# ON SOME PROBLEMS OF BIO-ENGINEERING WITH REFERENCE TO INSTRUMENTATION

*A Thesis*
*submitted in partial fulfilment*
*of the requirements for the Degree*
*of*
MASTER OF ENGINEERING
*in*
ADVANCED ELECTRICAL MACHINES

*By*
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# CERTIFICATE

Certified that the thesis entitled, "On Some Problems of Bio-Engineering With Reference To Instrumentation", which is being submitted by Sri V.K. Puri in partial fulfilment for the award of the Degree of Master of Engineering in Electrical Engineering (Advanced Electrical Machines) of the University of Roorkee, is a record of bonafide work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further certified that he has worked for 7 months from December 1969 to June 1970 for preparing this dissertation.

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# SYNOPSIS

During the last decade an extra-ordinary development has occurred in the application of physical and engineering principles to the understanding and solution of problems arising in medicine and biology. Development of bio-instrumentation is the most important aspect of bio-engineering. Measurement of such biological quantities as the pressure, temperature, velocity, and constituency of the blood, the capacity, frequency, sounds, and electrical activity of the heart are routine. An attempt has been made,here, to discuss some of the problems of bio-engineering in relation to instrumentation. This has been realised by grouping the problems under four headings, namely - 1) Bio-telemetry, 2) Telestimulation, 3) Measurement of physiological variables, and 4) Bio-control systems. Each group is recognized as a "Section".

First section incorporates - 1) The telemetry of body temperature, 2) A telemetring system for obtaining information on the motility of internal organs and 3) Telemetering the Electrocardiogram of free swimming fish. For body temperature telemetry, a Hartley Oscillator is used as the transmitter and a thermistor is used as the transducer. As the temperature sensed by the thermistor changes its resistance changes consequently, thereby producing a change in the frequency of oscillation of the transmitter. A radio receiver is used to pick up and detect the changes in the signal thus transmitted.

For securing information on the motility of internal organs a telemetering system using an elongation sensor and an implantable transmitter has been described. This can be used to study the motility of the internal organs such as stomach, heart, intestine, bladder, etc.

A telemetering system suitable for the purpose of transmitting the electrocardiogram of free swimming in the case of a fish that can be carried on the back of the fish has been described. This telemetering system is of frequency-modulated type. The transmitter can be operated with the help of a magnet which can be held in hand.

Second section has been devoted for discussion of telestimulation problem. In this case, for short range transmission of electrical stimulating signals, the receiving circuit is placed within the subject, which comprises a crystal set receiver. Near or around the subject is placed a transmitting coil which is activated by impulses of radio-frequency energy from a pulsed oscillator. At great ranges, radio transmitter can still be used to activate receiver and stimulators being carried by test animals.

Third section includes - 1) Ovulation detection, 2) Measurement of physiological motions, 3) Measurement of respiration rate, 4) Measurement of Oral and Nasal air-flow, and 5) Miniature Pressure transensor. Temperature measurements can be used to know the occurrence of ovulation. The location of the sensing device and the method of measurement play an important part in accurately predicting the the ovulation cycle.

The motion within the human body in the presence of foreign metallic bodies can be measured by the use of an electronic device which has been discussed under the heading - "Measurement of physiological motions".

The respiration rate in the case of critically ill patients can be determined by measuring the central venous pressure. This venous pressure is transmitted to a strain gauge transducer. A signal conditioning method described under the heading - "Measurement of respiration rate", is used by employing a low-pass filter to remove the pulsatile variations related to heart action which are superimposed on the low-frequency respiratory changes.

Unimpaired oral and nasal airflow during speech can be measured with the help of an integrating flowmeter described under the heading - "Measurement of oral and nassal airflow". Warm wire velocity sensors arranged in the form of two independent arrays are used to sample the oral and nasal flow fields. The indications of these velocity samples, which are linear, are added in order to determine the oral and nasal flows.

A method for measurement of intraocular and other physiological pressures has been described under the heading- "Miniature Pressure transensor". This method consists of a displacement transducer small enough to be implanted in the eye of a small animal. This passive resonant transensor absorbs energy from an oscillating coil outside of the animal at a frequency which will depend upon the pressure in the eye.

Fourth section includes - 1) Paralyzed muscles control, and 2) Neuromuscular control system. Myoelectric control of paralyzed muscles has been described under the heading- "Paralyzed muscles control". This is done by electrical stimulation which is used for restoring paralyzed muscles functions.

A human subject performs rapid skilled movements at such a rate that conscious control involves the strategic selection of a set of detailed plans of control which have been learned by the subject previously. This has been discussed under the heading- "Neuromuscular control system".

Practical models were constructed to demonstrate the principles of operation in the case of problems concerned with - 1) Ovulation detection, 2) Telemetry of body temperature, and 3) Telemetry system for obtaining information on the motility of internal organs.

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# INTRODUCTION

Bio-engineering, biomedical engineering, or engineering for biology and medicine, is that field which deals the interaction between the engineering sciences and biology and medicine. Because engineering is really two fields-"building", using scientific principles, and analysis of complex mechanisms - bioengineering also is two fields, that is, one concerned with building devices for biology and medicine or in other words, the development of instrumentation and data processing systems, and the other, the analysis of complex biological systems by means of the application of engineering science.

In medicine and biology good telemetry is the key to effective use of systems. All systems consist of an input, a medium to be traversed and an output. In a broad sense, the field of telemetry is responsible for unity and integrated function of these three parts of a system. Telemetry can be defined as any link between signal source and receiver. Biomedical telemetry can take many forms. Broadly speaking it could be a sound such as a baby's cry or it could be an odour such as coming from a diabetic.

Beyond the body's internal system, telemetry may be useful in the hospital area to study a patient while he is ill and can monitor him without disturbance. The same holds true for biological studies with other species. Telemetry from within the body is important because of the following reasons.

1) It gives quicker and at the same time accurate information of the physiological changes occurring inside the body.
2) When it becomes necessary for the accurate diagnosis that the patient should not be aware of what is being done with him to diagnose the disease, telemetry from within the body is useful.
3) In case of animal study where discussion and cooperation is impossible bio-telemetry is needed.
4) Animal tracking and the remote control of physiological changes occurring inside the body is possible only by means of telemetry.

The relevance of biomedical telemetry to many fields of zoology, ecology, and animal physiology is increasing steadily, due to the subminiature size of radio transmitters that can be swallowed or implanted in animals and which can provide the means of recording physiological variables in the free moving state. Recent developments include pressure transmitters small enough to be placed in the eye, units for tracking wild animals, and pill sized transmitters that can operate continuously for several years.

Out of many bio-variables, some of the variables that can be monitored are - motion or activity, internal temperature, breathing pattern, blood pressure, sound, heart and brain wave shapes and gastric, bladder or uterine pressures. If one wishes to record a particular information from a human or an animal, it is necessary to consider the sensor or transducer that will often prove the most uncertain or difficult past of the overall system. Physiological variable for which a sensor can be conceived can have its value telemetered if this is desirable.

