation from any pair of electrodes, and simultaneous multi-animal stimulation. Remote selection of the electrode to be stimulated has been achieved in two different ways. In the GE Mark II, an ultra-small 14-position electromagnetic stepping relay was developed. This switch is stepped by trigger pulses; positive activation is signalled by utilizing the energy stored in the coil to power a simple fixed frequency telemeter, and to provide an RF pulse back at the operating console. In the UAC unit, channel selection will be accomplished by subcarrier discrimination. The discriminators are crystal-stabilized, as is the transmitter, assuring continuous alignment. This approach has the advantage of avoiding electromechanical devices and their inherent high breakdown rate; it also readily permits the simultaneous activation of any subset of electrodes, thus allowing various drives and behavior patterns to compete and interact with each other, facilitating investigation of mutual enhancement or inhibition. For prolonged experiments, one can switch to a biphasic pulse mode, which reduces electrodes and tissue polarization to a low level and minimizes the likelihood of neural damage.

Thus, with respect to stimulators, all the essential features inherent in quality stimulator design are feasible within the severe size and power restrictions imposed on the design of miniature equipment.

Telemetry

High-gain AC amplifiers suitable for neurophysiological use are now available in quantity. The specifications and design in solid state are well known, and little need be said about them here. The amplifier, whether for telemetry or for conventional use, should operate in the microvolt-millivolt range, with bandwidths of approximately 2 to 2000 cycles per second. This bandwidth is greater, particularly at the high end, than that achieved in electroencephalography where the pen writers limit the high end of the band pass. However, the higher frequencies exist in the subcortical electroencephalogram, and also in unit discharges as recorded through the micro-electrode, and it is important to design amplifiers which will transmit them. In telemetry, the chief problem at the lower end of the band is the physical size of the capacitors needed to pass 2 cycles per second without serious attenuation; at the upper end, the inevitable presence of stray capacitance, if sufficient in magnitude, can shunt the higher frequencies to ground. However, experience so far has indicated that it will readily be possible to achieve the desired bandwidth.

The sensitivity of the amplifier necessitates at least moderate in-phase rejection of undesirable signals. Although external 60-cycle-per-second interference may generally be less troublesome, since the animal and the telemeter are isolated from the receiver, unwanted neural signals arising away from the recording electrode must be suppressed. Approximately 60 db. of in-phase rejection are adequate for this purpose.

Finally, it is essential to decouple the amplifier from the recording electrode by means of a high-input impedance. The impedance of electrodes varies in time, depending on the construction and on surface phenomena; and unless the electrode is coupled to an input impedance much higher than its own impedance, the amplitude of the signal received at the first grid will vary significantly. Input impedances of 1.0 megohm are satisfactory for nearly all telemetry purposes. Even the newer types of metallic extracellular microelectrodes need to possess impedances of no greater than 100 kilohms. Deposited resistors are not suitable for impedances in the megohm range; but by utilizing hybrid fabrication techniques and by incorporating ultra-small formed resistors, input impedances of 1.0 megohm can be obtained without undue waste of weight or volume.

Antenna Design

Antenna design is markedly affected by tele-restrictions. It is not practicable to have rods, helices, or wires projecting from the subject, for these are too vulnerable to damage. One must, then, settle for quite inefficient configurations, and increase the power radiated from the console. Several possible approaches may be taken.

One simple approach is to employ a carrier wavelength of roughly four times the animal's length. The body of the animal may then function as a not-too-inefficient 1/4 wavelength dipole, which is almost non-directional. This arrangement was successfully employed in the GE Mark I and Mark II.

Other approaches include the use of simple loop antennas. The loop may encircle the telemetry-telestimulator package, and should be embedded under a thin layer of radio-translucent material, such as plastic or rubber. However, a loop is directional, and there is always the danger of unreliable reception or transmission of information or power. To solve this problem in the U.A.C. unit (a system concerned both with information and with power), a pair of loops will be employed. The loops will encircle the package along its diagonals, and will be separated by approximately 60°. Together with the double waveguide power radiator, as described below, the system should operate reliably no matter what orientation the animal assumes.

Power Supply

Power supply design is the least developed area of those that are important to tele-equipment; and it is this deficiency more than anything else that prevents widespread use of such equipment. Power must be supplied in adequate amounts at all times. There are two possibilities: either (1) power must be generated at a locus remote from the animal and then radiated to the equipment via an electromagnetic field, or (2) power must be generated somewhere on or in the animal.

Considering the first possibility, power may be radiated from a point source. The density of such a field varies inversely with the square of its distance from the radiating point. This means translational movements of the animal in the direction of radiation will subject the equipment to major fluctuations of power density, with resulting unreliability of operation. This effect can be reduced by restricting such movements so that they comprise a small percentage of the animal's distance from the antenna, but such restrictions are a priori undesirable. Moreover, because of the rapid attenuation of the power field, the method is very wasteful of power and is prohibitively expensive. High powers in the kilocycle or megacycle band must be used; and, in order to avoid interfering with local radio, TV and aircraft navigational signals, the field must either be approved by the FCC or be confined. The former is time-consuming, and has the inherent disadvantage that a field at a density and frequency acceptable in one area near urban airport and TV stations may be unacceptable in other urban areas. Shielding a room suitable for primates is quite expensive: it can amount to $10,000 to $20,000 or more. In addition, the room must be lined with radioabsorbent material to prevent internal reflections, which is again expensive in both dollars and space. In the 200 MC band, for example, this material must be 12" to 24" thick, resulting in a loss of 2' to 4' in each direction. Thus, while the point radiation method can be used, it is expensive, space-consuming, and suited only for short-distance experiments.

An alternative approach is to radiate the field into a wave guide. The wave guide is essentially a duct with parallel sides. Losses of the field to the outside are prevented by internal reflections, and dissipation is prevented by the shape of the duct itself. The difference between this and the point radiator is precisely the difference between a shotgun shell exploding in the gun or out of it. This method is much more efficient than the previous one. Power requirements may be cut by a factor of 10 or more, and the field is automatically shielded from outside interference. Another advantage accrues by radiating half the acquired power at a slightly different frequency down a second wave guide at right angle to the first. This has the effect of filling in the low density areas and producing a multidirectional field. Only the two walls facing into the wave guide need be coated with radio-absorbent material. The major disadvantage of this system, inherent in all systems employing radiated power fields, is the necessity for restricting the animal's territory to the area of intersection of the wave guides. This disadvantage is offset by the large amount of power which is available to energize many channels of telemetry and telestimulation.

The possibility of a more general solution to the power problem lies in generating electric power directly on the animal subject itself. A number of approaches may be considered: thermoelectric generation of electrical energy, utilizing either the gradient normally existing between the animal and its ambient, or by heat produced in a radioactive material; or electromechanical devices capitalizing on the movements of the animal's extremities or viscera, such as heart or diaphragm. These and other approaches were discarded for various theoretical or practical reasons. One approach which appeared possible and practicable was the use of solar cells to extract electrical energy from the power contained in incident room or sunlight. This technique was developed successfully in the GE Mark II. To insure a power source stable against the effects of darkness, shadows, head-turning, etc., energy from the solar cells was stored in recharge nickle-cadmium batteries, which in turn energized the circuits. The limiting factors in this technique are the intensity of the incident light and the horizontal cross-sectional area of the animal's head. Six hundred foot-candles are adequate to energize the stimulator used in the GE Mark II. This level of illumination is brighter than average room lighting, but is considerably less bright than sunlight on a cloudless day. Monkeys adapt to it readily. The horizontal cross-section head area determines the maximum permissible size of the unit and the maximum exposure for the solar cells. The GE Mark II has an area of 20 cm^2 (4 cm x 5 cm) and was designed for the M. mulatta, one of the smaller primates. Use of larger primates in sunlight would be easier rather than more difficult, and thus the method is well adaptable for future exploitation in the study of apes or baboons in the field.

A second possible type of intrinsic power supply is one that extracts energy existing either in chemical form or as trans-membrane potential differences. Attempts to use the latter have been frustrated by the fact that membranes are high-impedance sources which depolarize and collapse suddenly when current is drawn. Another approach is via a fuel cell implanted in some tissue or body cavity. Preliminary calculations based on current parameters suggest there is sufficient glucose and dissolved oxygen in body fluids to generate useable power from a glucose-metabolizing fuel cell implanted, for example, in the peritoneal space. Further investigation is necessary to determine whether or not the fuel cell membrane would be poisoned by body proteins and electrolytes, and whether the end-products of the reaction, which need not be O_2 and CO_2, are toxic to the animal.

Behavioral Localization and Relevance

Forgetting for the moment problems revolving about the design and fabrication of a tele-unit, one may rightly wonder about the types and availability of behaviors which can be evoked by electrical stimulation. Of what use are these marvelous triumphs of technology without something biologically significant to manipulate? In the past several decades, several behavior patterns of fundamental importance in adaptation have been localized in the brain with increasing precision. Ready access to general activation and alerting, sleeping, feeding, drinking, food ejection and vomiting, agression, fear, and sexual patterns may be had by electrodes properly implanted in the forebrain. With intracerebral stimulation it is possible to pre-empt the animal's on-going behavior, and to channel his activities selectively into one or more of these spheres. The importance of telestimulation for guiding behavior, as opposed to the traditional methods of environmental manipulation and the like, lies in the precise control of timing, of selectivity, and of intensity that are possible with electrical stimulation.

In addition to manipulation of specific behavior patterns, it is also possible to manipulate general motivational states, as illustrated by the phenomenon of self-stimulation or that of escape-from-stimulation. The nature and biological meaning of these phenomena are not known. It is not even clear whether or not they are directly related to the behaviors discussed above. In our present context, their chief significance lies in the fact that they can function powerfully as non-specific rewards and punishments. They can be linked to any form of behavior. When properly used, they are very effective in shaping an animal's behavior toward preselected goals. Thus one has a method of evoking familiar adaptive behaviors, e.g. feeding, which might otherwise be inaccessible, or creating and evoking artificial behaviors which are useful in specific contexts. The importance of this will be emphasized below in the discussion of the uses of behavioral manipulation.

Surgical Techniques

Must the tele-equipment always remain outside the integument of the subject, or is there the possibility that it can be completely buried, antennae and all? The answer is that, except for the power supply, micro-fabrication techniques make it entirely feasible to bury completely under the scalp or other skin a fairly elaborate electronics system, including several stimulators and several telemeters. As was pointed out in connection the GE Mark I and II, proper choice of the carrier frequencies involved can make the subject's body function as a not-too-inefficient antenna; and informational transfer, which involves only small amounts of power, would be readily accomplished. If,in addition,power must be transferred, the chances of a practical working system would be quite small. For this reason the major direction of future research should lead toward the development of some type of power supply which can extract energy directly from the animal's body. When this has been accomplished, it will be possible to conceal a complete electronics package under the integument or in a body cavity.

Applications in Space

Of what value would tele-equipment be in the space flight of animals or humans? They would obviously have great usefulness. Proper control of behavior promises faster, more effective, and more extended adaptation of the animal to its environment, whatever that environment might be. First of all, the important behavior patterns of feeding, drinking, alertness, and sleep and rest, can be directly evoked and precisely modulated. Thus, on extended flights, an adequate diet could be assured despite nausea or anorexia caused by tumbling, radiation, or intercurrent illness. Control of the stimulation could be from within the spacecraft, from the ground station, or both. Likewise, sleep could be evoked at any time. The duration could be controlled from the ground station or be pre-set. Excessive fatigue could be prevented and the safety of the spacecraft increased. Should approaching danger be sensed, either by the astronaut, or by the instruments within the craft, or by the ground station tracking the craft, maximal and instantaneous alertness could be evoked. The astronaut or animal could then react to the situation at hand as previously trained.

It is important to note that this behavioral manipulation can be achieved either by activating the appropriate electrodes from the ground station, or alternatively the animal or astronaut could stimulate himself as needed. There is no theoretical reason why this cannot be done, although much research is necessary before the practicability of such self-manipulation is clarified.

Successful adaptation in space may require the animal to learn a number of involved sets of responses to complex challenges by the environment. The variety of behaviors which can be manipulated and controlled can be greatly extended by manipulating the administration of reward or punishment. In this manner, subjects can be motivated to learn complex behavioral sequences efficiently. It would well be that what is learned is normally beyond the usual capacity of the subject. That is to say, there is every reason to think that the adaptive capacity of individuals can be amplified, and also presumably attenuated, by judicious brain stimulation by remotely controlled equipment, since the essential role of reinforcement in the control and manipulation of behavior has been impressively demonstrated.

It is clear from the above discussion that the space program has a valid and pressing interest in the development of telemetry and telestimulation equipment, in the development of fuel cell or other types of power supply, and in the investigations needed to explore fully the potentialities of behavioral manipulation.

Applications in Medical Research

There is a very close relationship between the problem of manipulating the behavior of normal subjects, who are having difficulty adapting to the strange and severe stresses of space flight and exploration, and the problem of manipulating the behavior of individuals who are having difficulty adapting to the stresses of everyday life here on earth. In both cases, there is a discrepancy between the adaptive capacity and the demands made on it. It is highly likely that methods effective in reducing the discrepancy in one situation can prove to be effective in the other.

Teletechniques will aid basic research in the neurological sciences by facilitating brain-behavior studies in many areas. The development of techniques which possess a high degree of precision, sensitivity, and reliability for the control and manipulation of behavior--combined with recent advances in neurophysiological and biochemical techniques, and new concepts of behavior pattern formation and localization at the molecular level--make imminent the solution of a variety of problems related to the biological bases of behavior.

The study of neural changes during the evocation of copulation, feeding, fighting, or other behaviors can supplement to a significant degree our knowledge of neuronal behavior during the performance of complete adaptive behavioral sequences. The neural organization of a behavior pattern as it develops in time can also be investigated. The neurophysiology of social behavior can be studied.

These methods can be used to study a number of situations of the greatest significance for research in mental health. For example:

1. One could study changes in the behavior of a group of primates following manipulation of specific behaviors in selected members. Can one produce at will a stable, orderly group? An unstable one? Can the group as a whole be made to function more efficiently?

2. The influence of the manipulation of specific behaviors in youthful or adolescent monkeys, and the effect on their adult character, temperament, and adaptability could be studied. Does the persistent evoking of certain behaviors (e.g. sexual) result in the development of a certain type of adult character? Is the influence permanent? Is it beneficial? Can one produce whatever type of animal one wishes?

3. Can adult relationships, e.g. dominance, sexual pairing, be influenced temporarily or permanently by appropriate stimulation? Can a subordinate animal be made dominant by the aid of evoked behavior? Can an animal's level of successful functioning in a group be thus improved? Can his adaptive capacity be increased?

4. Will an animal manipulate his own behavior to attain certain ends, e.g. dominance?

5. Will an animal manipulate the behavior of other animals to obtain certain ends (6)? Which is preferred, manipulation of self, or of others? For example, would an animal prefer to achieve dominance by manipulating his own agressivity, or by manipulating the fear in his competitors? To gain sexual privileges with a desired female, what behaviors would be manipulated?

6. Can learning capacity or learning speed be increased by telestimulation?

7. Can the harmful effects of acute and overwhelming stress be mitigated by self-stimulation, as suggested by Lilly (7).

The importance of such studies to problems of human behavior seem clear. A great deal of useful knowledge could be gained which in the future might assist the psychiatrist in indirectly influencing the emotions and environment of a patient toward more complete and more rapid recovery. The dynamics of various social situations could be more precisely elucidated. The effects of reward and punishment in specific situations could be more easily evaluated.

It is even possible that these techniques could some day be applied directly to ill humans in the attempt to improve their lot. If the potential for improvement were demonstrated by prior studies on monkeys or apes, this step might be fully justified in many of the otherwise intractable situations that now frustrate all attempts at therapy. The possibilities are numerous:

1. Aid the mentally retarded and brain damaged (trauma, vascular accidents) by facilitating learning.

2. Rehabilitate the criminally insane by punishing criminal behavior.

3. Counteract depression or overwhelming grief by manipulating reward.

4. Ease the breaking of drug addiction either by supplying reward or by stimulating other behaviors during the withdrawal phase.

5. Improve the clinical status in the psychoses or in some of the more severe neuroses.

The dangers of implanting electrodes and electronic equipment in humans is probably considerably less than might be imagined. Experience with animals indicates that damage is small--much less than in pre-frontral lobotomy or in the surgical approach to Parkinsonism. Infection and hemorrhage are rare complications in animals, where less care is taken than would be in humans. The overall morbidity of the procedure should be acceptably low. In view of the tremendous morbidity from mental retardation and mental illness, and the disability they entail, the inherent risks do not seem prohibitive.

The Concept of Behavioral Prosthesis

The above discussion has suggested the possibility of manipulating and controling behavior in such a way as to replace those behavior patterns which are in some manner inadequate for the demands being made on the organism. This amounts to fabricating a behavioral prosthesis--custom-made for specific individuals and for specific situations. It could be that in such prostheses lies the greatest hope for mitigating some of the medical problems mentioned above, and for maximizing the probability of survival of individuals undertaking prolonged space voyages.

Future Developments

Efforts to improve current telemetry and telestimulation systems should continue and should be expanded. The field is in its infancy. One can confidently anticipate continued advances in miniaturizing electronic systems and in increasing their reliability. The area of greatest need is that of a power source to extract energy directly from the animal's body. Given such a power source, the potential for use of tele-equipment will be maximized, and an extremely powerful technique will exist for controlling behavior.

Benefits of Space Technology for Medical Research

The development of tele-equipment is an area as important to medicine as to astronautics. Here, more than in most cases, it is possible to visualize direct benefits to medical research and thus to the public at large. This happy result arises from the fact that in both fields a concern for the behavior of the humans involved is primary. The use of reliable tele-equipment will aid the space effort, will facilitate basic scientific investigations of neural organization and function, and will offer exciting possibilities of controlling behavior in such a way as to amplify the adaptive capacity of the subjects. For these reasons, the allotment of money to this portion of the space effort is not only a blow for national security and prestige--not only a vote for that romantic something in man's being that thrills to high adventure--but also a sound investment in medical research with potential benefit for all of us.

References

1. Robinson, B.W., Warner, H., and Rosvold, H.E. A head mounted remote-controlled brain stimulator. EEG Journal, In press.

2. The Mark II is currently being tested at the Section on Neuropsychology, National Institute of Mental Health, by H.E. Rosvold, H.W. Warner, and B.W. Robinson.

3. NASA Contract: NASw 542

4. Delgado, J.M.R. A transistor timed stimulator. EEG Journal, 11: 591-593, 1959.

5. Bonazzola, S. and Gualtierotti, T. Wireless tele-stimulation of the cat's motor cortex with constant stimuli. J. Physiol. (Lond.), 150: 1-2, 1959.

6. Delgado, J. M. R. Cerebral heterostimulation in a monkey colony. Science, 141: 161-3, 1963

7. Lilly, John C. The "start" and the "stop" patterns of behavior, in The Reticular Formation of the Brain, ed. H. H. Jasper, Boston, Little, Brown & Co., 1958, pp. 705-721.

Chapter VI

Telemetry Systems -- Reduction to Practice

Biotelemetry is being adopted. There are requirements for measuring more parameters with less patient interference. Equipment designers look to microminiaturization for reduced size, lower power and increased reliability. This new method of designing circuits will lead to better devices. But with each improvement will come the demand for still better units.

Microminiaturization of Biotelemetry Systems

The area of reduction to practice is one where space and civilian medical sciences are closely aligned. Bioastronautics is concerned primarily with a normal subject in an abnormal environment or under uncommon stress, while in conventional medicine the reverse is usually true. Nonetheless, the need for monitoring additional physiological parameters is increasing -- as is the need for less subject interference. Any cursory study makes it apparent that in space flight and in the outpatient situation or in surgery, it is most desirable to sense and display all the critical physiological parameters and yet leave the subject as free from encumbrances as possible. To achieve the goal of unrestricted movement of the subject, radio telemetry systems, in which the physiological intelligence is transmitted by wireless from the subject to an appropriate receiver, may well constitute an optimum choice. In application, this situation spotlights the problems of sensors, transducers, signal conditioners, transmitters and particularly power sources. These must all be reduced in bulk, weight and ease of application. Microminiaturization of circuits provides an avenue by which the bulk and weight of the system can be reduced. Systems designed to sense biopotentials will still require leads to pick up the signal, and the size of these leads will tend to set an inherent limit on the size reduction accompanying microminiaturization. The distance between electrodes and electrode geometry will, within limits, control the magnitude of the sensed potential which tends to set a bound on the degree of practical size reduction.

Micromodules

In microelectronics, major emphasis was originally on use of high-density packaging of discrete miniature components. Vacuum tubes were excluded, even the most modern miniature versions being giants compared to the transistor. The increase in number of components-per-unit-volume, resulting in reduced size and weight, led to more sophisticated packaging

P. R. Amlinger, MSEE, M. D.
M. L. Hanson, BSEE

arrangements called micromodules. The reliability of micromodular system vis-a-vis more conventional implementation, is generally satisfactory with the number of components used in a typical telemetry system.

Planar Techniques

New semiconductor techniques, and particularly the new planar techniques, led to integrated circuitry, functional electronic blocks and integral electronics. Concurrent with improvements in diffusion techniques -- the doping of a semiconductor wafer with impurities in a controlled atmosphere -- came surface passivation -- protection of semiconductor surfaces with an isolating envelope of silicon dioxide.

In the diffusion process, the semiconductor wafers are heated by high-frequency induction to about 1200° C. Impurities of the desired type, either negative or positive, are introduced in a gaseous atmosphere and are driven into the wafer. Doping levels, or penetration depth, and impurity concentration gradient are tightly controlled to fractions of microns. Replacement of the gaseous impurity by oxygen results in an isolating surface layer of silicon dioxide, completely encapsulating the silicon wafer.

After slicing and polishing to a thickness of a few mils, the semiconductor wafer is oxide coated. Next step in transistor processing is to remove the oxide at desired areas to open windows for selective diffusion. This is done by photolithography and etching techniques. For each diffusion, photographic masks are designed and placed on the wafer. Each mask exposes different areas of a photoresist surface cover to ultraviolet light. These areas and the underlying oxide are removed by etching. Active areas of the transistor (collector, base and emitter) are formed sequentially by diffusion of the desired polarity impurities through the particular windows.

Two key points in the planar process are:

1. As the diffusion penetrates vertically into the wafer surface it also spreads horizontally parallel to the surface, pushing the transition from one polarity to the other.

2. At the end of each diffusion a new oxide layer is grown over the wafer surface. This protects the previously exposed areas against the penetration of the diffusant in the next diffusion, except at the new window openings. Each different geometry requires a different mask for the new area in the sequence of different (polarity) diffusions. This is illustrated in Figure 1.

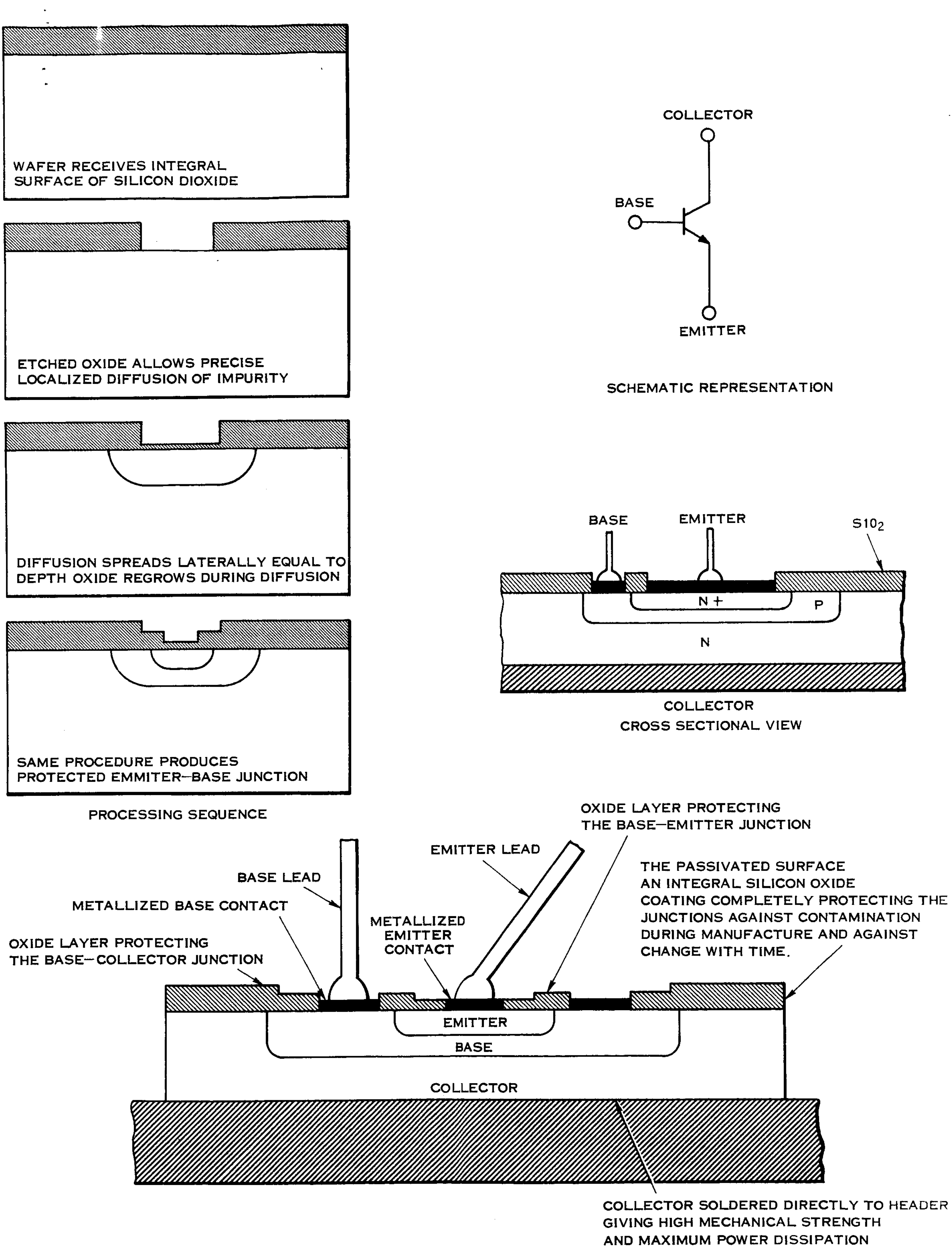


FIGURE 1 PLANAR PASSIVATED TRANSISTOR

With the last mask, windows are opened in the oxide surface layer for contact areas which are filled with metal by a vacuum deposition and alloying process. Metallic intraconnections running over the protecting oxide are formed simultaneously.

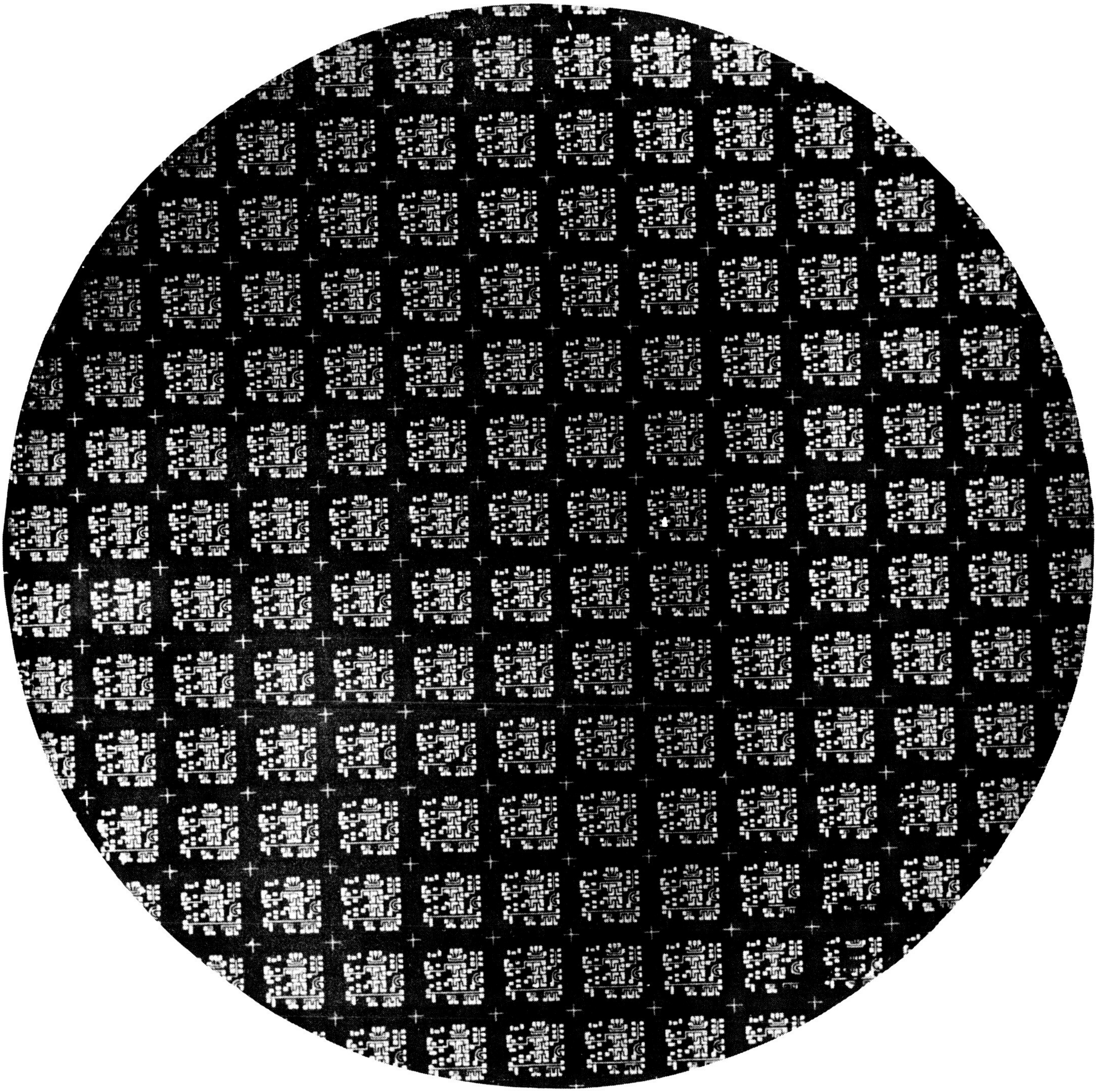
Figure 1 shows that in the planar process the transistor base is not only sandwiched between collector and emitter but is surrounded by the collector. The emitter is surrounded by the base except at the surface which is covered by the oxide layer. Major benefits of the planar process are: reduction of surface leakage, increased reliability and, because all the active areas reach the surface plane where contacts are made, a versatility of configurations unknown before.

In the oxide surface layer of a silicon wafer of one-inch diameter, hundreds of tiny windows can be etched simultaneously by high resolution photolithography that uses photographic masks with repetitive rows and columns of windows. After the wafer has been coated with a photoresist material, the multiple mask is laid upon the wafer. Ultraviolet light penetrating the openings renders the underlying area insoluble to the etch that follows. This etch selectively removes the photoresist and the oxide at desired areas. In the following diffusion the gaseous impurity enters the semi-conductor substrate only at areas determined by mask design.

Block geometrics with areas of a few tenths of a mil width require photographic equipment of high resolution and accuracy in the reduction of the orignal masks, which are about 100 times enlarged. In the step-and-repeat photographic process used to produce multiple masks with rows and columns of identical windows, as well as in application of the different masks in the sequential exposure and etching processes, all windows must fit exactly into the next ones. Several hundred transistors can be produced in one semiconductor wafer (Figure 2), and a number of wafers can be processed in one diffusion furnace. Thus, thousands of transistors are manufactured simultaneously. The result is increased uniformity and considerable reduction in cost compared with the individual growth of sequential layers by alloying processes.

After the metallization of contact areas (and intraconnections), the wafer is diced into tiny semiconductor chips, each containing one transisistor. These chips are mounted on a header, bonded and the enclosure sealed.

This discussion has considered processing of transistors only, and has stressed the geometrical configuration because it was the change in geometry which led to recent developments. Electronic circuits often require multiple inputs and/or outputs in one transistor, parallel or series arrangement of diodes, and many other configurations. All these previously required individual components. With the new technique, however, a great variety of such functional elements can be easily included in the basic



MULTIPLE MASK: WAFER ~ 0.8 inch (diameter)

FIGURE 2

geometry of an individual chip. Figure 3 shows how a multiple-emitter transistor is made by simply enlarging the base (and collector) area and diffusing several emitter areas into it. To achieve higher input impedance, a Darlington configuration, as shown in Figure 4, can be used to replace two separate transistors. This is accomplished in one unit by a simple change in the mask design: diffusing two bases in the same collector area, one emitter in each base, and running an interconnecting metal strip over the oxide from base No. 2 to emitter No. 1. An important by-product of this configuration is the reduction of outside connections.

The great versatility of this approach leads to new circuit configurations and has other vital consequences. Several individual components, transistors and diodes are replaced by one functional unit just by changes in the geometrical layout. The result is simplification of processing, reduction in soldering, and, most important, an increase in reliability by eliminating outside interconnections. In addition, intra-connections -- those connections running over the oxide layer from one contact area to another -- are vacuum deposited together with the contacts in one process. Resulting reduction of cost and increased reliability can be considered a real technical breakthrough.

This technical breakthrough represents a significant advancement in semiconductor technology. A clear picture of how integrated circuits came about can be seen by understanding the basic properties of semiconductors and tracing the evaluation of semiconductor products from diodes, through transistors, to integrated circuits.

Semiconductor Properties

A semiconductor, with respect to conductivity, stands between conductors and insulators--good conductors having high conductivity, and insulators displaying low conductivity. Metals like copper, silver, gold and aluminum are good conductors. In conductors the electrons can move around freely. The directed flow of these electrical charges is current. Pure (intrinsic) semiconductors are poor conductors; however, their conductivity can be increased many times and controlled by adding impurities, atoms of another element. Silicon and germanium have their atoms arranged in a regular crystal lattice pattern--both have four valence electrons in their outer orbit. These electrons are stable at room temperature. However, if small amounts of an impurity element with 5 valence electrons are added, the result is a surplus of electrons which can move around in the semiconductor lattice, thus increasing the conductivity of the parent material. Adding impurities with 3 valence electrons leaves a deficiency of electrons, called holes, which can move around in the crystal lattice as "negative" electrons or positive charges. This type of (hole) conductivity does not exist in metals.

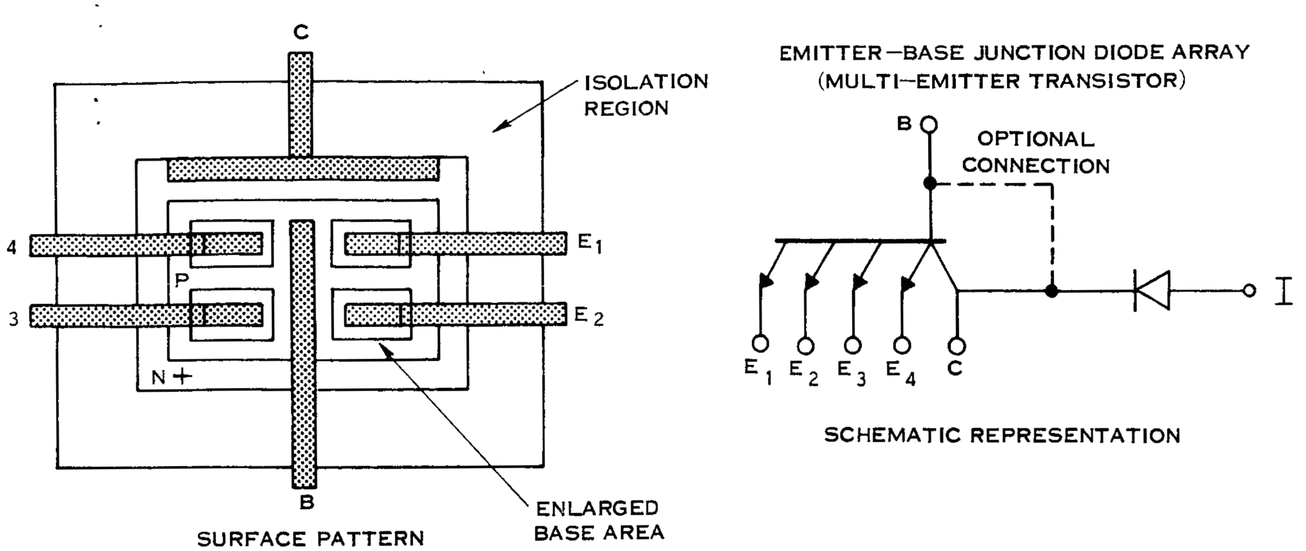


FIGURE 3 4—EMITTER NPN—TRANSISTOR

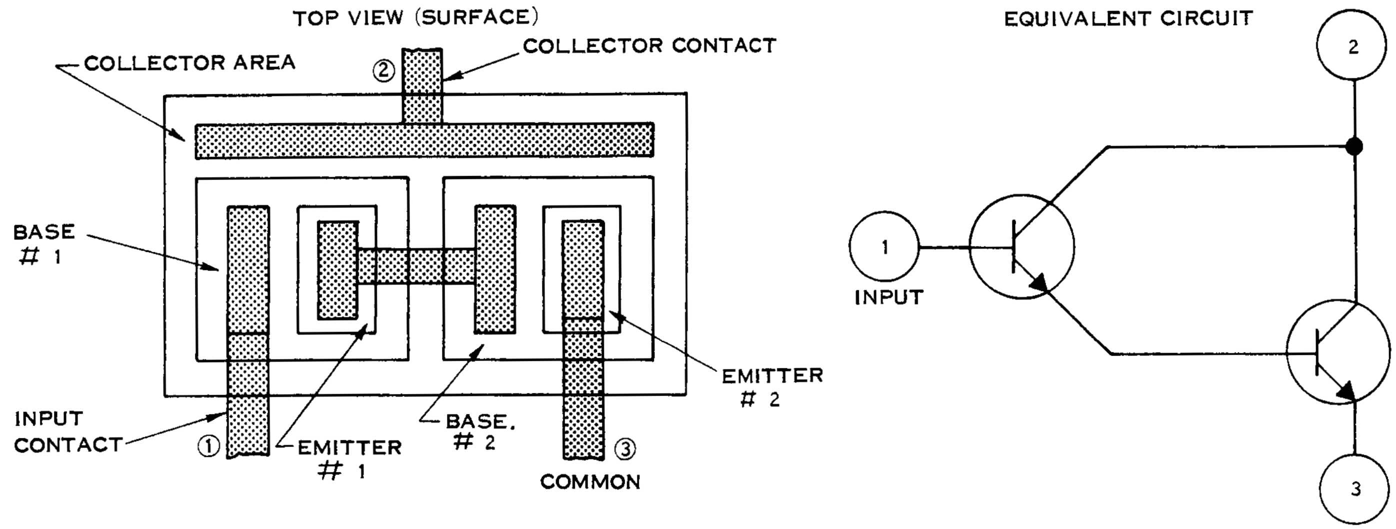
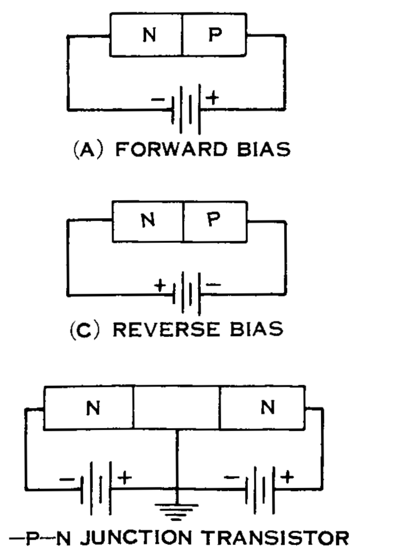