Ultrasonic energy is being used these days for monitoring position and movements of various body structures. In one of these methods an electrical impulse is applied to a piezoelectric element which gives out a sharp click of sound. Some of this outgoing sound energy is reflected back successively from each interface between structures within the body, and these returning echoes generate electrical signals in the original transducer. This succession of echoes can be displayed on an oscilloscope to get a pattern representing the cross-section of the body. In some cases, ultrasonic methods might substitute for radio telemetry. Thus the size of a small hollow bubble of glass varies with pressure, and can be monitored ultrasonically.

General activity is a parameter of interest, and it can be monitored in a number of ways. If the subject is confined to a general region, then the easiest way can be to reflect a sound beam off to him, and monitor any returning waves that is Doppler shifted in frequency due to movement. A subject carrying a sound transmitter of fixed frequency can also be monitored as to velocity by noting frequency shifts at one or two receivers. This may be particularly useful in determining the swimming speeds of certain animals. The rate of change of velocity gives acceleration, which is a measure of work capability, or of decceleration which is a measure of drag. The time integral of velocity gives an approximate idea of the position relative to some starting point. An accelerometer placed on an animal may be useful in monitoring these variables.

Social interactions might be studied by monitoring the separation of animals rather than their positions. A unit can be designed which will give out a sound click each time it "hears" a click. If one of these is placed on each of a pair of animals, then the resulting click rate decreases with separation. General nearness can be sensed by a magnet and transmitting magnetometer or related field strength measurements.

Besides the passive transducers, i.e. those that receive energy from biological sources and thus tell something of body function, there are active transducers that deliver power to the body for diagnosis, therapy and control. The familiar medical X-ray is an excellent example of the application of external energy to diagnosis.

Some interesting advancements being made in active transducers include the use of ultrasound, lasers, fibre optics, microminiaturization and implantation. The most significant electronic development of this decade, integrated microminiature circuits, has a direct application to bioengineering in implantable instruments for metering and control.

However, integrated circuits have a serious obstacle in their use for implants, that is the development of suitably small power sources. Biochemical generation of power internally or magnetic coupling of power through the skin is being employed.

Due to the fact that medical instruments now-a-days cover a wide area and have become socially and commercially important, their design is an important aspect for the bioengineer. Design criteria relating to signal to noise ratio, frequency response, sensitivity, impedance levels, reliability, stability, safety, size and power requirements are somewhat more important for biomedical instrumentation than for many other types. Noise arises from muscle tremor and galvanic effects, besides the usual source of noise i.e. random thermal sources present in all instruments. The slow varying nature of metabolic processes imposes strict requirements on low-frequency characteristics. Many bioelectric processes such as E.E.G. give rise to body-surface potentials in microvolts, and amplification is necessary. In the case of electronic failure, the currents delivered to human subjects impose a limit on the design of the circuit. Implanted instruments must be reliable and long-lived, stable, safe and small.

# SECTION

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## BIO - TELEMETRY

# CHAPTER I

## TELEMETRY OF BODY TEMPERATURE

### Introduction

This is a unique measurement in that it defines the activities of cellular metabolism (chemical changes going on in the cells of living matter) within the body. For example temperature of blood leaving the liver indicates the metabolic process taking place in that organ. The temperature of the muscle bundle increases with the tension of the activity of the muscle. As such temperature is the direct indicant of the energies being spent, the thermal storage capacity and the adequacy of the thermoregulatory system.

### Temperature Sensors

Mechanical expansions can be used to note the temperature changes. Among other sensors come thermocouple, diodes and thermistors. There are also transducers of temperature in which changes affect some parameter of the circuit such as resistance, capacitance, inductance, or mutual inductance. Sometimes it is convenient to use such components that show a change in resistance corresponding to a change in temperature. Thermistors are resistors which are sensitive to temperature and decrease in resistance with an increase in temperature. These have relatively high temperature coefficients and also show a negative resistance due to their high negative temperature coefficient.

## The Transmission

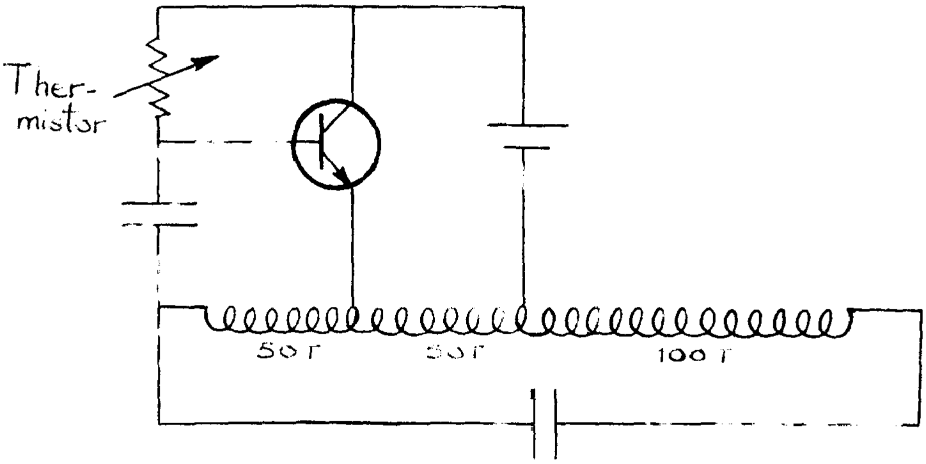
Body temperature can be transmitted in the form of radio signals for which an oscillator circuit can be employed. Here the changes in the frequency of transmission will give an indication of the corresponding changes in temperature of the particular organ or part of the body under investigation.

Figure 1.1 shows a squegging oscillator circuit, where the pulse rate is being controlled by a thermistor. In this case, the battery is tapped down on the coil to give a stronger radio signal. The clicking rate of this circuit is rather slow so that it can be distinguished by ear.

Thermistors are very less affected by pressure. However, higher resistance thermistors can give wrong information of temperature in the presence of moisture. With a thermistor, temperature changes of the order of 0.001° C can also be measured. For this bridge circuits should be used. The drift in a blocking oscillator having a rather long life may be of the order of 0.1°C per month due to such factors as battery aging. Such transmitters as these can be made rather small.