FIGURE 4 DARLINGTON CONFIGURATION



GURE 5 BIAS OF P—N JUNCTIONS

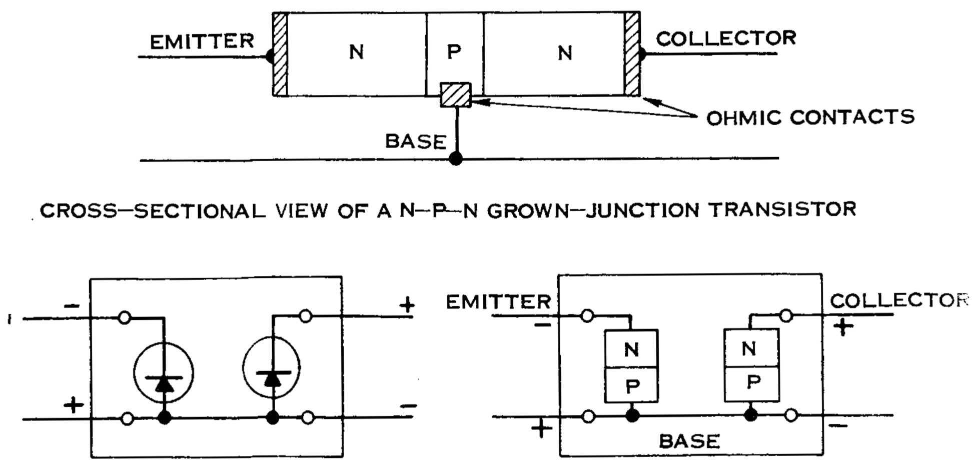


FIGURE 6
REPRESENTATION OF A TRANSISTOR AS A COMBINATION OF TWO DIODES

When silicon is doped with phosphorus, which is a V-element (5 valence electrons), electrons are the majority carriers, and this semiconductor is the N-type. However, when silicon is doped with boron, a III-element (3 valence electrons), the conductivity is due to the movement of holes as the majority carriers, and this semiconductor is now of the P-type. Even if the impurity concentration is very small, say about 1 impurity atom per 1 million atoms of the parent material, the conductivity is greatly increased.

Joining two semiconductors of opposite conductivity results in a semiconductor diode. The interface, that is the transition from one polarity to the other, is the P-N junction. By connecting the P-side (the anode) to the positive pole of a battery and the N-side (the cathode) to the negative pole, current flows easily. This connection is known as the forward biased condition. Reversing the polarity, P-side to negative pole and N-side to positive pole, produces reverse bias of the diode, resulting in a blocking of current as long as the applied voltage doesn't exceed the diode's breakdown voltage (see Figure 5). If the polarity the diode sees is reversed periodically, as with the standard 60 cycle alternating current used in homes, it will alternately conduct and block current, producing a DC voltage.

A transistor is two diodes in series, the emitter-base diode and the base-collector diode arranged back-to-back (Figure 6). In an NPN transistor the emitter is N-type, and the base P-type in series with the N-type collector. When a DC voltage is applied between collector and emitter, one of the two series diodes is forward biased, displaying low resistance to the flow of current due to the potential difference, and the other one is reverse biased, displaying high resistance. If the base is forward biased (for an NPN transistor made slightly positive with respect to the N-type emitter), then electrons are injected into the P-type base, electron current crosses the emitter-base junction, and a few holes are injected in opposite direction from the P-base into the N-emitter. The electron current crossing the base will be collected in the collector. Note that the base-collector diode is reverse biased.

In an NPN transistor the collector is N-type, with electrons being the majority carriers, and it is connected to the positive potential side. The P-type base, with holes as majority carriers, is connected to a lower potential point, negative with respect to the collector (though positive with respect to the emitter). The effect is that the free electrons in the collector are attracted by the battery's positive pole and are removed from the junction. Similarly, the free holes in the base are also attracted away from the reverse biased collector-base junction by the more negative potential so that no current will flow across it except the one from outside -- that is, the electrons injected from the emitter into the base as mentioned before. During the transport across the base, a small percentage of the electron current gets lost, and this loss (in gain) must be replaced through the base lead. Figures 7 and 8 show some of the construction details of the multiple-collector and planar transistors.

As mentioned before, the base vs. emitter potential determines the amount of current flowing through the transistor. If it is alternately increased and decreased, the current will be changed accordingly. Therefore, an alternating signal voltage will modulate the transistor current. In this way, small voltage or current changes at the signal input electrode results in large changes of voltage or current at the signal output. This is the essence of an amplifier.

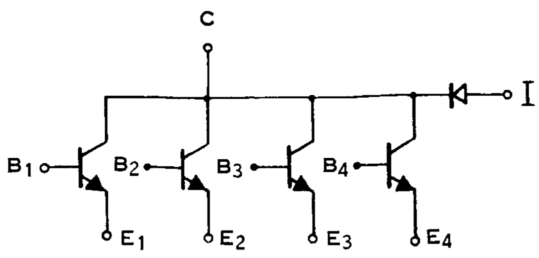
When a diode is reverse biased, the mobile carriers are drawn away from the junction, and only immobile ionized atoms of opposite polarity are lined up at the junction--fixed P-atoms in the N-side and N-atoms in the P-side. The junction, thus depleted of free carriers, acts like a capacitor, with the depletion area analogous to the distance of the capacitor plates. The higher the reverse bias across the junction, the wider the depletion layer, and hence the lower the capacitance. This is in striking contrast to the usual mechanical capacitor where the capacitance is independent of the voltage applied across the plate.

It is clear that any P-N junction is associated with capacitance, and thus plays a major role in the high frequency behavior of transistors. Capacitors do not pass DC; their resistance at low frequencies is infinite or extremely high. However, capacitive reactance decreases with increasing frequency in a transistor as well as in electronic circuits. These capacitors bypass the high frequencies, rendering them ineffective. Until recently it was not possible to apply transistors in the very high frequency range of tens and hundreds of megacycles. Today some transistors operate in the ultra high frequency range of several hundred megacycles. One of the most important parameters of a transistor is its high frequency limitation, which is expressed in the "α" and "β" parameters, also called h_{fb} and h_{fe}.

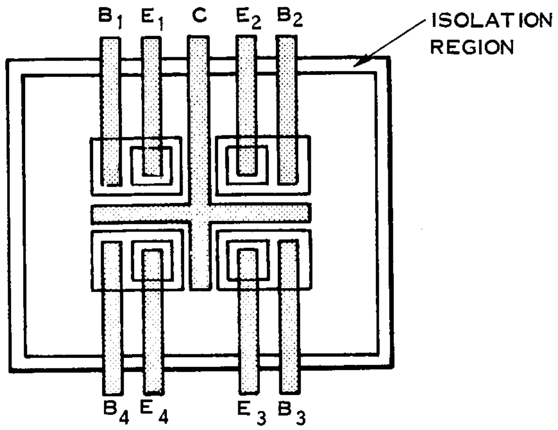
Electronic circuits consist of active and passive elements. The latter are resistors, capacitors and inductors. In conventional circuits these passive devices are separate, lumped elements, arranged in discrete components around the transistors and diodes. Connection between the separate elements are made through leads and soldered interconnections.

Semiconductor materials have a resistivity which is high for pure material and decreases with the amount of added impurities. This resistance can be used in circuits to replace discrete outside resistors. With new techniques, small and shallow resistive paths can be formed by diffusing P-impurities into an N-type semiconductor (Figure 9) into areas determined by masking. Base diffusion in an NPN transistor is of the same type, and thus resistive paths can be obtained simultaneously, by simply changing the photographic mask design. Note that the resistor is no longer a separate element but an inherent part of the semiconductor geometry.

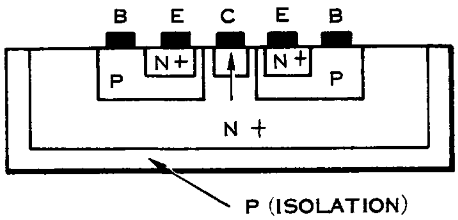
FOUR COMMON—COLLECTOR TRANSISTORS



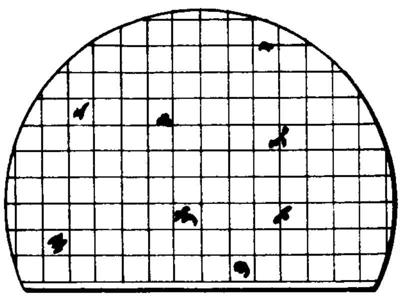
SCHEMATIC



SURFACE PATTERN



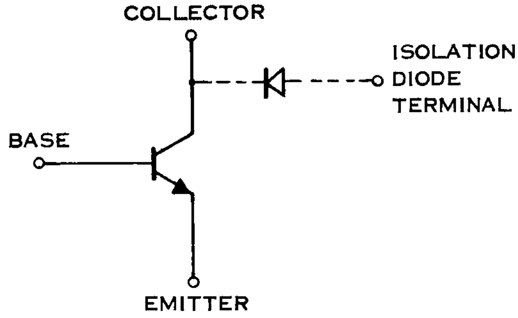
CROSS SECTION



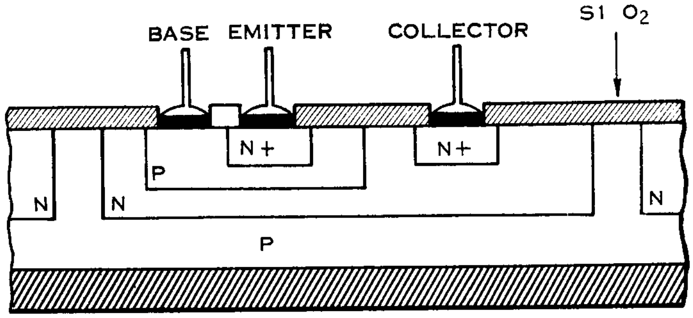
WAFER WITH TOTAL OF 139 CIRCUITS

$\frac{126}{139}$ = YIELD = 91 %

FIGURE 7 TYPICAL INTEGRATED TRANSISTOR CONFIGURATIONS



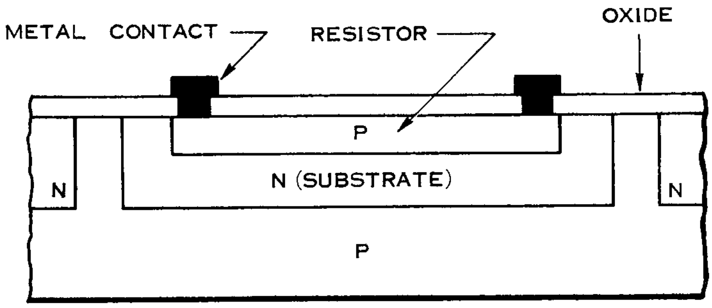
SCHEMATIC REPRESENTATION



ISOLATION DIODE TERMINAL

CROSS SECTIONAL VIEW

FIGURE 8 CONSTRUCTION OF AN INTEGRATED CIRCUIT PLANAR TRANSISTOR



A. DEVICE CROSSECTION

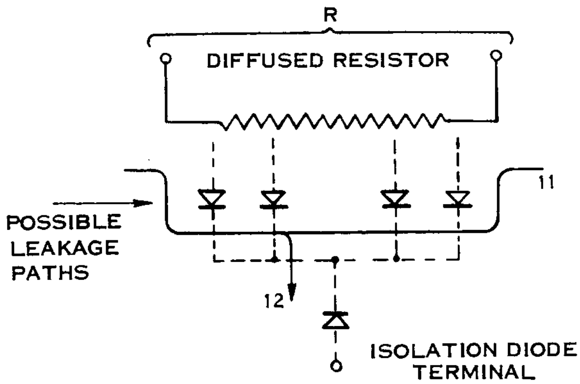


FIGURE 9 DIFFUSED RES'STOR STRUCTURES METAL CONTACT

In a similar manner, the capacitance of P-N junctions can be used in place of lumped outside capacitors. A reverse biased junction diode displays a large resistance to the flow of low frequency currents, acting as an insulator for DC. The larger the area, the greater is the capacitance, in junction diodes as well as in conventional capacitors.

In electronic circuits, the passive elements, resistors and capacitors, must be separated from the active elements, transistors and diodes, and also from each other. Therefore, the individual elements occupy certain areas in a semiconductor block, embedded in an area of opposite polarity. Thus, current may enter at one contact in the P-type path shown in Figure 8 and leave at the other end. This path displays a resistance dependent on the impurity level and the polarity, width and depth of the path. Hence, a series arrangement of many squares in a long meandering path can display a substantial amount of total resistance. However, the resistive path of P-material is embedded in N-material and this transition from P to N is nothing but a large junction, representing a capacitance distributed all along the path, and also a high resistance when reverse biased. Hence, the surrounding material, in this case N-type, must at all times be kept at a potential more positive than that of the resistive P-path in order to avoid forward biasing and become a short for DC and low frequency currents. In practice, the entire N-area is mostly connected directly to the highest positive potential supply.

With these new techniques, a tiny semiconductor chip can contain active as well as passive elements: transistors, diodes, capacitors and resistors in a heretofore unknown versatility of configurations -- all diffused together in the same sequence of photoengraving, etching and diffusion processes into the active semiconductor substrate; active because it separates electrically the distinct areas by virtue of distributed P-N junctions biased in a reverse direction. Thus, active and passive elements, representing a complete function such as amplifier, oscillator or logic function, are integrated in one monolithic block, inseparable from each other. Hence the names integrated circuitry, or functional electronic blocks (Figures 10, 11).

The New Era of Miniaturization

Called a technical breakthrough, the new technique was greeted with justified enthusiasm. Reduction of size and weight and decreased number of interconnections were coupled with anticipated cost reduction as technique evolved.

Only a few years before, the transistor had introduced a similar revolution and had gone through a similar evolution. Old and new companies rapidly plunged into a new era of miniaturization, called microminiaturization; and emphasis shifted from miniaturization to reliability and cost savings.

Monolithic, all-diffused, integrated blocks represent a true technical revolution compared with transistors -- a transition similar to that from vacuum tubes to solid state devices. This revolution presented obstacles immediately, since it developed that integrated circuits require an integrated team. Capable physicists, chemists, metallurgists, electronic and mechanical engineers, and mathematicians were required to generate one product, the tiny solid-state functional electronic block. Techniques and equipment had to be developed or improved to meet demands for production of ultra-pure substrate material, preparation of slices, photolithography masking and registration, ultracleanliness processing, controlled diffusion and doping levels, higher quality control and suitable packaging.

Another problem area resulted from the electronic design engineer not being equipped to handle the possibilities as well as the problems of the new techniques. The new area requires an abrupt change from the conventional component-oriented thinking to a function and material-oriented philosophy. Passive components now appear in distributed form, inseparable from the rest of the circuit, with associated functional restrictions. All this requires a new functional thinking -- from the circuit design engineer and the processing team as well as the systems analyst . . . in short, the concept of universal specialist.

Objective evaluation of this new technique must include its limitations. Linear circuitry, encountered in all kinds of communication devices, requires inductances which are not at all available in useful form in solid-state materials. Inductances in the form of coils, often wound around a metal core, which can be moved in the inductive field for tuning purposes, are a familiar sight. In integrated circuits they can often be replaced by different elements, mostly resistive-capacitive networks. However, to use these networks requires quite different circuits.

Because junction capacitors are limited in size, so is their absolute capacitive value. They are voltage dependent, showing decreasing capacitance with voltage in some non-linear fashion. Also, they are restricted by breakdown voltages. Resistive paths are limited in ohmic values determined by the sheet resistance and path length. They require wide circuit tolerances because of the basic difficulty of achieving close tolerances and the temperature dependence of the semiconductor material. Large values, often required in circuits, are not obtainable because of lack of space and -- possibly most important -- because of the detrimental effect of the large parasitic capacitance distributed all along the meandering resistive path. Resistors are also limited in voltages, similar to the capacitors. Resistive and capacitive trimming elements, like volume controls and variable capacitors, cannot be realized in semiconductor blocks; although taps in resistive paths and series and parallel combinations may be used for minor adjustments. This means that in the test and evaluation process

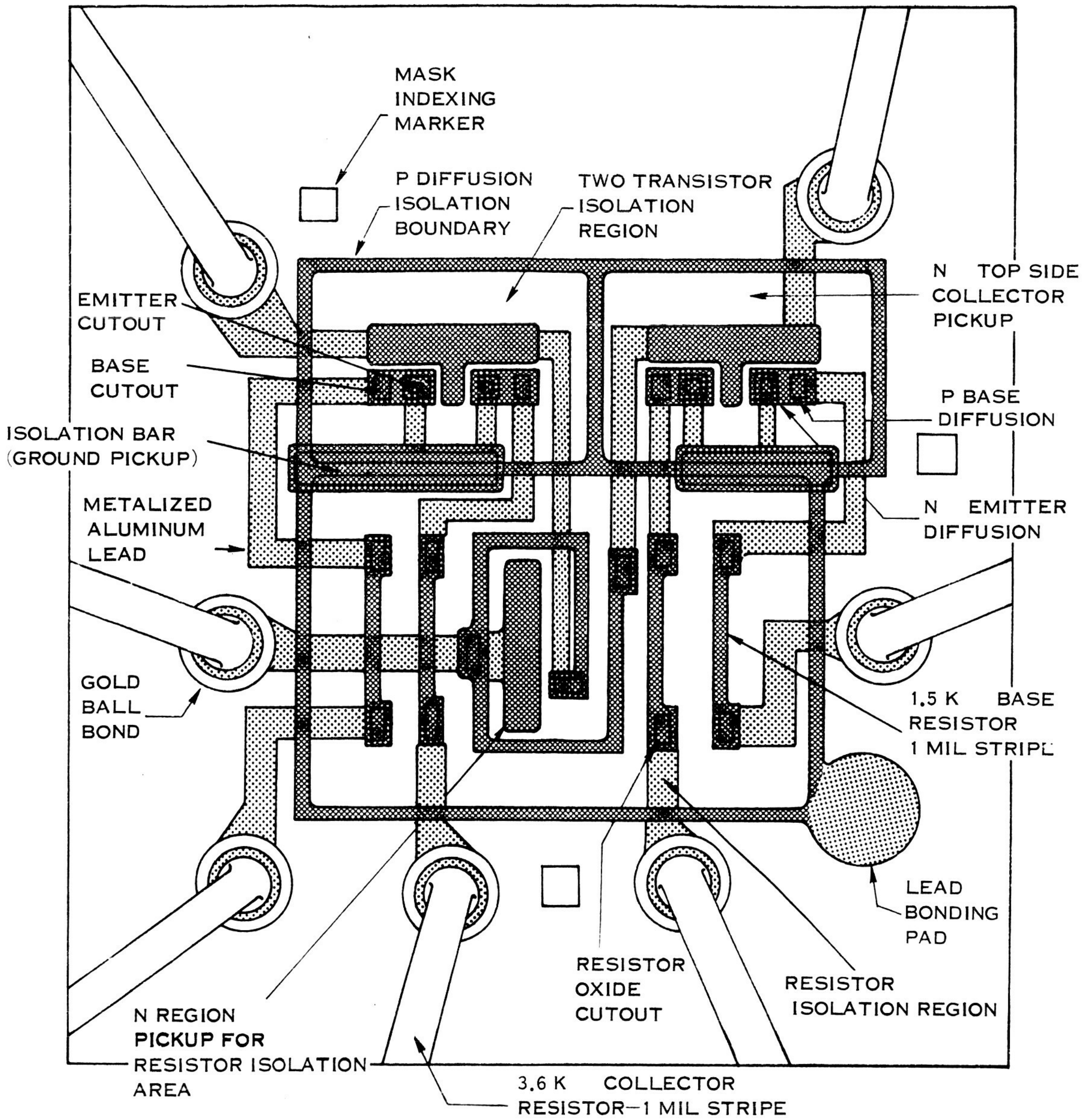


FIGURE 10 INTEGRATED NONOLITIC BLOCK

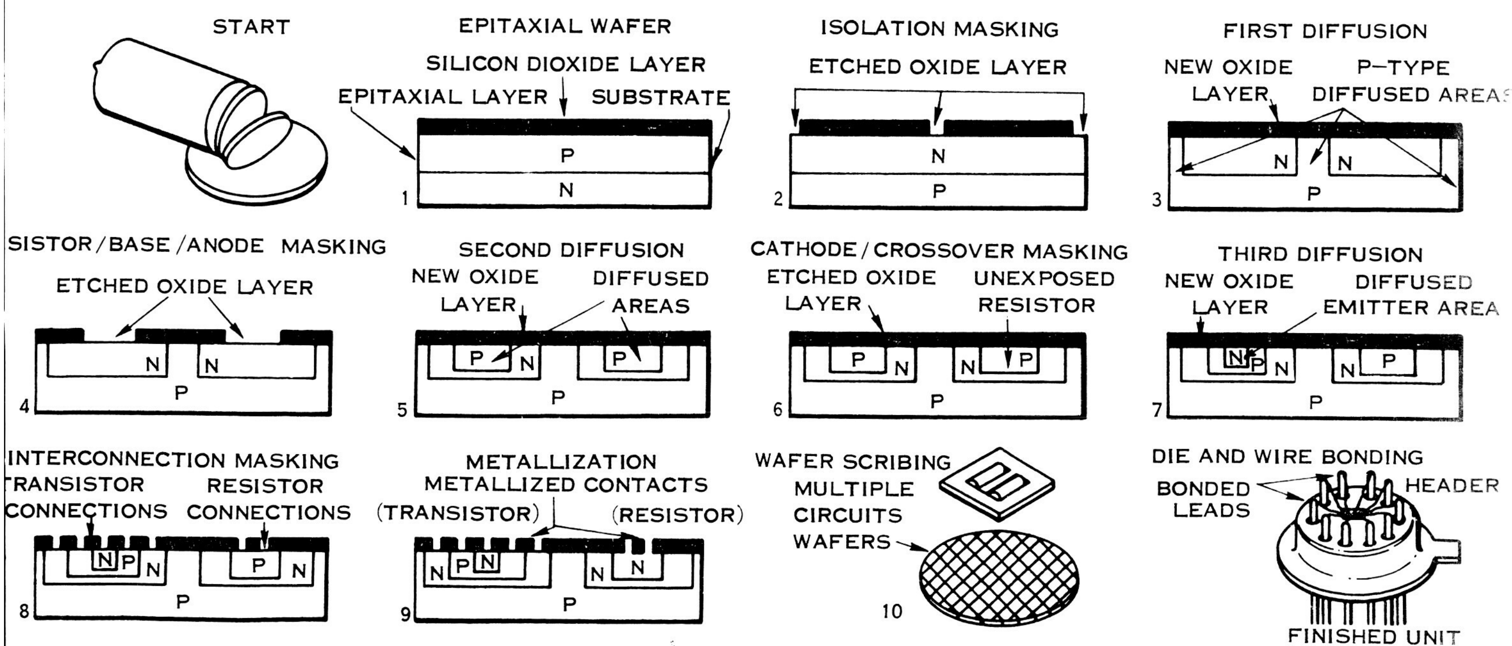


FIGURE 11 SEQUENTIAL STEPS OF INTEGRATED CIRCUIT FABRICATION

of individual blocks there is a choice of interconnections and points to which the wires may be bonded. However, once the tiny block is packaged and sealed, no further changes can be made.

The capacitances associated with a P-N junction are of fundamental importance in understanding the limitations of transistors and monolithic blocks. Inherent capacitances and other factors cause transistors and diodes to have an upper frequency limit. In a monolithic block, where the electrical isolation between active and passive areas is based on the performance of reverse-bias junctions, the parameters of those junctions -- breakdown voltage, leakage current, and parasitic capacitances -- represent severe limitations. In a transistor the collector has not only a detrimental capacitance to the base, but also to the surrounding substrate. In an NPN transistor, as in Figures 7 and 8, the N-collector is at a positive potential, embedded in a P-substrate which is mostly at ground (zero) potential to assure the reverse collector-substrate bias. This parasitic capacitance, which is even greater for the wide junction area of a long meandering resistive path (Figure 9) limits high frequencies by bypassing them to ground and thus rendering them ineffective. In addition, junction leakage and surface currents may result in poor isolation and cause interference between active and passive areas within the monolithic block. In other cases, small parasitic capacitances may be used for desired bypass purposes. Diodes or transistors (in a variety of configuration) can be designed for capacitances up to several hundred picofarads.

The semiconductor functional block is so small that it must be viewed under a microscope. Its width varies between about 50 to a few hundred mils side length, in some square or other rectangular form. Diffused or metallized contact areas may be as small as 0.0002 inch, approximately 5μ. This present limit is established by photographic resulution and mask fabrication. In such small areas, even the finest leads cannot be bonded with modern thermocompression techniques. Therefore, intraconnections require enlarged areas. These are deposited with the other metallic contacts on top of the isolating oxide layer (Figure 12). After embedding the block in a header (Figure 13), gold wires are bonded to these contact areas and to the leads protruding from the header. Then the header is finally sealed. Headers may be on ceramic bases, for isolation purposes; metallic, round, like conventional transistor packages; or flat, which is preferred for higher packaging density. These flat packages often have 4 to 6 leads protruding from opposite sides, providing greater flexibility for systems interconnections.

The advantages, limitations and problems of the material and the configurations require a new design philosophy. We've called it function and material-oriented, not component-oriented. New design concepts have been conceived and many more will come.

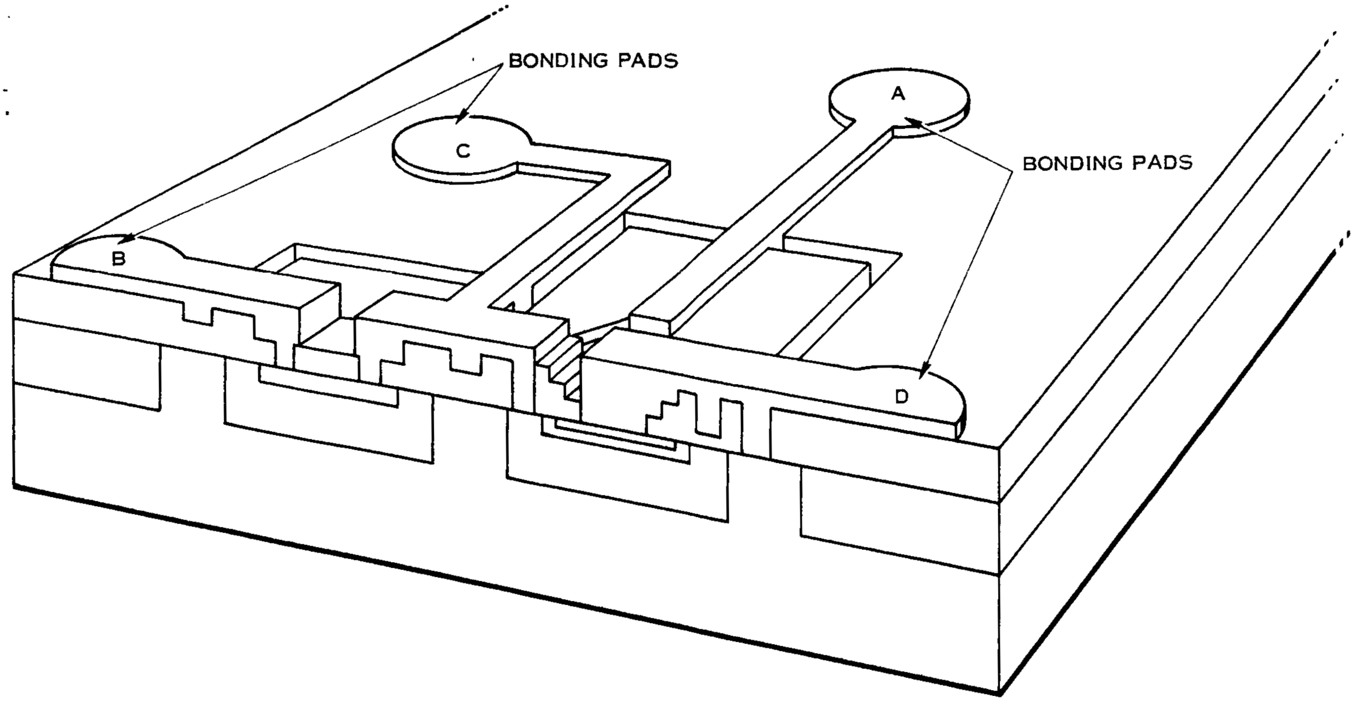


FIGURE 12 MONOLITHIC BLOCK WITH INTRACONNECTIONS

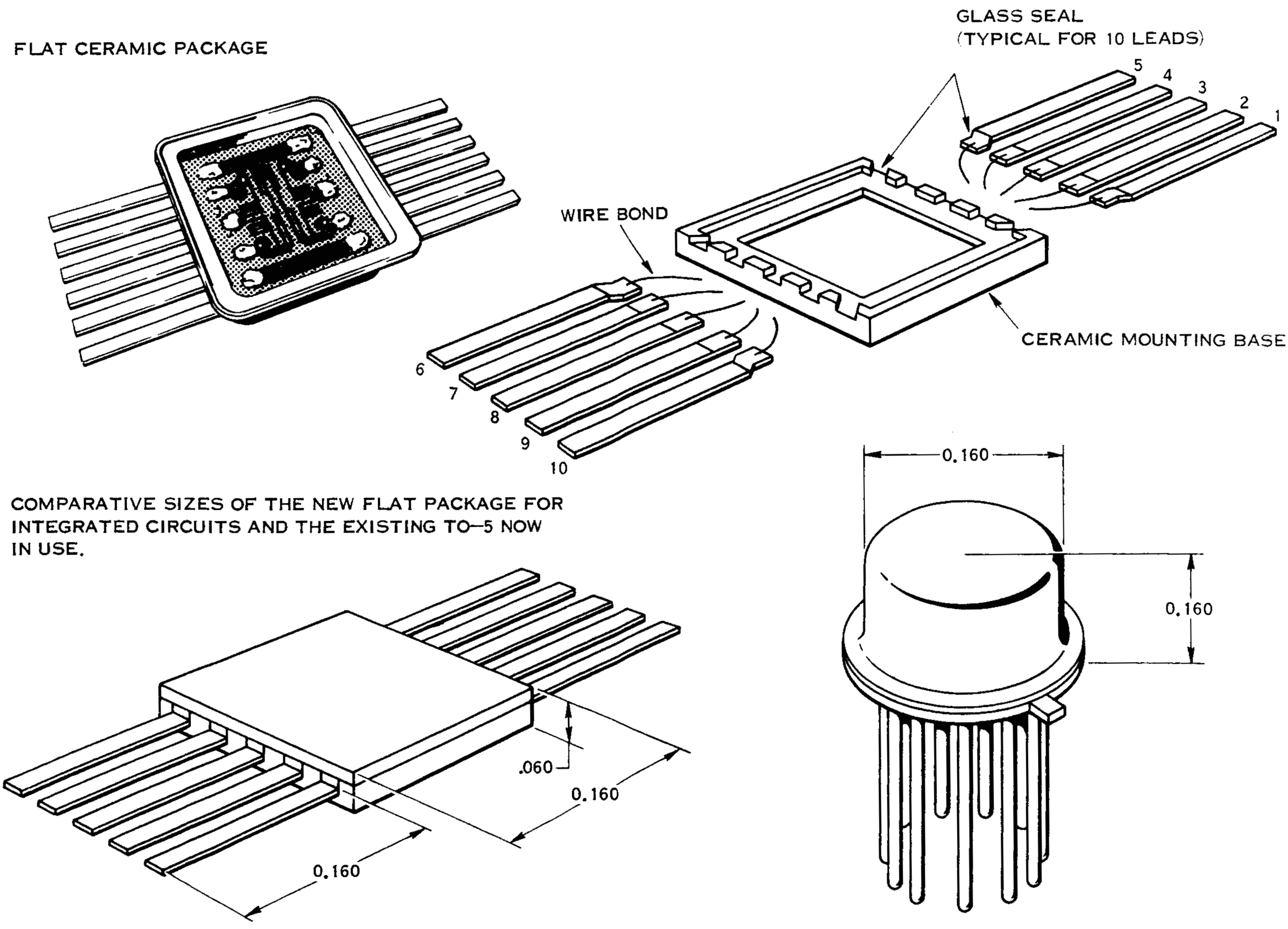


FIGURE 13 PACKAGING OF INTEGRATED BLOCKS

One such design philosophy, redundancy, appears to be ideally achievable in integrated circuit monolithic blocks. Redundancy -- the multiplication of elements or circuit functions most liable to failure, to assure correct systems functioning in case of malfunctions -- may play a vital role in circuits implanted in living organisms.

Hybridization

Summing up the limitations of monolithic blocks: limitation to small voltages between the ends of a resistor, between isolating areas and other junction capacitors; possibly insufficient isolation between the different block areas; often severe limitation of the high frequency response by the parasitic capacitance; lack of inductances and capacitive and resistive trimmers; limitation on resistor and capacitor values; and basic tolerance and temperature dependence. For these reasons a passive substrate may be more suitable. Such a substrate serves as a mechanical support and as an isolator for active and passive components mounted or deposited on it -- but not diffused into it together with the isolating areas.

All this speaks for hybridization in varying degrees. It is here where thin-film techniques (Figure 14) can be applied, depending on circuit requirements. With thin-film techniques, capacitors are formed in surface layers by subsequent deposition of various conductive materials on a passive substrate, and by means of an oxidation process forming the dielectric between the capacitor plates. Such a process can, of course, also be applied to the semiconductor block using a silicon dioxide surface layer as dielectric between the semiconductor material and a vacuum deposited metal layer as the capacitor electrodes. In effect, such a metal-over-oxide capacitor configuration (Figure 15) is used in the recent development of Metal Oxide Semiconductor Transistors (MOST) also called Insulated Gate Field-Effect Transistors. These units have almost unbelievable input impedance values of 10^{15} ohms. One problem lies in the thickness, or more accurately thinness, of the oxide dielectric. In physiological application, a serious problem with these new transistors is the required signal strength, which is incompatible with the millivolts and microvolts of the signals available.

Thin-film capacitors are voltage independent, and limited only by the breakdown voltage of the dielectric. However, in most cases voltage capability is far higher than that of the power source. These devices could easily be integrated into the semiconductor block, although not in the true sense of a diffusion. On the other hand, voltage dependence of a junction capacitor may be used as a modulating element as in an oscillator circuit for frequency modulation. Such a device is called a varactor diode, for variable (capacitive) reactance.

Recently developed thin-film techniques allow deposition of resistive films of a very high sheet resistance. Result is resistors of several megohms on a small area. In diffused blocks, low sheet resistances exclude the high values required for biasing and other functions, since such resistors occupy too much space and are consequently associated with increased parasitic effects. The basic tolerances and the resistive changes with temperature that often cause serious problems in monolithic blocks are much less pronounced in thin-film techniques. Thin-film resistors can be built on a silicon substrate (Figure 16).

In thin-film approaches to miniturization, after the deposition of passive elements, conventional transistors and diodes are mounted as individual single chips separately on the passive substrate (Figure 14). All the elements are well isolated from each other, but must be interconnected by as many leads as in conventional circuits built with discrete components.