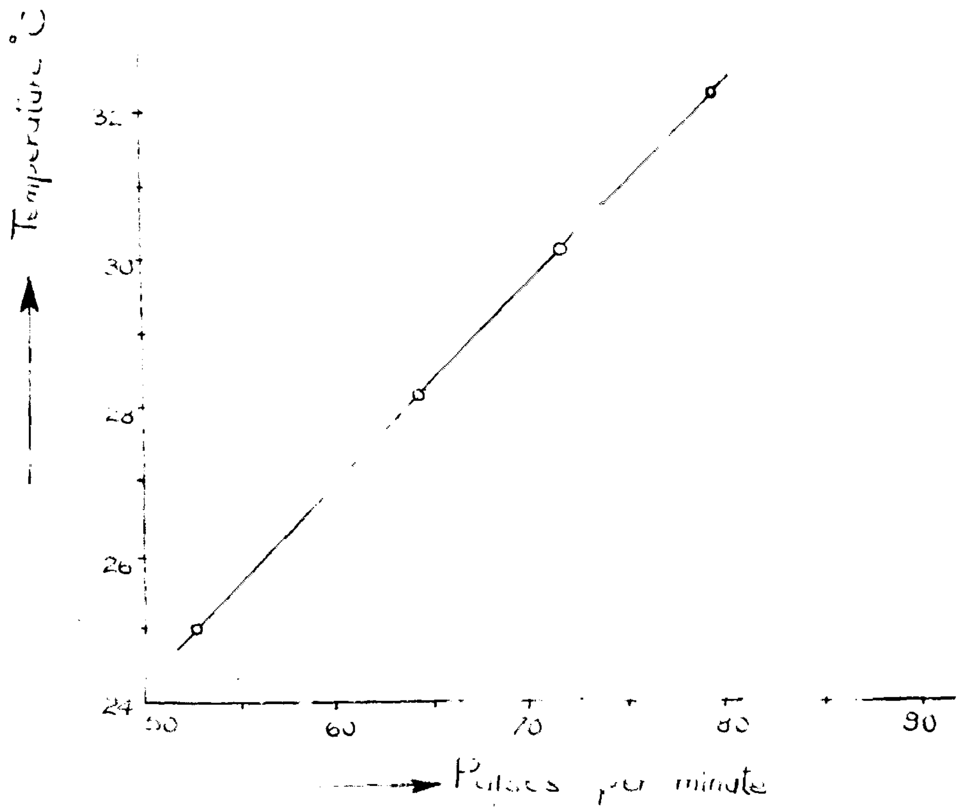
## Active Transmission

An active transmission is one containing a battery powering an oscillator. In this units should be included that contain active element (transistor or tunnel diode)



(a)

Fig. 1·1 Squegging Oscillator Circuit



(b)

Fig. 1·1 Showing response of a Blocking-oscillator temperature transmitter.

energized by a biological power source, by a storage battery recharged by external fields or by direct induction from an external source.

## Passive Transmission

A passive transmission is not as efficient as an active transmission due to rather weak and unreliable signals in the former case. However, in the following four circumstances passive transmission is necessary.

1. To study small animals which could not carry a heavy transmitter. Telemetry of temperature from mice is a possible example.

2. In human beings one might wish to follow the progress of recovery from surgery by a telemetring device that could be left in place indefinitely. A small passive unit in the ventricle of the head might be inserted through a hyperdermic needle with less risk than a unit containing some sort of a battery.

3. Instances where extreme reliability of the unit is critical.

4. In connection with the glaucoma problem a very small, long lived, pressure transmitter is needed.

## Echo Capsule

This capsule contains no battery and is energized from outside the human body. Figure 1.2 shows the circuit for this. Its principle of operation is described as follows.

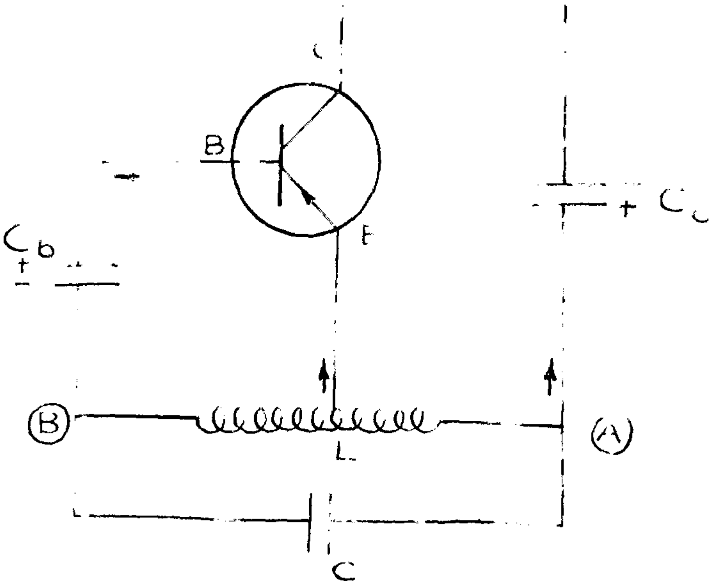


Fig. 1·2 Fundamental Circuit of Echo Capsule

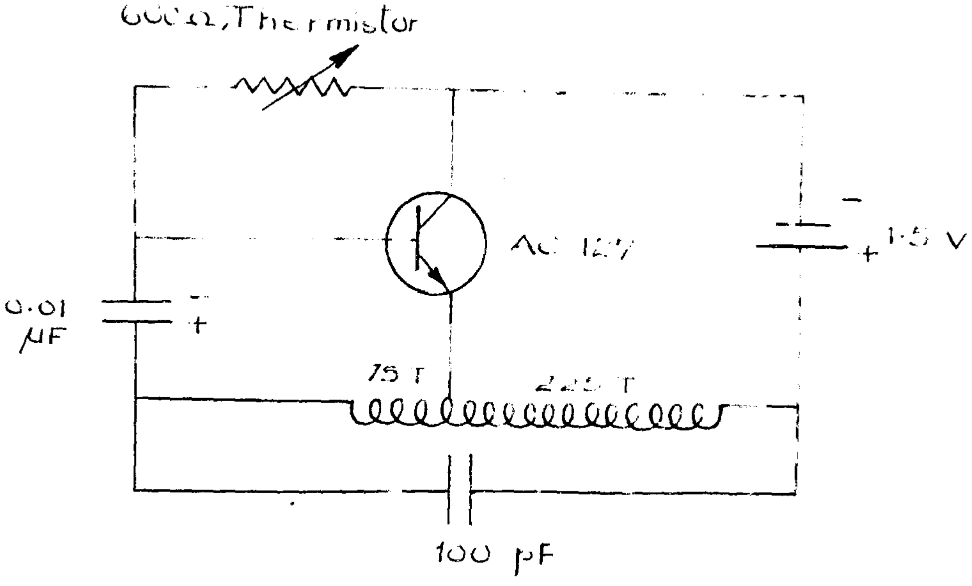


Fig. 1·3 Circuit of Demonstrative Model for Telemetry of Body temperature

Battery is replaced by $C_c$, a storage capacitor. High frequency power in tune to the resonant circuit induces an emf. In the case of p-n-p transistor, current due to rectifying action of the transistor flows in the arrowed direction for a positive half cycle at terminal A. The capacitor $C_c$ and a blocking capacitor $C_b$ are charged as shown. If, now, forced input disappears, electric charge on $C_b$ is discharged from base to collector, and at the time the transistor changes from "cut-off" to "on", oscillation is started. In the case of an n-p-n transistor, the situation is the same with reversing the direction of charge and discharge.

Demonstrative Model

A model was constructed for the purpose of demonstration of the principle of operation in the case of body temperature telemetry system. The circuit employed for this is shown in figure 1.3. An n-p-n, AC 127, transistor was used here. Thermistors (three in series having a total resistance of 600 ohms) were used as a sensor. The circuit was powered by a single dry cell of 1.5 V. The coil was wound on a pencil bunching the turns into a small space.

The signals transmitted by this circuit could be received by a transistorized pocket receiver. It was found that the radio frequency generated covers a broad range, and thus the tuning of the receiver was not critical in this case. This can be an advantage if the investigator is trying continuous recording, because if there is any drift in the receiver the signal will still be properly received. However, with this system it is difficult to work with several transmitters in the same vicinity, inspite of the fact that their rates of pulse repetition can be sufficiently varied so that they are recognizeable individually though received at the same time at the loud-speaker.