Such techniques are quite distinct from integrated, all-diffused circuits -- and these include epitaxial growth techniques, the deposition of a controlled impurity layer at the semiconductor substrate to form an inseparable unit with the substrate (Figure 17). In thin-film techniques, active areas are not yet available and must be borrowed as unpackaged transistor chips, for mounting together with the passive thin-film components on the passive substrate.

Another way to overcome parasitic intercoupling between component elements is to dissect the semiconductor block in as many parts as active and passive areas -- separating them in individual chips and mounting them separately on an isolating substrate or directly on an isolating header. The difference between this approach and that of the thin-film techniques is that the passive components are of the diffused type, not deposited thin-films.

All degrees of hybridization, including printing inductances and other elements like quartz crystals which cannot be integrated at all, are used in individual circuits and in total systems, dependent on the complexity, reliability, required miniaturization and cost aspects. This approach is often referred to as integrated circuitry packaging, and may have little in common with true integrated circuits as defined here.

In summary, the major problem with thin-film devices is the lack of active elements and the necessary wiring of individual components. Chief advantages are: better tolerances, better temperature behavior and power handling, high freedom of intercoupling, higher values of resistors and capacitors, increased radiation resistance, and probably lower cost for limited production. Higher tooling costs and the many different skills needed for the design and pilot processing of integrated monolithic blocks require production on a large scale to spread such costs over many units.

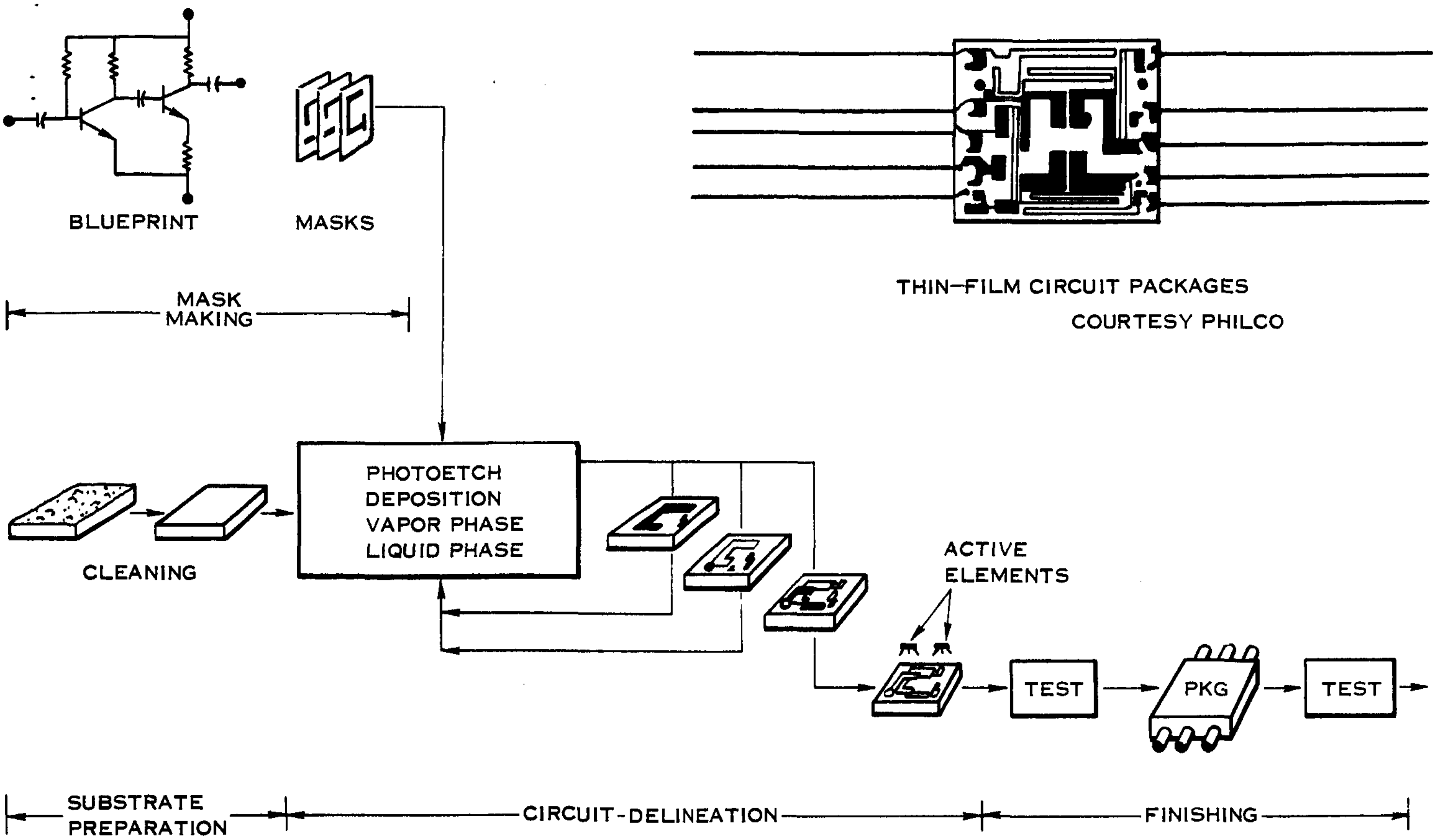


FIGURE 14 THIN–FILM FABRICATION SEQUENCE

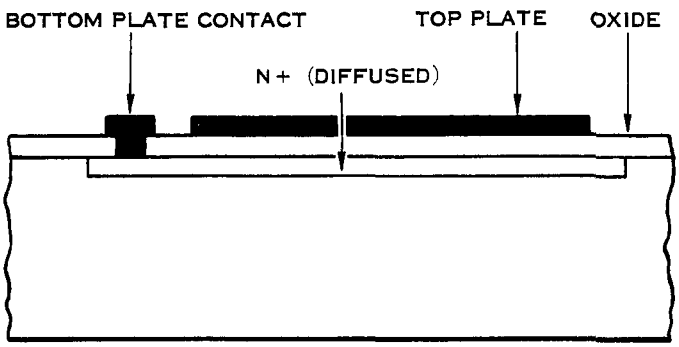


FIGURE 15 METAL OVER OXIDE CAPACITOR

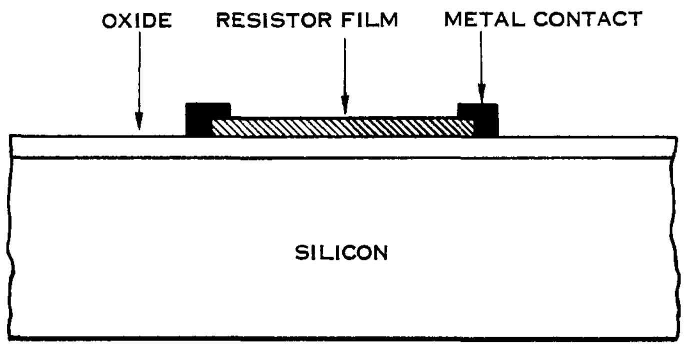
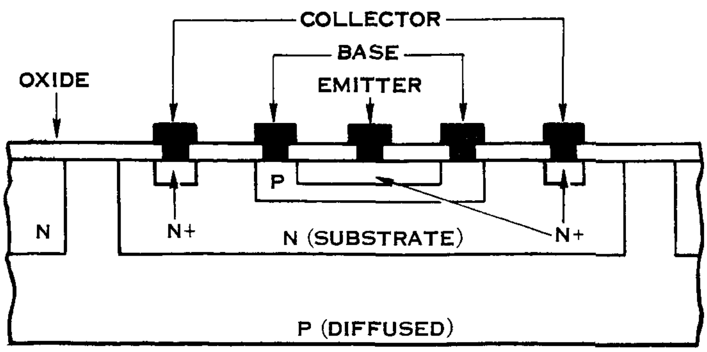
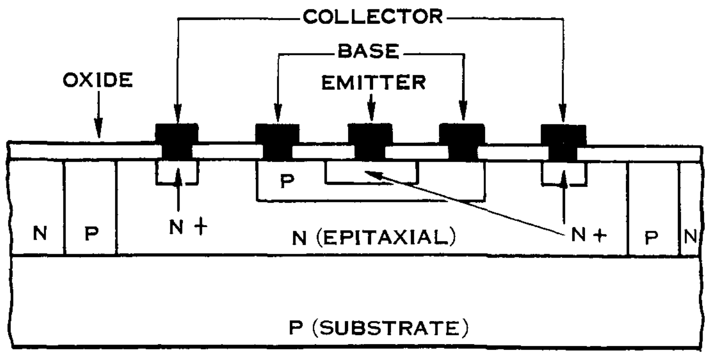


FIGURE 16 THIN FILM RESISTORS



A. ALL DIFFUSED



B. DIFFUSED EPITAXIAL

FIGURE 17 INTEGRATED TRANSISTORS STRUCTURES

This latter aspect, and the difficulties in achieving linear circuit functions, as well as the limitations of circuit elements needed in linear circuitry, has caused industry to concentrate, so far, on using monolithic blocks in computer logic circuits (Figure 18). In such circuits there is no linearity problem as the circuits shift momentarily from saturation to cut-off. Resistors and capacitors are the only passive elements required. Such circuits need a multitude of input-output configurations which can be designed easily and processed simultaneously. This, plus the great quantities of identical circuits needed, results in low cost per unit. The advantages of size reduction are more than evident. Present practical limit of circuit complexity is about a dozen transistors and 20 resistors in a single monolithic block. A practical example is the vidio amplifier block shown in Figure 19.

Reduction of size, weight and power consumption, increased reliability and decreased costs are the main goals in microminiaturization. The conflicting aspects require compromises which can be solved only in an objective evaluation of all factors, including technical, biological and economical ones. In this respect, monolithic and thin-film techniques should be considered complimentary. However, with the maturing of techniques, increased yield in integrated monolithic blocks is reducing costs, and new circuit functions are being invented. Result will be an expected trend away from hybridization. Predictions are that integral blocks will be the choice for biological applications wherever miniature dimensions play a major role, particularly in implantation in living organisms; and will lead to new developments hitherto undreamed of.

Microminiaturization versus Conventional Components

Much of the material in this publication has been presented in terms of telemetry systems and transducers, fabricated as integrated circuits or as hybrid circuits. This section is primarily concerned with the factors of cost and performance which must be considered when a biotelemetry system is about to be implemented.

In many practical situations, a prospective user of a proposed new biotelemetry system will have to answer such questions as:

(1) Should a wired or a wireless system be employed?

(2) What are the tolerable limits with respect to weight, power and size?

(3) How much maintenance and what degree of component reliability is needed and at what cost?

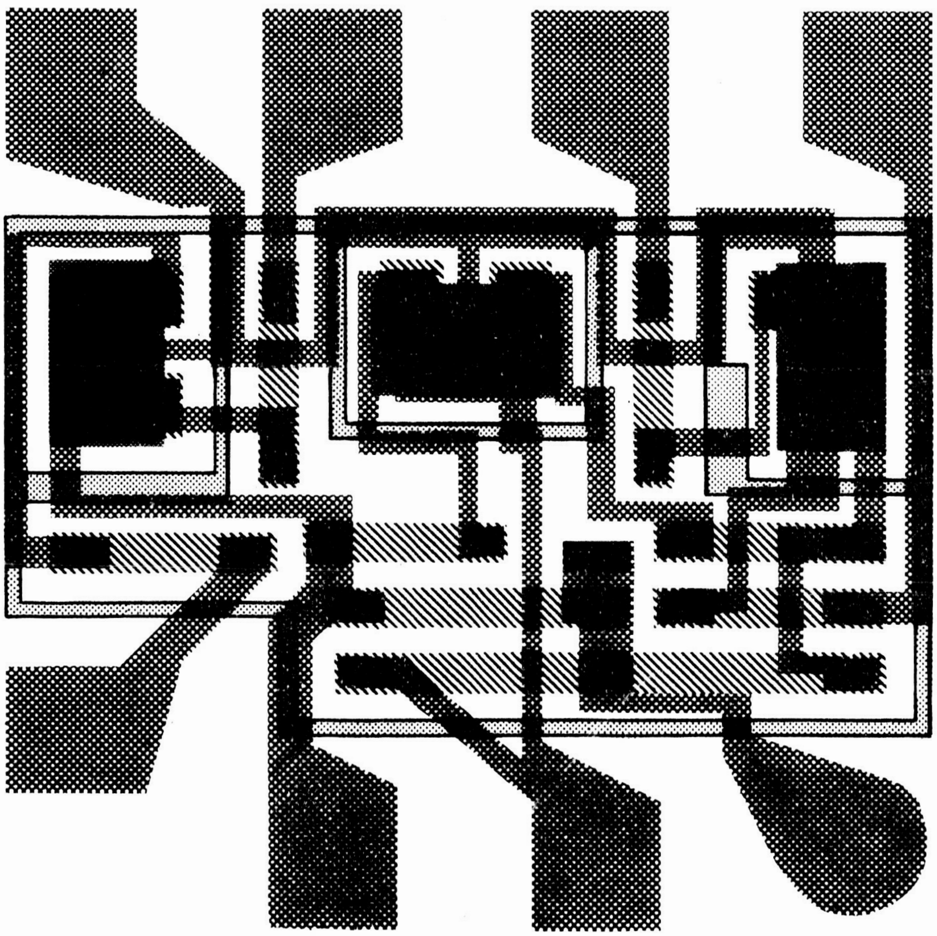


FIGURE 18 EPITAXIAL MICROLOGIC (FAIRCHILD)

The operational requirements and expected environment may determine the form of the proposed system. For example, if one were interested in obtaining information about the internal body temperature of free flying birds, it is clear that minimum size, weight and power consumption are imperative, and that a wireless system is the only practical way of implementing the system. In this instance, it might also be necessary to consider physical implantation of the signal emitter in the bird. Microminiaturization in this situation might well be mandatory.

On the other hand, the problem might be the construction of a superficial heart rate monitor to be used in an operating room. A small unit built out of conventional components and connected by hard wire to a data display system constructed out of conventional solid-state components might well suffice for this application. This could be developed at a cost substantially less than that involved in a wireless system with a miniaturized signal emitter.

Integrated and hybrid circuits tend to place tighter restriction on the design engineer than do conventional circuits. The very nature of the integrated circuit severely curtails the freedom with which the various circuit parameters can be adjusted during design.

Very satisfactory telemetry systems, which in many instances will satisfy the operational and environmental requirements generated by the application, can be fabricated of conventional components. Such systems, in general, cannot be made as small as the corresponding integrated or hybrid version, but as pointed out, many applications do not demand the ultimate in size reduction.

At NASA Ames Research Center, Moffet Field, California, a subminiature, high-performance biopotential telemetry system has been developed. Features of the transmitter include: extremely small size; use of conventional, easily available, inexpensive components; and an assembly technique which permits easy construction. The transmitter operates at approximately 90 megacycles. Interchanging three components in the basic circuit developed provides two versions of the device: one has a two-day operating life with a 100-foot range while the other has a 48-day operating life with a 10-foot range. Careful circuit design and the use of new silicon transistors operated at very low current levels allow these features to be attained without sacrificing performance.

In Tables I and II the relevant parameters of several variants of this system are tabulated. The system is fabricated from relatively low-cost components in compact packages. In many cases, devices such as these offer a most

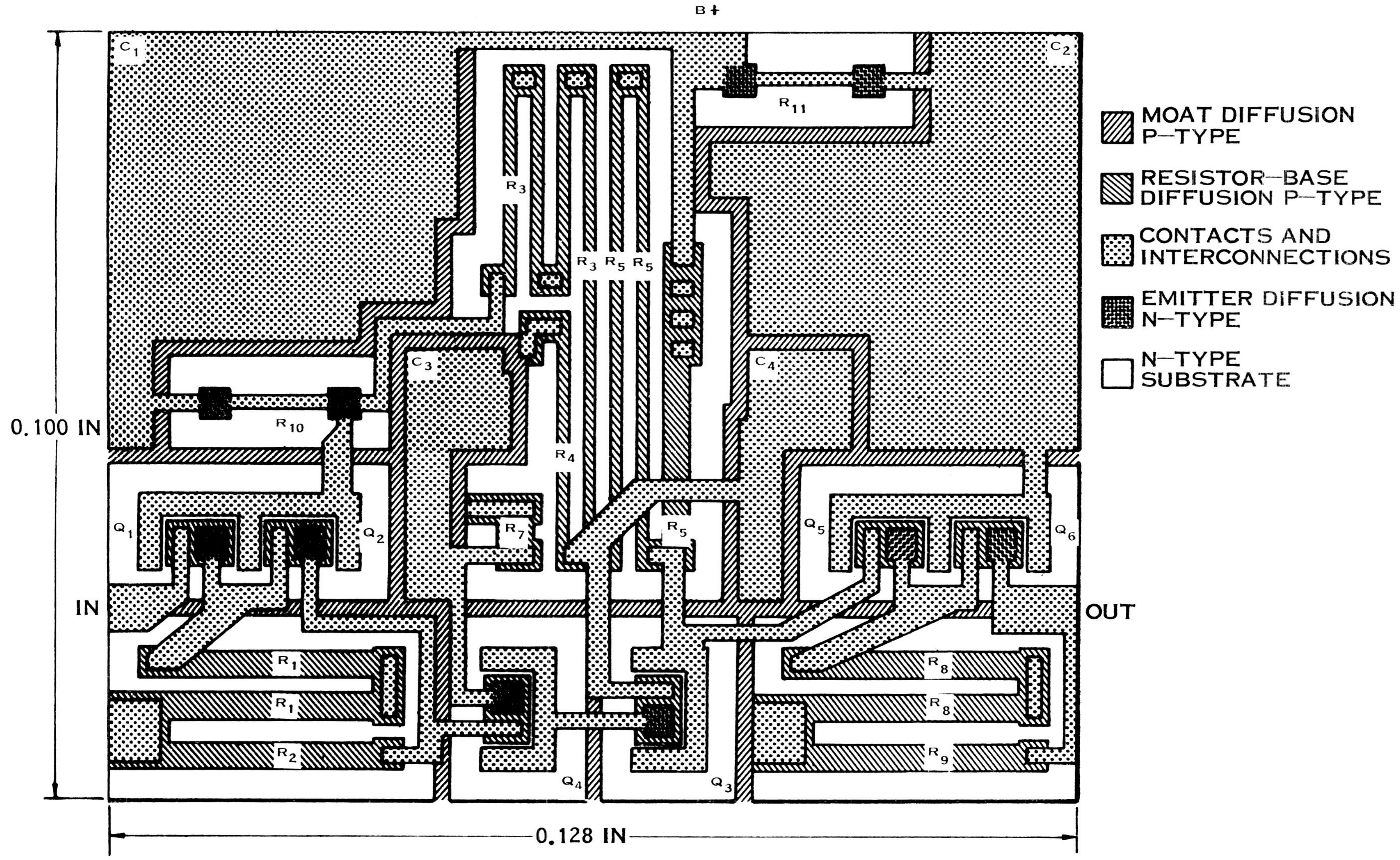


FIGURE 19 VIDEO AMPLIFIER LAYOUT

COURTESY NORDEN DIV. UNITED AIRCRAFT

acceptable compromise of power, weight and size consistent with the requirements of the problem. Availability of such devices may well provide a feasible solution to a biotelemetry problem at relatively low cost. Further information about them can be obtained from the Director of the Ames Research Center.

For the purpose of comparison, the third column of Table I tabulates the corresponding parameters of a hybrid electrocardiograph (EKG) developed for NASA under contract NASw 542 by United Aircraft Corporation. Details can be obtained from the manufacturer.

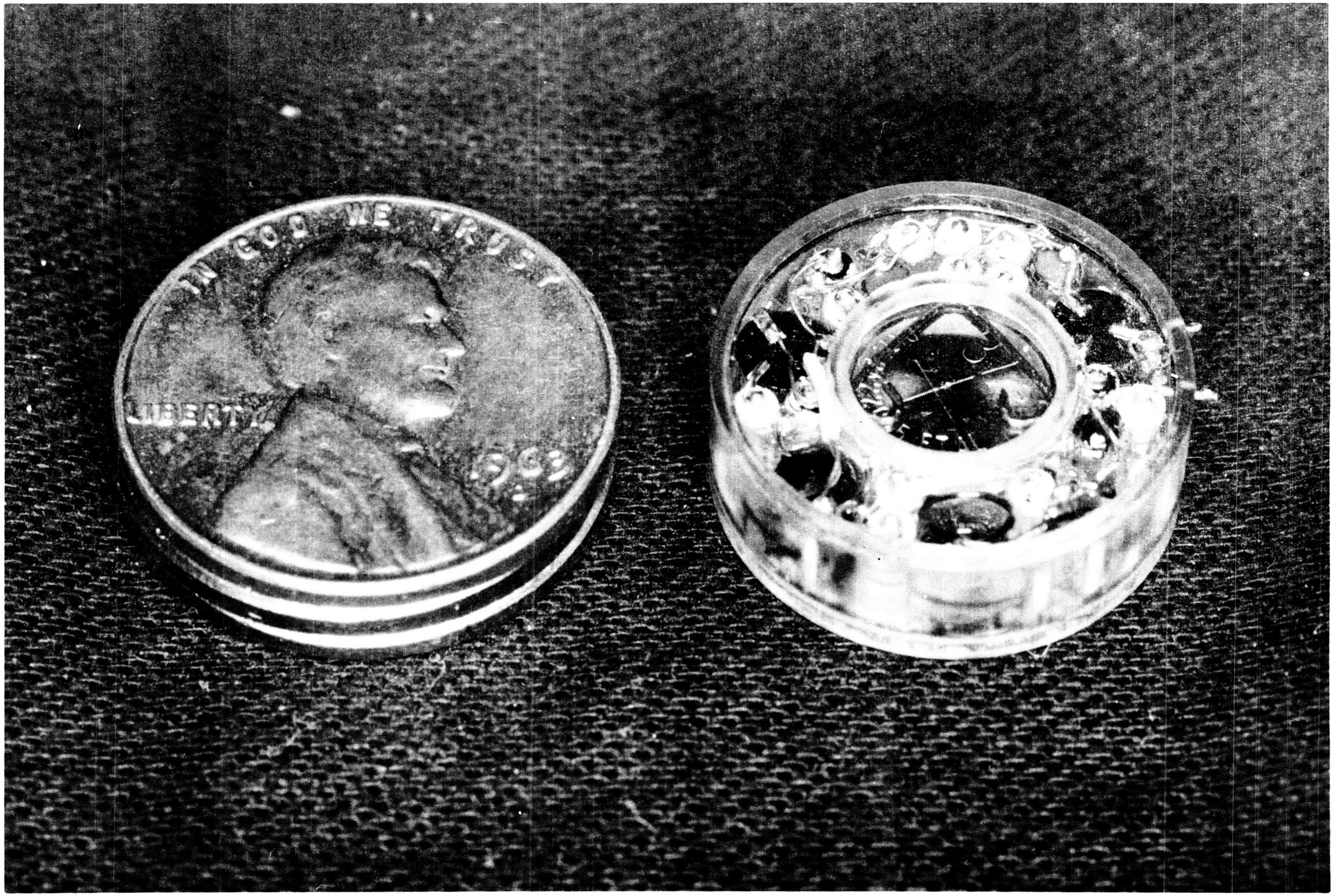


Fig. 20: Compact Biotelemetry Transmitter
NASA-Ames Research Center

TABLE I

Function	EKG, EEG, EMG	EKG, EEG, EMG
System	Long Life Short Range Telemetry	Long Range Short Life Telemetry
Gain	-	-
Frequency Response	0.3 cps. - 1000 cps.	.3 cps. -1000 cps.
Equivalent Input	0.5 uV RMS .3-100 cps.	0.5 uV RMS .3-100 cps.
Noise	1.5 uV RMS .3-1000 cps.	1.5 uV RMS .3-1000 cps.
Maximum Input	±3 mV	±3 mV
Maximum Output	-	-
Input Impedance	10 Megohms	10 Megohms
Output Impedance	-	-
RF Carrier	90 Mc/s Pulsed RF	90 Mc/s FM
Sub Carrier	1 Kc/s	10 Kc/s
Power Supply	1.35 V	1.35 V
Battery Life	4 weeks	5 days
Size	.18x.73 ins. dia. incl. battery	.18x.73 ins. dia. incl. battery
Range	10 feet	100 feet
Sensor	-	-

TABLE II

Function	Temperature
System	Long Life Short Range Telemetry
Construction	Pellet Components
Gain	-
Response time	0.03 sec. exclud. sensor
Equivalent Input Noise	-
Maximum Input	10° C
Long-term accuracy	±.05° C
Resolution	>.01° C
Output Impedance	-
RF Carrier	90 Mc/s Pulsed RF
Sub Carrier	50 cps.
Power Supply	1.35 V
Battery Life	4 months
Size	.18x.73 ins. dia. incl. battery
Sensor	Thermistor
Range	10 feet

TABLE III

EKG Transmitter Integrated Electrodes

Sensitivity	80 cps./μV
Frequency Response	0-20 KC
Input Noise	$\sim 1\mu V$
Maximum Output	± 4 mV
Input Impedance	3.3 Kohm
RF Carrier Frequency	86.5 MC
Sub Carrier	None
Power Supply	1.4 volt cell, type 400
Battery Life	40 hours
Range	20 feet
Size	0.51 height x 0.62 ins. dia.

Summary

Telemetry has been one of the areas in which the National Aeronautics and Space Administration in recent years has achieved major technological advances. Under the exigencies of space exploration, and in response to the needs of the space program, techniques have become available in NASA and in industry which now permit the fabrication of tiny circuits capable of a wide range of functions.

In this document, pertinent facts have been discussed about biotelemetry systems which are implemented by such microminiaturized circuitry. These techniques are now being employed to develop biotelemetry systems, for instance, to serve in such areas as the wireless stimulation and monitoring of the behavior of free moving primates, unencumbered by wires or other gear. Similarly, large industrial organizations -- as a result of their involvement with the space effort, and the capabilities thus achieved -- have gone on in their own laboratories to develop systems which provide a multiparameter monitoring complex for acutely ill patients. Here again, telemetry frees the patient from the need of physical connection with the central display system.

It has also been pointed out that microminiaturized or hybrid devices, while characterized by desirable low-power, smallness and good reliability, are nevertheless costly to implement. In many cases, the prospective user of such a system may not require this maximum degree of refinement, for which costs may prove prohibitive. Under such circumstances, the possibility exists of using conventional solid-state elements as pelletized components. Devices of this type are well exemplified by the excellent series of biomedical telemetry units now being developed by the NASA Ames Research Center. These units probably represent the minimal limit in physical size attainable by this particular technology; but even so, under many requirements, they prove sufficiently small for practical use in most biological contexts.

In conclusion, much remains to be said about modern biotelemetry, and a great deal more remains to be done. This document will have served its purpose if it prompts the reader to undertake some of the necessary research and development effort himself. The Office of Technology Utilization of the National Aeronautics and Space Administration in Washington, D.C. stands ready to put prospective users of biotelemetry procedures in contact with technical personnel, both in and out of Government, who can provide detailed information about available systems and techniques.

GLOSSARY

Terms Frequently Used In Telemetry

Amplifier. A device using an electron tube, transistor, magnetic unit, etc. to increase the strength of a signal without appreciably altering its characteristic waveform. An amplifier transfers power to the signal from an external source, whereas a transformer changes signal voltage or current without adding power.

Amplitude. The value of a varying quantity at a specified instant; when applied to vibratory conditions it pertains generally to the peak magnitude.

AM, Amplitude Modulation. A modulation in which the amplitude of the carrier wave is varied in accordance with the low frequency intelligence signal to be transmitted.

Analog to Digital Conversion. A process by which a sample of analog information is transformed into a digital code.

Analog to Digital Converter, (also called Digitizer or Encoder). A device which will convert an analog voltage sample to an equivalent digital code.

Band (Width). A bounded continuous portion of a frequency spectrum.

Bias. A DC (direct current) voltage applied to a transistor control electrode to establish the desired operating point.

Binary. Having only two possible alternatives.

Binary Code. A code composed of a combination of characters each of which can assume one of two possible states and which is identifiable in time and space.

Binary-Coded Decimal System. A system of number representation in which each of the decimal digits is expressed by binary numbers.

Binary Number System. A number system which uses two symbols, usually denoted by 0 and 1 and, therefore, has 2 as its base, just as the decimal system uses 10 symbols (0, 1, 2, . . . 9), and has the base 10.

Biotelemetry. Composed of three Greek words: Bios = life, tele = far off, at a distance, and metron = measure.

Bit (Binary Digit). A quantity of intelligence which is carried by an identifiable entity and which can exist only in either of two states.

Carrier. A wave or a periodically recurring series of pulses suitable for being modulated to transmit intelligence; the modulation presents the information, and the original wave is used only as a "carrier" of the modulation.

Carrier Frequency. In a periodic carrier, the reciprocal of its period. In a PCM (Pulse Code Modulation) system, the midpoint between the deviation limits.

Channel. A band of radio frequencies (RF) allocated for a particular purpose. A path for a signal.

Code. A system of characters and rules for representing information.

Commutation. Sequential sampling, on a repetitive time-sharing basis, of multiple data sources for transmitting and/or recording on a single channel.

Commutator. A device used to accomplish time-division multiplexing by repetitive sequential switching.

Cross Talk. Interference in a given transmitting or recording channel which has its origin in another channel.

Crystal. A natural or synthetic piezoelectric or semiconductor material.

Cycle. One complete sequence of values of an alternating quantity. A set of operations that is repeated as a unit.

CPS (cps). Cycles per second (abbr.).

Decommutator. Equipment for separation, demodulation, or demultiplexing commutated signals.

Demodulation (Detection). The process of recovering the modulating wave from a modulated carrier.

Detector. The stage in a receiver at which demodulation takes place.

Digital. Expressing value in terms of numbers. Measurable in discrete, discontinuous steps.

Digitizer. A device which converts analog data into numbers expressed in digits (see Bit) in a system of notation.

Discriminator, FM. A device which converts variations in frequency to proportional variations in voltage or current, e.g. a detector for frequency-modulated (FM) transmitters.

FM (Frequency Modulation). The modulation of a sine-wave carrier in which the instantaneous frequency of the modulated wave differs from the carrier frequency by an amount proportional to the instantaneous value of the modulating wave. The aplitude of the modulated wave is constant.

HF (High Frequency). The band from 3 to 30 Mcps (Megacycles; 1 Mcps = 1,000,000 cps).

Harmonic. A sinusoidal component of a periodic wave, having a frequency that is an integral multiple of the fundamental frequency. The frequency of the second harmonic is twice that of the fundamental, etc. Any waveshape can be composed of a series of a fundamental and harmonic sinusoidal waves.

I-F (Intermediate Frequency). The frequency produced by combining the received signal with that of the local oscillator in a superheterodyne receiver.

Impedance (Z). The total opposition offered by a component or circuit to the flow of an alternating (AC) or varying current. Impedance is a combination of Resistance (R) and Reactance (X); resistance is the opposition to the flow of direct current (DC); reactance is the opposition offered to the flow of AC by pure inductance (L) or capacitance (C).

Intelligence. Data, information, or messages that are to be transmitted.

Intermodulation. Modulation of the components of a complex wave by each other.

kV (kilo-Volt). One thousand volts = 10^3 volts.

Linearity. The condition wherein the change in the value of one quantity is directly proportional to the change in the value of another quantity.

Load. The device which receives the useful signal output of an amplifier, oscillator or other signal source. A device that consumes electric power.

Local Oscillator. The oscillator in a superheterodyne receiver, whose output is mixed with the incoming modulated RF carrier signal in the mixer circuit to give the frequency conversion needed to produce the I-F signal.

Logic. The basic principles and application of truth tables. interconnections of on-off circuit elements, and other factors involved in mathematical interrelationships required in a computer of data processing system.

Magnetic Tape Recorder/Reproducer. A machine which converts electrical data signals to magnetic patterns on a magnetic tape during a recording process and/or converts the remanent magnetic patterns on a magnetic tape to electrical data signals during a reproducing process.

Matching. Connecting two circuits by a coupling device so as to give maximum transfer of energy.

Memory, storage. The act of storing information. Any device in which information can be stored, sometimes called Memory device. In a computer, a section used primarily for storing information, called Memory or Store.

mV (milli-Volt). One-thousandth of a volt (10^{-3} V.).

μ V (micro-volt). One-millionth of a volt (10^{-6} V.).

Modulation. The process of impressing information on a carrier for transmission. (AM, Amplitude Mod.; FM, Frequency Mod.; PM, Phase Mod.; see also Pulse Modulation).

Monitor. An instrument used to measure, continuously or at intervals, a condition that must be kept within prescribed limits.

Multiplexing. The simultaneous transmission of two or more signals within a single channel. The three basic methods of multiplexing involve the separation of signals by time division, frequency division, and phase division.

nsec (nanosecond). One-billionth of a second (10^{-9} sec.).

Noise. Any unwanted disturbance or signal which degrades the desired data. In television, noise voltages produce small **black** or white spots over the entire image area.

Octave. The interval between two frequencies having a ratio 2:1.

Oscillation. A periodic recurring change in a variable as in the amplitude (magnitude) of an alternating current (AC), or the swing of a pendulum.

Oscillator. An electric circuit that generates alternating current at a frequency determined by the values of its components, generally inductance and capacitance in a so-called tank-circuit.

Parameter. Any physical entity to be measured.

Phase. The position of a point on the waveform of an alternating or other periodic quantity with respect to the start of the cycle; usually expressed in degrees; phase-angle.

Piezoelectric Effect. Generation of a voltage between opposite faces of a piezoelectric crystal as a result of strain due to pressure or twisting, and the reverse effect in which application of a voltage to opposite faces causes deformation to occur at the frequency of the applied voltage.

Pulse. A momentary, sharp change in a current, voltage or other quantity that is normally constant. A pulse is characterized by its amplitude (height), duration (length), rise and decay. Also called Impulse.

Pulse Modulation. Modulation of a carrier by a pulse train.

PAM. Pulse Amplitude Modulation.

PAM/PFM. Frequency modulation of a carrier by pulses which are amplitude modulated by information.

PCM (Pulse Code Modulation). Modulation of a carrier by coded information. A pulse code consists of various combinations of pulses, such as the Morse code (a message-transmitting code consisting of dot and dash signals), or the binary code (having only two possible alternatives).

PDM (Pulse Duration Modulation) (also called pulse-width or pulse-length mod.). A form of pulse-time modulation in which the duration of a pulse is varied without changing the Pulse-Repetition-Rate (PRR), i. e. the number of times per second that a pulse is transmitted.

PFM (Pulse Frequency Modulation). A form of pulse-time modulation in which the PRR (Pulse-Repetition-Rate) is the characteristic varied.

PPM (Pulse Position Modulation). A form of pulse-time modulation in which the position in time of a pulse is varied.

Quantization. The process of converting from continuous values of information to a finite number of discrete values.

Radio-Endosonde. A radio transmitter implanted into the body (living organism) that measures and transmits physiological data.

Radio Telemetry. Telemetry in which an RF (radio frequency) link is used as a portion of the transmission path.

Radio Transmitter. The equipment for generating and amplifying an RF carrier, modulating it with intelligence and feeding it to an antenna for radiation into space as electro-magnetic waves.

Sidebands. The frequency bands on both sides of the carrier frequency within which fall the frequencies of the wave produced by the process of modulation.

Signal. An output of intelligence emanating from a device.

Single-Sideband Transmission. That method of operation in which one sideband is transmitted and the other sideband suppressed. The carrier wave may be either transmitted or suppressed.

Solid-State Physics. The branch of physics that deals with the structure and properties of solids, including semiconductors, i.e. a material whose electrical resistivity is between that of insulators and conductors. (Generally used semiconductors are silicon and germanium.)

Stimulus. The cause which produces change.

Strain Gage. A strain-sensitive element designed to be attached to a member in which strain is to be measured. It is usually connected into a bridge circuit that feeds a recorder directly or through an amplifier.

Subcarrier. A carrier which is applied as a modulating wave to modulate another carrier or an intermediate subcarrier.

Telemetry. The science of measuring a quantity, transmitting the results to a distant station, and there interpreting, indicating, and/or recording the quantities measured.

Thermocouple. A device consisting of two dissimilar conductors welded together at their ends to form a junction. When this junction is heated, the voltage developed across it is proportional to the temperature rise.

Time-Division Multiplex. A system for the transmission of information about two or more quantities (measurands) over a common channel, by dividing available time intervals among the measurands to form a composite train. Information may be transmitted by variation of pulse duration, pulse amplitude, pulse position, or by a pulse code.

Transducer. General term for any device that converts energy of one form to another, mechanical energy to electrical, or vice versa (pressure, acceleration, vibration, etc.) as in straingages, microphones, phonograph pick-ups, loudspeaker.

Transistor. An active semiconductor device having three or more electrodes. The three main electrodes used are the emitter, base and collector. Conduction is by means of electrons (elementary particles having the smallest, negative electrical charge that can exist) and holes (mobile electron-vacancies equivalent to a positive charge).

UHF (ultra high-frequency). The band from 300 to 3000 Mcps.

VHF (very high-frequency). The band from 30 to 300 Mcps.

Video Amplifier. A wideband amplifier capable of amplifying video frequencies, picture signals or the sections of a television system that carry these signals.