The clicking rate of this transmitter is rather slow and due to this reason the signal can be interpreted by the human ear. This slow clicking rate is governed by the relatively high capacitance (1 microfarad) in the base connection of the transistor. It was found that if this capacitor was replaced by one of lesser capacitance, for example 0.01 microfarad, then a tone was heard coming from the receiver whose pitch varied with temperature. However, direct recording by a penwriter can also be done by employing simple circuits which convert this changing frequency into a variable voltage. The pulses can be recorded directly by a magnetic tape recorder for later use.

Such transmitters are known as "endoradiosondes" for practical purposes. They are also known as radio-pills, transensors, and the like.

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# CHAPTER II

## A TELEMETERING SYSTEM FOR OBTAINING INFORMATION ON THE MOTILITY OF INTERNAL ORGANS.

### General Description

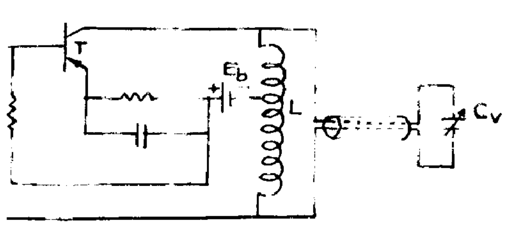
A telemetering system using an elongation sensor and an implantable transmitter is described here which can be used to study the motility of the internal organs such as stomach, heart, intestine, bladder, etc.

The transmitter can be turned on and turned off by use of a pulsed radio-frequency source. A sensor can be constructed, capable of giving a usuable signal when elongated by as little as 0.05 mm, which may require a force of approximately 0.30 gram.

Data can be observed directly on the screen of an oscilloscope, or can be recorded permanently on a strip chart for detailed study.

By making the turning on or turning off operations of the implanted transmitter controllable by the proximity effect of a pulsed radio-frequency signal, the battery life in the implanted unit can be increased, thereby allowing data - taking over long periods after surgery. However, the limitation on useful life span of the device due to the seepage of body fluids into the transducer and the transmitter will be there.

The telemetering system consists of the following units :-



Circuit diagram of implantable transmitter

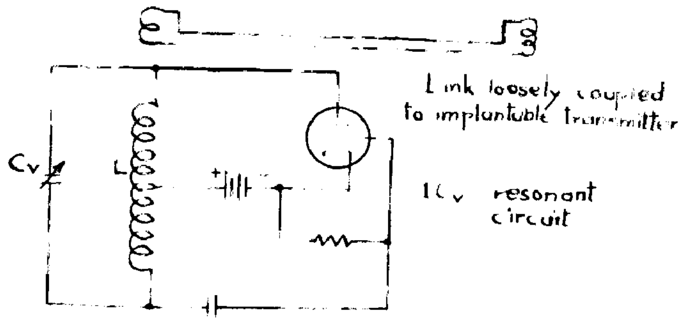


Fig. 2.2 Self-pulsing transmitter to start and stop implanted oscillator

Fig. 2.3 Sketch showing principle of transducer construction

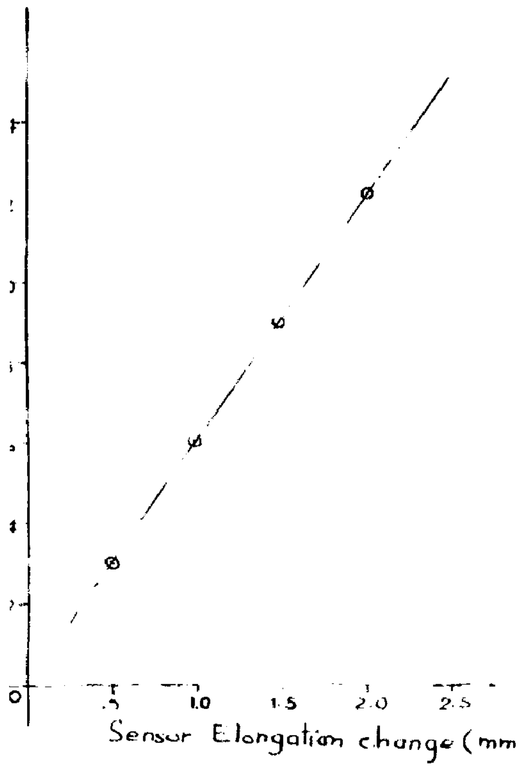


Fig. 2.4 Change in sensor capacitance as a function of elongation

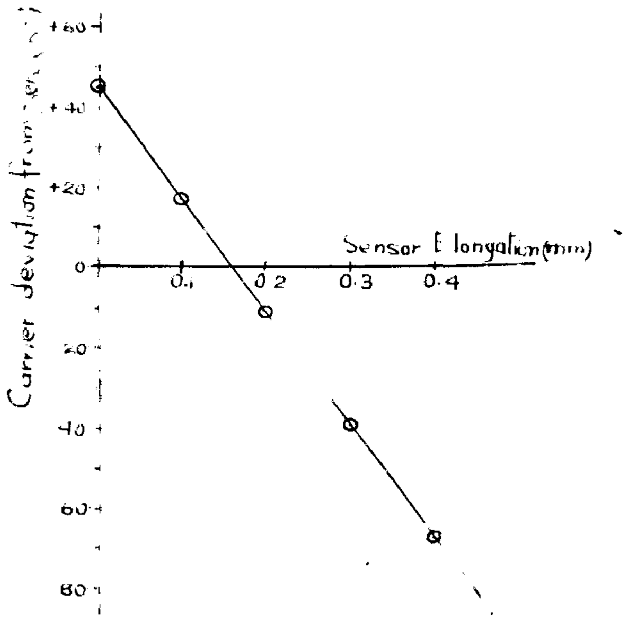


Fig. 2.5 Carrier frequency deviation as a function of sensor elongation

1) the implantable transmitter
2) the elongation sensor
3) the turn-on, turn-off pulsing transmitter
4) the receiver, and
5) the recording apparatus

## The Implantable Transmitter

A transmitter employing frequency modulation and operating with a carrier frequency of the order of say 10 Mc/s can be used here. A usable range in excess of 20 meters can be easily realized without the use of a directional receiving antenna. A schematic diagram of the transmitter circuit suitable for this purpose is shown in figure 2.1. This is recognized as a Hartley oscillator using the variable capacitive reactance of the sensor to produce frequency modulation. To make the turn-on, turn-off feature possible, a bypassed resistor, $R_e$ is inserted in series with the emitter lead and d.c. base return, $R_b$ is made to the positive terminal of the power source rather than to the negative terminal as is customary.

For a practical implantable transmitter, a mercury cell can be used, and the cell and all other components can be placed inside the coil area and shielded by a thin copper sheet. The use of a good conducting material as a shield will assure that nearly complete field cancellation will occur in the center of the coil area near the mercury cell and the other components. Without such a shield, eddy currents in the relatively poor conducting material comprising the cell case, and in other components, will absorb appreciable energy from the circuit, degrading its performance. The transmitter and transducer can be covered with a protective coating making them ready for implantation.

Returning the base lead of the transistor through $R_b$ to the positive terminal of the battery results in a condition of zero-base bias, which in turn sets the transistor operating point so low that negligible collector current flows and oscillation fails to take place. Under these conditions, no voltage drop will occur across $R_e$, and $C_2$ will remain uncharged. Now, when a sufficiently large pulse of radio-frequency energy at, or near, the resonant frequency of the tank circuit is coupled to the transmitter, an a.c. voltage is momentarily applied to the base circuit which is then carried to high enough levels for oscillation to start. Once "on" the circuit continues to give performance in a normal manner. The $R_eC_2$ combination functions to produce a voltage drop of approximately 0.30 volt, which is insufficient to stop oscillation but which makes the turn-off operation possible.

Once the oscillator is in operation, it will continue to function as long as the stored energy in the resonant circuit stays above a certain minimum level. Therefore, to turn off the transmitter, it is necessary that the a.c. voltage level in the oscillator tank drops below this critical level.

## Operation Control of the Oscillator

To stop the oscillator, a pulsed radio-frequency signal may be coupled to its tank circuit. The frequencies of the pulsed signal and the oscillator differ from each other, say by f c/s, a beat frequency phenomena will take place in the oscillator tank and as a result the peaks and troughs will occur at the rate of f times per second. Now, if the troughs drop the signal level below its critical value for the oscillator, and if a pulse is so adjusted as to fall to zero during a trough of the beat, the oscillator will turn off.

The $R_e$ $C_2$ combination helps the turn-off operation by lowering the collector potential of the oscillator, and simultaneously moving the bias point further in the direction of Class C operation. These two actions raise the minimum energy level needed in the oscillator tank for sustained operation and in this way make the turn-off operation easier.

Therefore, the oscillator can be put into operation by loosely coupling it to a pulsed transmitter which operates at any frequency close to the tank resonance. Similarly it can be turned off following the same process. Practically, it is essential only to couple the two circuits loosely to make the transmitter turn on or off.

## Turn-on, Turn-off Pulsing Transmitter

The circuit diagram of the pulsing oscillator used to start or stop the implanted transmitter, is shown in figure 2.2. It is a self-excited oscillator, biased for grid blocking action. This self-blocking arises due to the long time constant used in the biasing circuit. Pulse rate of approximately one per second and of duration 18 - microseconds may be obtained by employing a grid-circuit time constant of 1.10 seconds. The turn-on, turn-off range with this system may be obtained of the order of say 5 meters, but reliable operation limits the operation range to 25 cms.

## The Transducer

The transducer or the elongation sensor which can be used here to modulate the frequency of oscillation of the transmitter should be of a variable capacitor type. This can easily be constructed by winding two insulated wires side by side in a helix form,as shown in figure 2.3. The wires may be wound on a temporary form to provide the necessary support, and then can be removed from the form and a coating of an elastic waterproof material can be done afterwards. The wire used for the conductors in the transducer should have the property of being flexible and be able to withstand repeated bending.

The sensor responds to changes in spacing between the wires of the helix and, therefore, gives a small indication when twisted or when bent. The amount of twisting action to which the unit is subjected is quite small since it is confined to the wall of the organ at each end by threads which cannot transmit torque.

Another source of error comprises in the placement of the implanted transmitter. If the placement of the transmitter relative to the transducer is such that relative motion of these two units causes a tension on the interconnecting lead, then this will lead to an error. This tension can, in turn, result in an actual elongation between the tie points on the transducer producing an undesirable indication. Although proper placement of the units minimizes this difficulty but under the conditions of movement of the whole body large unwanted readings will occur.

The transducer acts as a variable capacitor decreasing in value with elongation. The function that relates this change in capacity to sensor elongation is of the nonlinear character. However, for the very small increments of length coming across in this application, the change in capacity is very closely proportional to the increase in length. Figure 2.4 shows a plot relating $\Delta C_v$ to $\Delta L$ and indicates good linearity within the range measured.

The transducer when used here as part of the tuning capacity across the resonant circuit of the oscillator, the natural frequency of the $LC_v$ combination varies inversely with $\sqrt{C_v}$. However, if $\Delta C_v$ is very small compared to $C_v$, resulting in relatively small shifts in the resonant frequency, a nearly linear relationship occurs. The frequency deviations being of the order of less than 0.3 percent of the carrier can be considered quite small. Now since $\Delta C_v$ is approximately proportional to $\Delta L$ of the sensor, and $\Delta f$ is approximately proportional to $\Delta C_v$, $\Delta f$ becomes closely proportional to $\Delta L$ of the sensor. Figure 2.5 shows the plot of practical results establishing the correctness of this statement, where the change in frequency is shown as a function of the sensor elongation. Here it is observed that an elongation of 0.162 mm corresponds to zero-frequency deviation. As this particular value depends on the tuning of the receiver it is not of much significance.

## The Receiver And The Recorder

An F.M. communications type receiver with an approximately linear discriminator response over a frequency deviation of 150 Kc/s each side of response can be used to detect the signal output of the transmitter.

For direct viewing of the telemetered data, a d.c. coupled oscilloscope can be connected across the discriminator output. Additional gain available in the oscilloscope amplifiers can give signal levels above usable values and therefore the slight disturbance or motion of the particular organ under study can give changes which become easily noticeable.

## Some Practical Recordings

A general idea can be formed about the results

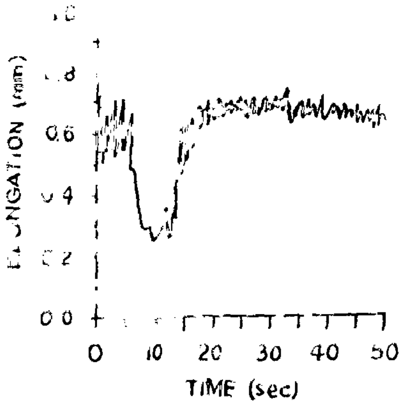


Fig. 2.6(a) Shows respiratory arrest

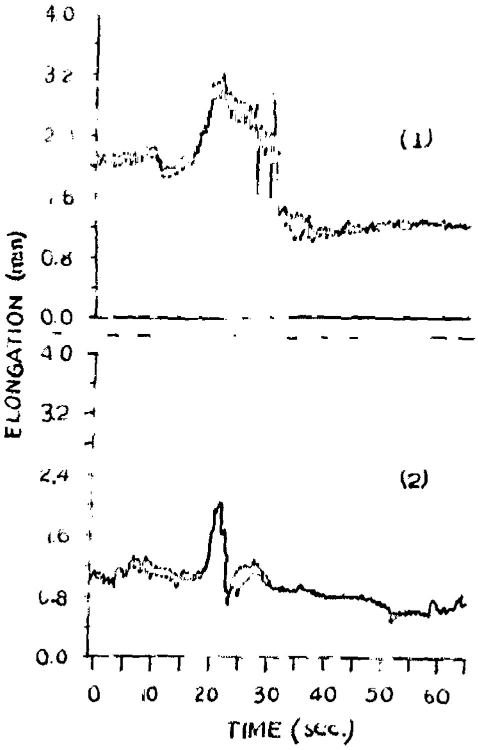


Fig.2.6(b)(1) Stomach activity shortly after feeding (2) Stomach activity several minutes after feeding.