ALPHABETICAL DIRECTORY

Biotelemetry Equipment and Component Sources

Adage, Inc., Cambridge, Mass.

Adelco Laboratories, Bellaire, Texas

Advanced Instruments, Inc., Newton Highlands, Mass.

Airborne Inst. Laboratories, Deer Park, L.I., N.Y.

Air-Shields, Inc., Hatboro, Pa.

Allen B. DuMont Laboratories, Clifton, N.J.

Aloe Scientific, St. Louis, Mo.

Alpha Scientific Laboratories, Inc., Berkeley, Calif.

American Electronic Laboratories, Inc., Colmar, Pa.

American Optical Co., Buffalo, N.Y.

Ampex Corp., Redwood City, Calif.

Arco Electronics, Inc., Great Neck, N.Y.

Argonaut Associates, Inc., Beaverton, Oregon

Atomium Corp., Billerica, Mass.

AVCO, Research & Advance Development Div., Wilmington, Mass.

Avionics Research Products Corp., Los Angeles, Calif.

Avnet Electronics Corp., Westbury, L.I., N.Y.

Baird-Atomic, Inc., Cambridge, Mass.

Barber-Colman Co., Rockford, Ill.

Barnes Engineering Co., Wilton, Conn.

Bausch & Lomb, Inc., Rochester, N.Y.

Beckman Instruments, Inc., Spinco Div., Palo Alto, Calif.

Beckman Instruments, Inc., Scientific Instruments Div., Fullerton, Calif.

Bell Aerosystems Co., Buffalo, N.Y.

Berkeley Tonometer Co., Berkeley, Calif.

Beta Corp. of St. Louis, St. Louis, Mo.

Bio-Assay Laboratory, Dallas, Texas

Boeing Co., Seattle, Washington

Boonshaft and Fuchs, Inc., Hatboro, Pa.

Brewer Pharmacal Engineering Corp., Upper Darby, Pa.

Brinkmann Instruments, Inc., Westbury, L.I., N. Y.

Bronwill Scientific, Rochester, N.Y.

Brush Instruments, Cleveland, Ohio

Burdick Corp., Milton, Wisconsin

Burrell Corp., Pittsburgh, Pa.

Canal Industrial Corp., Bethesda, Maryland

Cary Instruments, Monrovia, Calif.

Central Scientific Co., Chicago, Ill.

Chemetron Corp., National Cylinder Gas Div., Chicago, Ill.

Chemtronics, Inc., San Antonio, Texas

Coulter Electronics, Inc., Hialeah, Florida

Dallons Laboratories, El Segundo, Calif.

Decker Corp., Bala-Cynwyd, Pa.

Digital Equipment Corp., Maynard, Mass.

Disc Instruments, Inc., Santa Anna, Calif.

Douglas Aircraft Co., Santa Monica, Calif.

Dowalco, Inc., Los Angeles, Calif.

Electro-Age Corp., New York, N.Y.

Electromagnetic Probe Co., Winston-Salem, N.C.

Electronic Aids, Inc., Baltimore, Md.

Electronic Associates, Inc., Long Branch, N.J.

Electronic Engineering Co. of Calif., Santa Anna, Calif.

Electronic Medical Specialties, Inc., Cleveland, Ohio

E-M-D, Inc., Farmingdale, N.Y.

E & M Instrument Co., Inc., Houston, Texas

Epsco, Inc., Cambridge, Mass.

Executone, Inc., Long Island City, N.Y.

Fisher Scientific Co., Pittsburgh, Pa.

F & M Scientific Corp., Avondale, Pa.

Garrett Corp., Los Angeles, Calif.

General Dynamics/Astronautics, San Diego, Calif.

General Electric Co., X-Ray Dept., Milwaukee, Wisconsin

General Electric Co., Missiles & Space Div., Valley Forge, Pa.

General Instruments Corp., Woodbury, Conn.

Gerber Scientific Instrument Co., Hartford, Conn.

Gilford Instrument Labs, Inc., Oberlin, Ohio

Gilson Medical Electronics, Middleton, Wisconsin

Glassco Instrument Co., Pasadena, Calif.

Gulton Industries, Inc., Metuchen, N.J.

Harris Mfg. Co., Inc., Cambridge, Mass.

Harvard Apparatus Co., Inc., Dover, Mass.

Hewlett-Packard Corp., Palo Alto, Calif.

Hi-G, Inc., Windsor Locks, Conn.

Honeywell, Denver Div., Denver, Col.

Houston Instrument Corp., Bellaire, Texas

Hughes Aircraft Co., Fullerton, Calif.

Hydor Therme Corp., Philadelphia, Pa.

IBM, Data Processing Div., White Plains, N.Y.

Industrial Acoustics Co., Inc., New York, N.Y.

International Medical Instrument Corp., Stoneham, Mass.

Invengineering, Inc., Belmar, N.J.

Isotopes, Inc., Westwood, N.J.

IT&T Corp., San Fernando, Calif.

Jonker Business Machines, Inc., Gaithersburg, Md.

Kaman Nuclear, Colorado Springs, Colo.

Kenelco, Inc., Santa Monica, Calif.

Labindustries, Berkeley, Calif.

Lear-Siegler, Inc., Santa Monica, Calif.

Leeds & Northrup Co., Philadelphia, Pa.

Leishman X-Ray Engineering Corp., Los Angeles, Calif.

Lexington Instruments Corp., Waltham, Mass.

Limit Research Corp., Darien, Conn.

Litton Systems, Inc., Medical Electronics & Bionics Dept., Beverly Hills, Calif.

Lockheed Missiles & Space Co., Sunnyvale, Calif.

Loenco, Inc., Altadena, Calif.

MacDonnell Aircraft Corp., St. Louis, Mo.

Magnetics Co., Inc., Palo Alto, Calif.

Martin Co., Denver Colo.

Medicon, Los Angeles, Calif.

Mediquipment Corp., Santa Fe Springs, Calif.

Med. - Science Electronics, Inc., St. Louis, Mo.

Medtronic, Inc., Minneapolis, Minn.

Melpar, Inc., Falls Church, Va.

Metrix, Inc., Deerfield, Ill.

Minneapolis Honeywell Co., Minneapolis, Minn.

Mnemotron Corp., White Plains, N.Y.

Motorola, Inc., Dahlberg Div., Chicago, Ill.

North American Philips Co., Inc., Ashton, R.I.

Nuclear-Chicago Corp., DesPlaines, Ill.

Nuclear Data, Inc., Madison, Wisconsin

Nuclear Magnetic Resonance Specialties, New Kensington, Pa.

Packard Instrument Co., Inc., LaGrange, Ill.

Perkin-Elmer Corp., Norwalk, Conn.

Philco Corp., Philadelphia, Pa.

Phipps & Bird, Inc., Richmond, Va.

Physical Electronics Labs, Menlo Park, Calif.

Physical Instruments, Inc., Coral Gables, Florida

Picker X-Ray, White Plains, N.Y.

Pocketronics Corp. of America, Fort Wayne, Inc.

Polymetric Co., Reading, Pa.

Precision Instrument Co., Palo Alto, Calif.

Precision Products, Inc., Los Angeles, Calif.

Pro-Tech, Inc., Broomall, Pa.

Quindar Electronics, Bloomfield, N.J.

Radiation Technology, Inc., Atlanta, Ga.

Radio Corporation of America (RCA), New York, N.Y.

RDF Corp., Hudson, N.H.

Reactor Experiments, Inc., Belmont, Calif.

Research Specialties Co., Richmond, Calif.

Royco Instruments, Inc., Palo Alto, Calif.

Sage Instruments, Inc., White Plains, N.Y.

Sanborn Co., Waltham, Mass.

Sarns, Inc., Ann Arbor, Michigan

Savant Instruments, Inc., Hicksville, N.Y.

Schoeffel Instruments Co., Hillsdale, N.J.

Sonotone Corp., Elmsford, N.Y.

Sonomedic Corp., Westwood, N. J.

Space Labs, Inc., VanNuys, Calif.

Sperry Products, Danbury, Conn.

Starling Corp., Los Angeles, Calif.

Systron-Donner Corp., Concord, Calif.

Teca Corporation, White Plains, N. Y.

Technical Measurements Corp., North Haven, Conn.

Technical Products Co., Los Angeles, Calif.

Tektronix, Inc., Beaverton, Oregon

Telemedics, Inc., Southampton, Pa.

Tenney Engineering, Inc., Union, J. J.

Texas Instruments, Inc., Houston, Texas

The London Company, West Lake, Ohio

Thompson Ramo Wooldridge, Inc., Canoga Park, Calif.

Tracerlab, Inc., Waltham, Mass.

Trident Corp., Boston, Mass.

Turner Associaties, Palo Alto, Calif.

Twin City Testing Corp., Tonawanda, N. Y.

United Aircraft Corp., HSD Div., Space & Life Systems, Bio-Sciences & Technology, Windsor Locks, Conn.

Vacudyne Corporation, Medical Sciences Div., Chicago Heights, Ill.

Ward Laboratories, Durham, N. C.

Waters Electro-Medical Instruments, Rochester, Minn.

Westinghouse Electric Corp., X-Ray Dept., Baltimore, Md.

Whitcomb Associates, Baltimore, Md.

BIBLIOGRAPHY OF BIOTELEMETRY

I. GENERAL TELEMETRY

II. AEROSPACE TELEMETRY

III. ENDORADIOSONDES, IMPLANTED TRANSMITTERS AND BIOLOGICAL POWER SOURCES

I. GENERAL TELEMETRY

Battye, D. K. A telemetering electromyograph with a single frequency-modulated channel. Electronic Eng., 34:398, 1962.

Beenken, H. G. and Dunn, F. L. Short distance telemetry of physiological information. I. R. E. Tr. M. Electronics, PGME 12:53, 1958.

Beenken, H. G. and Dunn, F. L. Short distance telemetering of physiological information. I. R. E. Tr. Space Electronics & Telemetry, SET 2:82, 1959.

Breaksell, C. C., Parker, C. S. and Christopherson, F. Radio transmission of the human electroencephalogram and other electrophysiological data. EEG & Clin. Neurophysiol., 1:243, 1949.

Briskman, B. A. Telemetry today. Electronics, McGraw-Hill, Sept. 6, 1963.

Brown, S. G. A telephonic stethoscope. Scient. Am., 102:496, 1910.

Burroughs, J. T. & al. a new concept of intensive-care patient monitoring. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Bushor, W. E. Medical Electronics. Electronics, McGraw-Hill, Feb. 1961.

Cole, L. C. Radiotelemetering of environmental conditions for ecological field studies. Department of Zoology, Cornell University.

Coyne, J. M. Neuro-Engineering -- the "New Frontier" for life sciences research. Proceedings San Diego Symp. Biomed. Engineering 1963.

Craighead, F. C. and Craighead, J. J. Radiotracking of grizzly bears (abstract). National Geographic Society and Montana State University.

Davis, D. A. & al. The clinical applications of telecardiography. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Dunn, F. L. and Beenken, H. G. Short distance telemetering of physiological information. J. A. M. A., 169:1618, 1959.

Dunn, F. L. and Rahm, W. E., Jr. Electrocardiography: modern trends in instrumentation and visual direct recording electrocardiography. Ann. Int. Med., 32:611, 1950.

Einthoven, W. Le telecardiogramme. Arch. Internat. Physiol., 4:132, 1906.

Eisenberg, L. & al. Transistorized Pacemaker for remote stimulation of the heart by radio-frequency transmission. IRE Trans. Bio-Med. El., October 1961.

Electronics. Biotelemetery: Prime space needed. Electronics, McGraw-Hill, Feb. 22, 1963.

Telemetry on muscle power. Electronics, McGraw-Hill, Sept. 20, 1963.

Eliassen, E. A Method for Measuring the Heart Rate and Stroke/Pulse Pressures in Birds by Normal Flight, p. 22. Bergen, 1960. Norwegian Universities Press.

Ellis, D., Schneidermeyer, F. Multipack, a three-channel system of physiologic/psychophysiologic instrumentation. The American Journal of Med. El., Oct., Dec. 1962.

England, S. J. M. and Pasamanick, B. Radiotelemetry of physiological responses in the laboratory animal. Science, 133:106, 1961.

Essler, W. O. Electrocardiographs and temperatures by radio telemetry. University of Vermont and EE Dept., Burlington, Vt.

Essler, W. O. and Folk, G. E. Determination of physiological rhythms of unrestrained animals by radio telemetry, Nature, 190, p. 90, 1961.

Evans, W. F. and Sutherland, W. W. Studied communication of confined dolphins at Marineland of the Pacific. Acoustics Laboratory, Lockheed, Burbank, California.

Fischler, Frei, E. H. Subminiature apparatus for radiotelemetering of EEG data. IEEE Transaction Bio-Med. Electronics, Jan. 1963.

Franklin, D. L. & al. FM sonic gauge for continuous measurement of organ dimensions in ambulatory experimental animals. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Fuller, J. T. and Gordon, T. M. The radio inductograph. Science, 108:287, 1948.

Galler, S. R. Biophysical telemetering system. Electronic Products, July 1961.

Galler, S. R. and Fix, C. E. Animal tracking gone modern. Naval Res. Rev., pp. 11 - 14, 1961.

Geddes, L.A., Hoff, H.E. and Spencer, W.A. The broadcast demonstration in physiology. J.M. Educ., 34:107, 1959.

Geddes, L.A., Hoff, H.E. and Spencer, W.A. Short distance broadcasting of physiological data. IRE Tr. Biomed. Electronics, 8:168, 1961.

Glasscock, W.R. and Holter, N.J. Radioelectroencephalograph for medical research. Electronics, 25:126, 1952.

Glenn, W.G. & al. Bioinstrumentation and telemetry for immunochemical analysis. Proceedings 1963 National Telemetering Conference, Albuquerque, N.M.

Gold, D.C. and Malcolm, J.L. Action potentials recorded by radio transmission from the cortex of a nonanesthetized unrestrained cat. J. Physiol., 135:5p., 1957.

Gold, D.C. and Perkins, W.J. A miniature electroencephalograph telegraph telemeter system. Electronic Eng., 31:337, 1959.

Goldman, J. and Ross, D.K. Measuring work performance. Electronics, 34:196, 1960.

Grau, R.B. Semiconductor strain gages in bioinstrumentation. 18. Ann. ISA Conf. & Exh., Chicago, September 1963.

Griffen, D.R. Potential uses of telemetry in studies of animal orientation (abstract). Biological Laboratories, Harvard University.

Griffith, R.S. Mouse transmits own temperature. Radio Electronics, pp. 101, 106, 1960.

Hanish, H.M. Telemetry of Respiration and the Electrocardiogram from the same pair of electrodes. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Hess, O.W. Litvenko, E.E. Telemetering physiolog. data: Instrumentation of fetal EKG and radiotransmission of intrauterine pressures. Proceedings 1963 National Telemetering Conference, Albuquerque, N.M.

Hickmann, D.M. & al. A portable miniature transistorized radio-frequency coupled cardiac pacemaker. IRE Trans. Bio-Med., El., October 1961.

Himwich, W.A., Hambrecht, F.T. Telemetry systems in physiological research. Proceedings 16. Ann. Conf. Engineering in Medicine & Biology, Baltimore, Nov. 1963.

Hoare, D.W. and Ivison, J. M. Measuring the heart rate of an active athlete. Electronic Eng., 33:6, 1961.

Hoefner, C.E., Seal, H.R. A central cardiac monitoring system. Proceedings 16. Ann. Conf. Engineering in Medicine & Biology, Baltimore, Nov. 1963.

Holter, N.J. Radioelectrocardiography. Ann. New York Acad. Sc., 65:913, 1957.

Holter, N.J. and Gengerelli, J.A. A miniature amplifier transmitter for the broadcasting of bioelectric potentials. 117th Annual Meeting American Association Scientific Bulletin, 1950.

Holter, N.J. and Gengerelli, J.A. Remote recording of physiological data. Rocky Mt. M.J., 46:749, 1949.

Jacobsmeyer, H.T., Cooper, T.H. Telemetry in clinical and experimental cardiovascular physiology. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Johnston, E.B. Telemetry of physiological data. Proceedings 1963 National Telemetering Conference, Albuquerque, N.M.

Ko, E., Yon, E. and Thompson, W. Tunnel diode FM transducer for medical research. Case Institute of Technology, Cleveland, Ohio, 1962.

Ko, W.H. Progress in microelectronics biotelemetry. ISA Conf. Chicago, Sept. 1963.

Larks, S.D. Regional FM phone data transmission. Digest 15 Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Ley, W. Rockets, Missiles and Space Travel, p. 263. New York, 1958, Viking Press.

Lindgren, N. Bionics. Electronics, McGraw-Hill Publ. Co., Feb. 9, 1962.

Long, F.M. Biological energy as a power source for a physiological telemetering system. 1962 IRE Internat'l. Convention Record, Part 9.

MacInnis, H.F. The clinical application of radioelectrocardiography. Connecticut M.A.J., 70:574, 1954.

Mack, E. An apparatus for recording heartbeat of a fetus. IRE Transactions Med. Electronics, Dec. 1958.

Malcolm, J. L. The electrical activity of cortical neurones in relation to behavior as studied with microelectrodes in unrestrained cats. In Ciba Foundation Symposium in the Neurological Basis of Behavior, pp. 295 - 301. Boston, 1958. Little, Brown & Co.

Marshall, W. H. Development and use of short wave radio transmitters to trace animal movements. Progress Report, National Science Foundation Grants #GS-8644 and G-17858. March 1, 1962.

Marshall, W. H. Radio-tracking of porcupines and ruffed grouse. Presented at the interdisciplinary conference on the "Use of Telemetry in Animal Behavior and Physiology." American Museum of Natural History, New York, March 28 - 31, 1962.

Marshall, W. H., Gullion, G. W. and Schwab, R. G. Early summer activities of porcupines as determined by radio-positioning techniques. J. Wildlife Management, 26:75, 1962.

Oviatt, M. C. Bio-electronic telemetry system. Presented at 13th Southwestern IRE Conference and Electronics Show, Dallas, Texas, April 19 - 21, 1961.

Parin, V. V. Problems of biological telemetry (in Russian), Abstract in Aerospace Medicine, July 1963, #607.

Peiss, C. N., McCook, R. D., Rovick, A. A. and Randall, W. C. Electronic instrumentation in a medical physiology laboratory. J. M. Educ., 35:660, 1960.

Pessar, T. H. & al. The application of telemetry to industrial medicine. The American Journal of Med. El., Oct. - Dec. 1962.

Potter, A. G., McMechan, J. D. A pulse-rate modulation system for biomedical radiotelemetry. Digest 15. Ann. Conf. Engineering in medicine & Biology, Chicago, Nov. 1962.

Radcliffe, G. The necessity of physiological monitoring in the general hospital. Tr. New York Acad. Sc., 23:1, 1960.