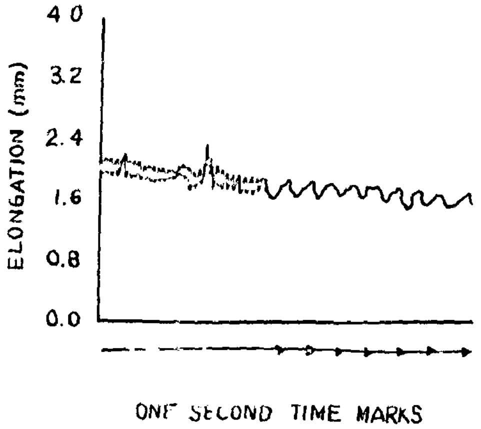


Fig.2.6(c) Normal peristalsis at two different writing speeds

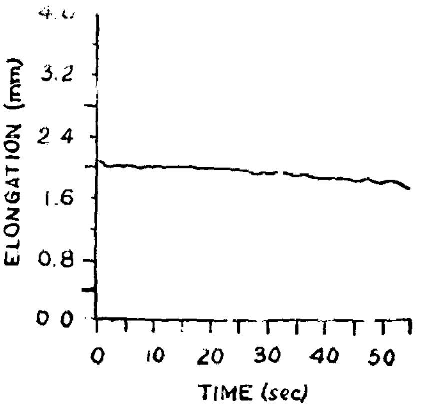


Fig.2.6(d) Quieting effect of drinking on stomach activity

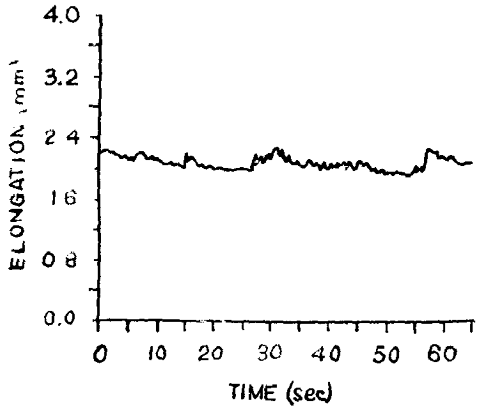


Fig.2.6(e) Effect of fright on stomach activity

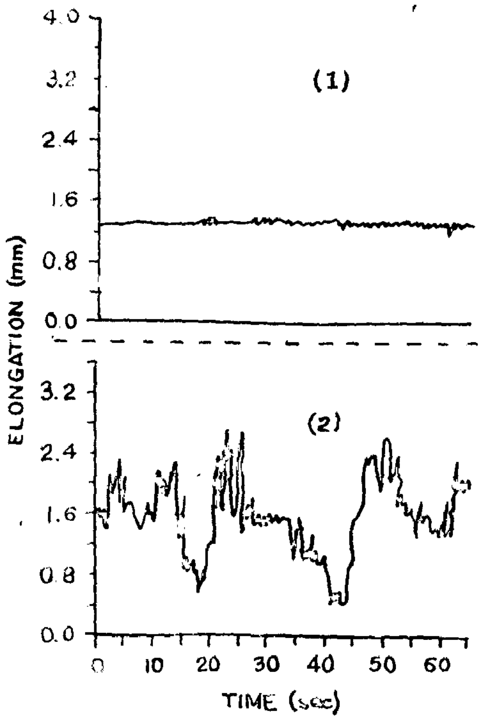


Fig.2.6(f)(1) Normal stomach motion when empty (2) Stomach activity immediately after injection of methacholine

obtained from this type of telemetering system, used to study the motility of an internal organ, by observing the stomach activity recordings for a rat under various physiological conditions as well as recordings taken when the animal was subjected to a drug and to a sudden fright. These recordings are shown in figure 2.6.

Figure 2.6(a) is a recording taken shortly after surgery. Here the deep inhalation followed by a period of rapid shallow breathing can be noticed.

Figure 2.6(b) shows two distinct types of motions when the animal is eating. The small regular contractions shown are indications of gastric peristaltic waves. These are superimposed at irregular intervals on much larger and more prolonged contractions, which are the peristaltic rushes associated with moving partially digested food from the stomach into the small intestine.

It is observed from records taken every half hour for a period of twelve hours after feeding that stomach activity is somewhat periodic. Approximately one hour after eating, the stomach becomes quiet. About ninety minutes after eating the stomach again becomes active, although the movement is not as great as during feeding. The activity continues to increase and decrease within a period of from one to two hours until the next feeding.

Figure 2.6(c) presents a record of normal stomach activity while digesting. Here, the marked regularity of peristalsis at a rate of approximately one contraction per second can be noticed.

Fig.2.6(d) shows a record taken while the animal was drinking water indicating that stomach became quiet during drinking.

It is known that fright causes an activation of the sympathetic nervous system. The effect of this emotion on the motility of stomach is shown in figure 2.6(e). Here, there is an indication of relative inactivity and the irregular character of what action remained.

Since the nerves associated with the stomach are cholinergic, the muscles of the stomach will be stimulated by acetylcholine or related chemicals. The effect of methacholine on the motility of the stomach is shown in Figure 2.6(f).

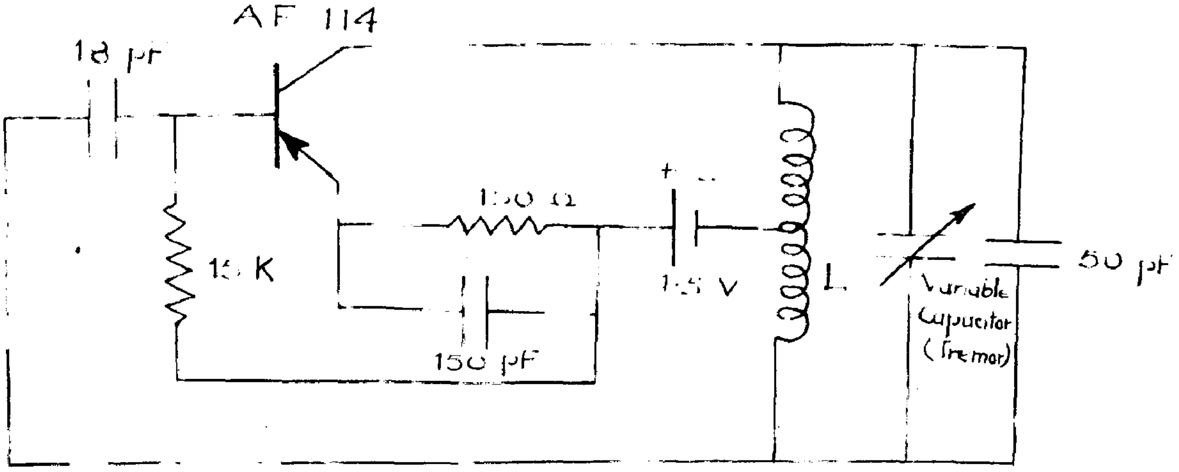
## Conclusion

This type of telemetering system can be used for certain types of research work where surgical implants are permissible. The turn-on,turn-off feature of this system extends battery life in the implanted unit.

Problems of seepage of body fluids into the transducer and the transmitter after a period of several weeks may be coming across while working on this system of telemetry.

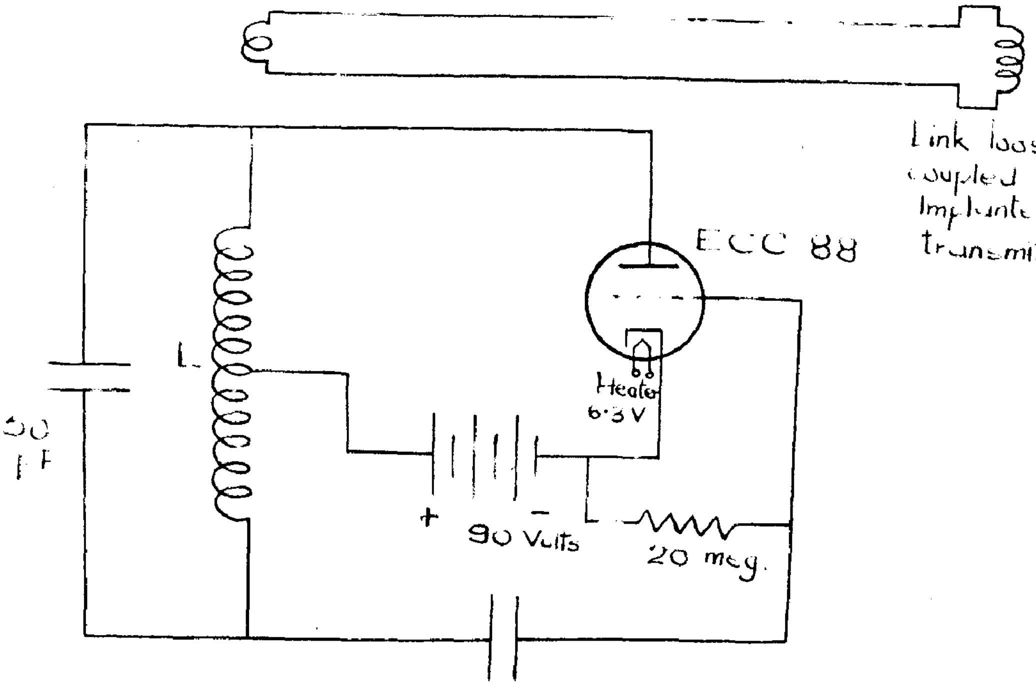
## Demonstrative Model

A model was constructed for demonstrating the principle



L - 6 turns No. 18 wire on 1.5 cm. dia centre tapped

Fig. 2.7 Circuit diagram of the Implantable Transmitter



Link loosely coupled to Implanted transmitter

L - 8 Turns No. 18 wire on 1.5 cm. dia centre tapped

Fig. 2.8 Circuit diagram of Turn On, Turn-Off Pulsing Transmitter

Figures showing the Circuit diagrams of the Demonstrative Model for Telemetering System for obtaining information on the motility of Internal Organs.

of operation of the telemetering system for obtaining information on the motility of internal organs as discussed earlier. For this purpose, a transmitter circuit was built employing a Hartley oscillator. The actual circuit used for this is shown in figure 2.7. It consists of a single transistor (high frequency), and a resonant circuit employing an inductance in parallel with a variable capacitive reactance of the sensor to produce frequency modulation. An AF 114 p-n-p transistor was used for this circuit. The circuit was powered by a single dry cell of 1.5 volt. The transmitter employs frequency modulation and operates with a carrier frequency in the vicinity of 1 Mc/s. A usable range of nearly 4 meters was realized without the use of a directional receiving antenna. For actual telemetering system, the transducer should be an elongation sensor, that is, a variable capacitor formed by winding two insulated wires side by side in a helix. But as the wire suitable for this purpose was not available, the elongation sensor could not be constructed. The demonstration purpose was, however, achieved by employing a variable capacitor (tremor) in place of the elongation sensor.

In order to turn-on and turn-off the above mentioned Hartley oscillator, a pulsing transmitter was used. The actual circuit for this is shown in figure 2.8. It uses a double triode valve, ECC 88 which operates at an anode voltage of 90 volts with respect to the cathode. Only one triode was made use of in this circuit. The resonant circuit in this case was built having approximately same frequency of oscillation as the Hartly oscillator.

The two circuits were loosely coupled through a link which was made by bunching the copper wire turns closely in two parts on a pencil. The transmitted signal was received on a FM type radio receiver. It was in the form of a variable pitch continuous click tone. It was observed that the pitch of the sound heard in this way changed by changing the capacitance in the resonant circuit through the tremor.

The transmitted signal was also picked up by using a built antenna. The voltage picked up by this antenna was seen on an oscilloscope which was in the form of pulses. It was noted that the frequency of these pulses changed corresponding to the changes made in the variable capacitance (tremor). The amplitude of the pulses also changed but very slightly. This demonstrated the principle of operation of the actual telemetering system for obtaining information on the motility of internal organs.

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# CHAPTER III

## TELEMETERING THE ELECTROCARDIOGRAM OF FREE SWIMMING

### General Description

A telemetering system suitable for the purpose of transmitting the electrocardiogram of free swimming in the case of a fish that can be carried on the back of a fish is described here. This telemetering system is of frequency modulated type. The transmitter can be operated with the help of magnet which can be held in hand. The transmitter, in this case of this particular telemetering system has a useful life of more than 135 hours when operating continuously. The transmitter has the novel feature in that the organism is allowed to remain in its natural surroundings without any disturbance to normal activities.

The telemetering system consists of the following components :-

1. a portable Transmitter
2. electrodes, and
3. the receiving and recording apparatus.

### Engineering Aspect

1. The Portable Transmitter : The transmitter employs frequency modulation and operates with a carrier frequency of the order of 100 Mc/s. The usable range can be increased with the help of a directional antenna. The order of usable range, however, is six feet in this case. Figure 3.1 shows the schematic diagram of the transmitter circuit.

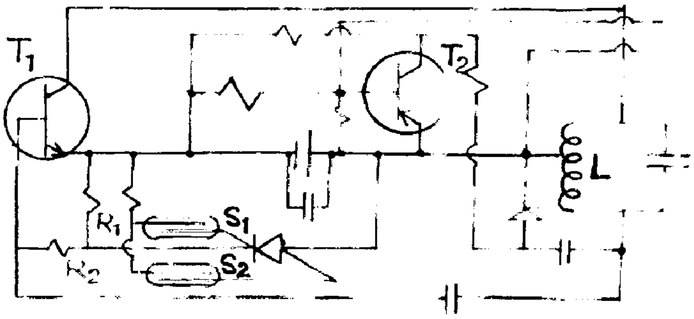

Fig 3.1 Schematic diagram of transmitter circuit

Fig 3.2 Electrocardiogram telemetered for normal cardiac rate

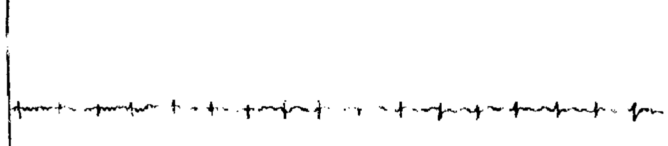

Fig.3.3 Effect of anesthetic (Urethane) on cardiac rate

This transmitter circuit is recognized as a Hartley oscillator where a voltage variable capacitor is used to modulate the frequency of the oscillator coil L. In this oscillator the coil is tapped, and the tap point is at ground potential. Therefore, the F.M. signal at each end of the coil will be 180° out of phase with other end. However, the transmitter provides another 180° phase shift in the common emitter type of connections to sustain oscillations. If the coil is center-tapped, the capacitor in the base circuit is made small in value in order to match the high impedance tuned circuit to the low base impedance. Poor frequency stabilization in the oscillator will result due to this bedause of the reason that the base capacitor will form a capacitive voltage divider together with the base-emitter capacitance of the transmitter. It is, therefore, desirable that the transistor should be operated harder by placing the coil tap near the collector end of the coil and a smaller value of capacitance in the base circuit should be employed.