Ray, C. D., Bickford, R. G. Electroencephalographic and response-averaged bioelectric data transmitted via telephone link. Proceedings 1963 National Telemetering Conference, Albuquerque, N. M.

Robbins, K.E., Marko, A. An improved method of registering respiration rate. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Schuder, J.C. & al. Theoretical analysis of micromodule pacemaker receiver. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Shipton, H.W. A simple telemetering system for telemetering electrophysiological data. E.E.G. Clin. Neurophysiol., 12:922, 1960.

Speery, C.J. and Gadsen, C.P. Miniature subcutaneous frequency-modulated transmitter for brain potentials. Science, 134:1423, 1961.

Spencer, W.A. & al. Automation in the Hospital Care. 1962 IRE International Convention Record, part 9.

Stander, R.W. & al. Telemetry of physiologic data during parturition.

Proceedings 1963 National Telemetering Conference, Albuquerque, N.M.

Sullivan, G.H. and Bredon, A.D. Biotel-human biological telemetry system. Presented at the National Telemetering Conference, Chicago, May 24, 1961.

Sullivan, W.E., Farr, J.T. and Steinberg, C.A. A physiological telemetry and data conversion system. Presented at the IRE National Convention, New York, March 1960.

Tursky, B. & al. Problems encountered in telemetering of physiological activity of schizophrenics in an experimental psychiatric ward. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Warner, H.A. A remote control brain stimulator system. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Webb, J.C., Campbell, L.F. and Hartsock, J.G. Electrocardiograph telemetering (radio). IRE Nat. Convention Rec., 9:43, 1958.

Winters, S.R. Diagnosis by wireless. Sc. Am., 124:465, 1921.

II. AEROSPACE TELEMETRY

Barr, N. L. An account of experiments in which two monkeys were recovered unharmed after ballistic space flight. Aerospace M. J., 30:871, 1959.

Barr, N. L. Long-distance telephone technic is latest aid to diagnosis. Modern Hosp., 91:64, 1958.

Barr, N. L. The radio transmission of physiological information. Mil. Surgeon, 114:79, 1954.

Barr, N. L. and Voas, R. B. Telemetering physiological responses during experimental flights. Am. J. Cardiol., 5:54, 1960.

Breckler, A., Kaeburn, L., Ettlesch, B. L. and Douglas, D. W. Space canaries: implicit biological monitoring. Presented at the ARS 14th Annual Meeting, Sheraton Park, Washington, D. C., November 16 - 20, 1959.

Brown, E. J. Biomedical instrumentation as applied to the astronauts and primates of project Mercury. Paper ISL 61. Instrument Society of America, St. Louis Meeting, January 17-19, 1961.

Bugrov, B. G., Gorlov, O. G., Petrov, A. V., Serov, A. D., Yugov, Y. M. and Yakovlev, V. I.
Preliminary results of scientific investigations carried out with the aid of the first Soviet artificial earth satellites and rockets. III. Medico-biological investigations with rockets. Sbornik Statey (Collected Reports) No. 1, 1958.

Carlson, L. D. Requirements for monitoring physiological function in Space flight. Space Medical Symposium; Astronautik (Stockholm), 2(4): 310 - 320. 1961.

Chambers, R., Nelson, J. G. Biomedical and psychological instrumentation for monitoring pilot performance during centrifuge simulation of space flight. Proceedings, San Diego Symp. Biomed. Eng., 1963.

Discoverer III biomedical data report. Directorate of bioastronautics projects. A. F. Ballistic Missile Division, Hq. A. R. D. C., Los Angeles 45, California. WDZP report No. 2.

Flickinger, D. The dynamic survival potential in manned space operations. 1958 IRE WESCON Convention Record, part 5.

Galkin, A. M. et al. Investigations of the vital activity of animals during flights in hermetically sealed cabins to an altitude of 212 km. III. Sbornik Statey Collected Reports, No. 1, pp. 1 - 26, 1958.

Goldberg, M. N., Mills, R. A. and Brockley, W. V. Instrumentation package for in-flight studies. W. A. D. C. TR 60-83. Feb., 1960.

Graybiel, A. An account of experiments in which two monkeys were recovered unharmed after ballistic flight. Aerospace Med., 30:871, 1959.

Graybiel, A., McNinch, J. H. and Holmes, R. H. Observations on small primates in space flight. In: Tenth International Aeronautical Conference, 1959, 1:394 - 401, 1960.

Green, C. D. et al. Studies of escape from ballistic space vehicles. I. Biomedical evaluation. II. Instrumentation. School of Aerospace Medicine, Brooks AFB Report 61-29, April 1961.

Hanish, H. A subminiature biological telemetry system. Proceedings of the Pilot Clinic on the Instrumentation Requirements for Human Comfort and Survival in Space Flight. Ohio State University, October 26-27, 1959.

Hanson, M. L., Preston, R. J. Bio-telemetry with molecular electronics. Proceedings San Diego Symp. Biomed. Eng. 1963.

Hendler, E. and Santa Maria, L. J. Response of subjects to some conditions of a simulated orbital flight pattern. Aerospace Med., 32:126, 1961.

Henry, J. P., Ballinger, E. R., Maher, P. G. and Simons, D. G. Animal studies of the subgravity state during rocket flight. J. Aviation Med., 23:421, 1952.

Henry, J. P. Flight above 50,000 feet: a problem in control of the environment. Astronautics, 1:12, 1954.

Henry, J. P. Physiological laboratories in rockets. Bull. M. Res., 10:2, 1956.

Henry, J. P. Problems of escape during flight above 50,000 feet. In: Physics and Medicine of Upper Atmosphere. A study of the Aeropause, XXIV, pp. 516 - 532. Edited by White, C. S. and Benson, O. O., Jr. Albuquerque, 1952. University of New Mexico Press.

Henry, J. P. Some correlations between psychologic and physiologic events in aviation biology. J. Aviation Med., 29:171, 1958.

Henry J. P. The 1950 symposium on space flight. J. Space Flight, 2:8, 1950.

Henry, J. P. et al. Animal studies of the effects of high negative acceleration. Rep. 1, Memo Rep. No. MCREXD-695-74N, USAF, January 20, 1949.

Hetherington, A. W. Performance assessing human capability in space. 1958 IRE WESCON Convention Record, part 5.

Hixson, P., Paludan, C. T. and Downs, S. W. Primate bioinstrumentation for two Jupiter ballistic flights. IRE Tr. M. Electronics, ME 7:318, 1960.

Holden, G. R., Smith, J. R. and Smedal, H. A. Physiological instrumentation systems for monitoring pilot response to stress at zero and high G. Presented at annual meeting of Aerospace Medical Association, Chicago, Illinois, April 24 - 27, 1961.

Holden, G. R., Smith, J. R. and Smedal, H. A. Physiological instrumentation systems for monitoring pilot response to stress at zero and high G. Aerospace Med., 33:420, 1962.

Kelly, G. F. and Phipps, C. G. In-flight bioinstrumentation in a near space operational environment. USN Missile Center, Pt. Mugu, California, Misc. Publ. NMC-MP-62-2, February 28, 1962.

Kousnetzov, A. G. Some results of biological experiments in rockets and Sputnik II. J. Aviation Med., 29:781, 1958.

Laughlin, C. P. In-flight measurement, transmission and assessment of astronaut physiologic responses. Aerospace Eng., Jan. 1962.

Manhigh III USAF manned balloon flight into the stratosphere. US Department of Commerce, Office of Technical Services. AFMDC-TR-60-16, April 1961.

Mayo-Wells, W. J. Radio telemetering. In: Physics and Medicine of Upper Atmosphere, A study of the Aeropause, XXIV, pp. 457-59. Edited by White, C. S. and Benson, O. O., Jr. Albuquerque, 1952, University of New Mexico Press.

Mazza, V. High altitude bailouts. J. Aviat. Med. 22:403, 1951.

McLennan, M.A. Application of radio telemetering to biophysical research. Presented at National Telemetering Conference, 1953.

Miller, B. System monitors bioastronautic data. Aviation Week and Space Technol., Oct. 23, 1961.

Paludan, T.U. Thermistors, the key to biomedical measuring in space. Electronic Industries, Vol. 19, April 1960.

RCA. Techniques of physiological monitoring. Vol. 1. Fundamentals. Aerospace Med. Div., Wright-Patterson AFB, Ohio, Sept. 1962.

Roman, J.A., Ware, R.W. Adams, R.M., Warren, B.H. and Kahn, A.R. School of Aerospace Medicine physiological studies in high performance aircraft. Aerospace Med. 33:412, 1962.

Simons, D.G. Air Force Missile Development Center technical report. AFMDC-TR-59-24, Holloman Air Force Base, New Mexico, 1959.

Simons, D.G. Air Force Missile Development Center technical report. AFMDC-TR-59-28, ASTIA Document No. AD 216892, Holloman Air Force Base, New Mexico, 1959.

Simons, D.G. Psychophysiological aspects of the Manhigh experiment. Presented at Sealed Cabins Session, American Rocket Society 13th Annual Meeting, New York, November 17-21, 1958.

Simons, D.G., Flinn, D.W. and Hartman, B. Psychophysiology of high altitude experience. Prepared for book. "Unusual Environments and Human Behavior." To be edited by Burns, N.M. and Chambers, R.M. School of Aerospace Medicine, Brooks AFB, Texas.

Simons, D.G. A personalized radiotelemetry system for studying CNS function in aerospace flight. Digest 14. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Stuart, J. Extraterrestrial biological Instrumentation Problems. Proceedings San Diego Symp. Biomed. Eng. 1963.

WU, L.S. A proposed medical instrumentation system for early manned research spacecraft and space laboratory. Proceedings San Diego Symposium for Biomed.

III ENDORADIOSONDES, IMPLANTED TRANSMITTERS AND BIOLOGICAL POWER SOURCES

Allington, R.W. What's the stomach pressure? University of Nebraska Blue Print, pp. 10-11, May 1959.

Ardenne, M.V. Der verschluckbare intestinal sender. Ein Beispiel fur Den Einsatz Moderner Technik in Der Medizin. Die Technik, 1958, 13. Jahrgang, Heft 9, Seit 614 -16.

Ardenne, M.V. and Sprung, H.B. A swallowable intestinal transmitter. Ztschr. Gesamte inn. Med., 13:269, 1958.

Ardenne, M.V. and Sprung, H.B. Uber versuche mit einem verschluckbaren intestinalsinder. Die Naturwissenschaften, 1958, 45. Jahrgang, Heft 7, Seit 154 - 55.

Bagno, S., Liebman, F. and Cosenza, R. Detecting muscle potentials in unanesthetized animals. Electronics, 33:58, 1960.

Beaupre, M.A. and Evans, H.A. Internal biological telemetry system feasibility study. North American Aviation Report N60-1086 Contract No. AF04(647)-585. Los Angeles, California.

Brewer, A.A. and Hudson, D.C. Application of miniaturized electronic devices to the study of tooth contact. J. Dent. Res., 39:758, 1960; School of Aviation Medicine Report 61-12, October 1960.

Busser, J.H. and Mayer, M. Radio thermometer that fits in a penguin egg. ONR Research Reviews, June 1957.

Cholvin, N.R. Development and operation of chronically implanted electronic devices with their effects in experimental animals. 1962 IRE Convention Record, part 9.

Connell, A.M. and Rowlands, E.N. Wireless telemetering from the digestive tract. GUT, 1960.

Cooper, W.N. and Beaupre, M.A. Internalized animal telemetry system engineering considerations. North American Aviation, Inc. Presented at the 32nd Annual Meeting of the Aerospace Medical Association at Chicago, Illinois, April 26, 1961.

Dordick, H.S., Balin, H., Israel, S.L. and Hatke, F. The determination of Ovarian function by means of permanently implanted endoradiosondes. International Conference on Medical Electronics, New York, July 1961.

Douglas, D.W. and Seal, H.R. Internalized animal telemetry system electronic considerations. Presented at the Aerospace Medical Association 32nd Annual Meeting, Chicago, Illinois, April 24 - 27, 1961. Spacelabs, Van Nuys, California

Eklund, C.R. and Charlton, F.E. Measuring the temperatures of incubating penguin eggs. Am. Scientist, 47:80, 1959.

Essler, W.O. State University of Iowa studies in natural history. Radio telemetry of electrocardiograms and body temperatures from surgically implanted transmitters. State University of Iowa, Vol. 20, 1961.

Ettelson, B.L. Internal animal telemetry - a feasibility test program. American Rocket Society, Publ. 1426 - 60, New York, 1960.

Ettelson, B.L. and Pinc, B.W. Development of an internalized animal telemetry system. Presented at the 32nd Annual Meeting of the Aerospace Medical Association, Chicago, Illinois, April 24 - 27, 1961. Spacelabs, Inc., Van Nuys, California.

Farrar, J.T., Berkley, C. and Zworykin, V.K. Telemetering of intraenteric pressure in man by an externally energized wireless capsule. Science, 131:1814, 1960.

Farrar, J.T. and Bernstein, J.S. Recording of intraluminal gastrointestinal pressures by a radio-telemetering capsule. Gastroenterology, 35:603, 1958.

Farrar, J.T. and Zworykin, B. Telemetering of gastrointestinal pressures in man by means of intraluminal capsule energized from an external wireless source. The Physiologist, August 1959.

Farrar, J.T., Zworykin, B.D. and Berkley, C. Telemetering of physiological information from the gastrointestinal tract by an externally energized capsule. International Conference on Medical Electronics, July 1960.

Farrar, J.T., Zworykin, V.K. and Baum, J. Pressure-sensitive telemetry capsule for the study of gastrointestinal motility. Science, 126:975, 1957.

Fox, R.H. and Wolff, H.S. A high sensitivity, high stability temperature-sensitive radio pill. International Conference on Medical Electronics, July 1961.

Gillings, R.R.D., Kohl, J.T. and Graf, H. Study of tooth contact patterns with the use of miniature radio transmitter. International Conference on Medical Electronics, New York, July 1961.

Haynes, H.E. and Witchey, A.L. The pill that talks. RCA Engineer, 5:52, 1960.

Honig, W.M. Microminiature passive telemetry for biological voltages. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Jacobson, B. Antenna servo systems for tracking endoradiosonde movements. International Conference on Medical Electronics, New York, July 1961.

Jacobson, B. Endoradiosonde techniques for telemetering physiological data from the alimentary canal. Second International Conference IFME, Paris, 1959.

Jacobson, B. Endoradiosondes. Svenska. Lak., 55:587, 1958.

Jacobson, B. and Lindburg, B.F.M. receiving system for endoradiosonde techniques. I.R.E. Tr. M. Electronics, ME-7:334, 1960.

Jacobson, B. and MacKay, R.S. A pH endoradiosonde. Lancet, 1:224, 1957.

Kantorowitz, A. Clinical experience with an implanted controllable cardiac pacemaker. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Keller, J.W. & al. An implantable synchronous cardiac pacer. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

MacKay, R.S. Endoradiosondes, further notes. I.R.E. Tr. M. Electronics, ME-7:67, 1960.

MacKay, R.S. Radio telemetering from within the human body. I.R.E. Tr. M. Electronics, ME-6:100, 1959; Science, 134:1196, 1961.

MacKay, R.S. and Jacobson, B. Endoradiosonde. Nature, 179:1239, 1957.

MacKay, R.S. and Jacobson, B. Pill telemeters from digestive tract. Electronics Engineering, 31:51, 1958.

Marchal, M. and Marchal, M.T. Nouvelle methods d'exploration de la digestion per capsule radio electrique ingerable. Compt. rend. Acad. Sc., 246:3519, 1958.

Nickel, V. and Allen, J. Conference on External Power, Lake Arrowhead, California, 1960, National Academy of Sciences, National Research Council Publications 874, December 1961. Library of Congress Card 61-60022.

Noeller, H.G. Endoradiosondes for oxygen measurement: structure, function and practical clinical significance. International Conference on Medical Electronics, New York, 1961.

Noeller, H.G. Endoradiosondes for the determination of oxygen content. International Conference on Medical Electronics, New York, 1961.

Noeller, H.G. The techniques of measuring by endoradiosondes and their adaption to pediatrics. Second International Conference IFME, Paris, 1959.

Payne, L.C. Simple telemetering system for signalling high rumen pressure. Science, 131:611, 1960.

Ramorino, M.L. and Lepri, F. Studies on gastrointestional motility; radiotelemetered recordings combined with synchronized cinefluorography. International Conference on Medical Electronics, New York, 1961.

Smyth, C.N. and Wolff, H.S. Application of endoradiosonde or wireless pill to recording of uterine contractions and fetal heart-sounds. Lancet, 2:412, 1960.

Sprung, H.B. Clinical results of the application of the intestinal transmitter. Second International Conference IFME, Paris, 1959.

Steinberg, C.A., Sullivan, W.E. and Farrar, J.T. A physiological telemetry and data conversion system for gastrointestinal pressures. Presented at SWIRECO, Houston, Texas, April 20-22, 1960.

Storer, E.H., Dodd, D.T., Snyder, P.A. and Eddlemen, C.O. A telemetering capsule for gastrointestinal pH measurement. International Conference on Medical Electronics, New York, July 1961.

Sullivan, G.H., Schulkins, T.A. and Freedman, T. Internalized animal telemetry biomedical surgical considerations. Presented at the Aerospace Medical Association 32nd Annual Meeting, Chicago, Illinois, April 24 - 27, 1961. Spacelabs, Inc., Van Nuys, Calif.

Wegner, M.A., Henderson, E.G. and Dunning, J. S. Magnetometer method for recording gastric motility. Science, 125:990, 1957.

Young, I.J., Naylor, W.S. Implanted two-way telemetry in the laboratory cat. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

Zworykin, V.K., Farbar, J.T., Bostrom, R.C. Hatke, F. L. and Deboo, G. J.

The measurement of internal physiological phenomena using the passive type telemetering capsule, part 9, pp. 141 - 44, I.R.E. Convention, New York, March 1961.

Zworykin, V.K. & al. New advances in passive telemetering implants. Digest 15. Ann. Conf. Engineering in Medicine & Biology, Chicago, Nov. 1962.

The bibliography is based on the system used in "A Bibliography of Biological Telemetry" in The American Journal of Medical Electronics, October-December 1962.

Further Sources

"Telemetering Systems for the Life Sciences - A Survey"
North American Aviation, Inc., Downey, Calif., March 15, 1963.

"Selected Bibliography on Biotelemetry" Bibliography No. Q 497, Nov. 1963, by R. J. Potocko, Man Machine Information Center, Documentation, Inc.

"Bio-Telemetry; the Use of Telemetry in Animal Behavior and Physiology in Relation to Ecological Problems" by L. E. Slater; a Pergamon Press Book, the Macmillan Company, New York 1963.

"Bibliography on Medical Electroncs" prepared by Medical Electronics Center of the Rockefeller Institute; published by PGME, IRE, New York, July 1960.