As the voltage at the collector of the transistor $T_2$ is changed, the frequency of transmission changes. This particular transistor is biased in the common emitter type of connections across the battery supply. The base is biased in order to provide a voltage drop across the collector emitter leads.

Two reed switches and a silicon controlled switch (S.C.S.) form the switching circuit. The negative voltage supplied by the battery through the resistor $R_1$ makes the end junction of the S.C.S. to bias in the forward direction turning it on. $S_1$ is momentarily held in the closed position by the field of the permanent magnet which is used to turn the transistor on. The negative voltage from the batteries is thus placed on the S.C.S., thus turning it on. $S_2$ is, however, held closed by the field of the permanent magnet when the transmitter is off. This will place the negative voltage from the batteries on the opposite end junction of the S.C.S., turning it off. There will be a tendency for the current through the S.C.S. to increase with the rise in temperature. When the S.C.S. is turned on the current passes through the voltage divider of the two resistors $R_1$ and $R_2$ as shown in the figure 3.1. This increases the forward bias of the emitter of the oscillator amplifier. The collector current of this transistor is thus increased together with the overall loop gain of the circuit making the occurrence of oscillations possible.

The battery here is shunted by means of a capacitor which extends the useful life to a considerable extent by providing a low reactance path around the battery for the transistor currents having high frequency.

2. <u>The Receiver</u>: A commercially built frequency modulated radio can be used as a means for receiving the transmitted electrocardiogram signals, with a modification done by installing a connection directly across the discriminator.

## Practical Aspect

The electronic circuit, reed switches, and batteries are required to be coated with silicon grease and then a covering of several layers of a latex material is applied. The entire system should be made water tight and well protected against any damage resulting from abrasion.

In order to calm or immobilize the cold water animals such as fish, the anesthetic diluted solution is used.

## Some Results

Figure 3.2 shows the electrocardiogram record in the typical case of a fish. The fish is transferred from a fresh water source to the anesthetic solution. After several minutes the rate of opercular oscillation is markedly reduced which indicates a general slowing of muscular activity. The fish is then removed from an esthetic and placed on a bench to set in position the transmitter and electrodes. The gills are flushed with water in order to avoid drying while the fish is out of the water. Finally, the fish is returned to the fresh water acquarium where the data can be collected.

After recovery from the anesthetic solution, the fish begins to swim in a manner that appears normal. The ECG at this point shows a heart rate of 88 beats per minute. Electrodes here are tried at various locations, which results in the recordings of figure 3.3. These recordings show no large muscle potentials resulting from the periodic movement of the gills.

# SECTION

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# TELESTIMULATION

# CHAPTER IV

## TELESTIMULATION

### Introduction

Telestimulation or remote stimulation means the induction of electrical power into the body of an animal from a distant point. The concept of telestimulation is rather an old one as compared to that of outward transmission of radio signals carrying information. An early method used for this purpose employed one or more primary transformer coils surrounding an animal cage and activated one or more secondary coils placed within the body of the animal, which was allowed free movement about the cage during stimulation. In this case, usually a capacitor was discharged through the primary transformer winding, this giving very high currents, and there was little control over the waveform in the secondary coil. A more efficient production of power into an internal secondary winding can be made by going to higher frequency electromagnetic signals.

### Short Range Telestimulation

Figure 4.1 shows a system for the short range transmission of electrical stimulating signals. In this case, the receiving circuit is placed within the animal, which comprises mainly a crystal set receiver. Near or around the animal is placed a transmitting coil which is activated by impulses of radio-frequency energy from a

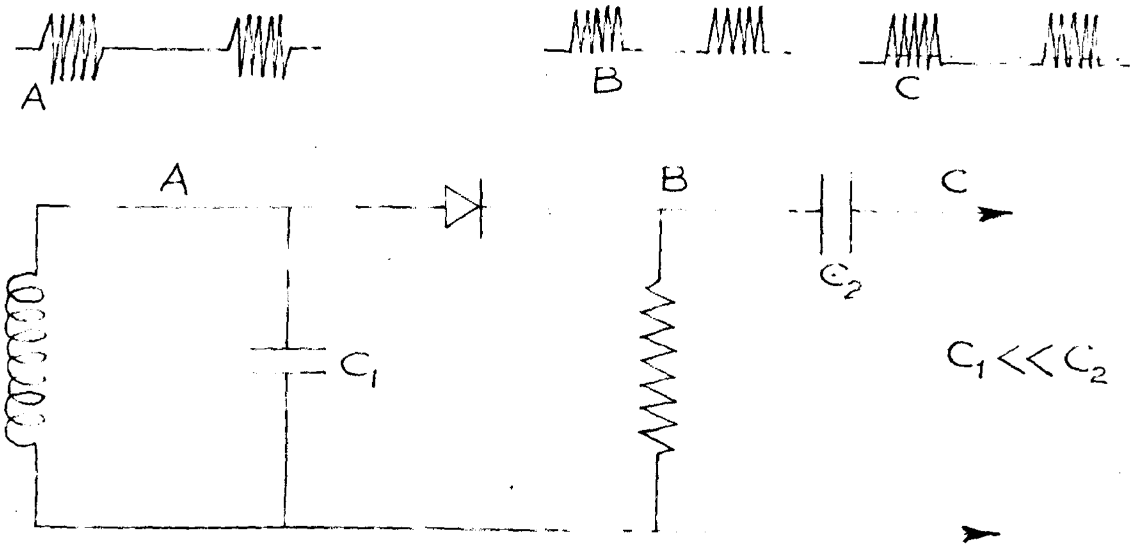

Fig. 4·1 Circuit showing the case of short range Telestimulation.

pulsed oscillator. At the top of the figure is a set of waterforms shown at several points within the circuit.

If one intends to apply a periodic pulse to an electrode embedded in excitable tissue, then the waveform in the coil might be such as shown at A in the figure. In the implanted receiver at the left is a resonant circuit consisting of a receiving coil and its capacitor $C_1$, and this combination is tuned to the radio frequency at which the signal is transmitted. Thus across the circuit at A, there appears the waveform shown directly above. The voltage across the circuit at A is applied through a diode to give the waveform, as shown at B. These bursts of unidirectional impulses are able to exert a stimulating effect upon tissue where the high-frequency waveform at A would not be. Therefore, it can be said that radio frequency positive half cycles are neutralized in their effect by the immediately following negative half cycle at A, although low-frequency alternatimg currents are able to stimulate tissue.

A capacitor can be placed across the circuit at B to filter the waveform into square unidirectional impulses without fluctuations. In this particular case, there is always a net flow of current in one direction, and this can lead to problems at the electrodes. If a relatively large capacitor is placed in series with the output lead, for example in the position of $C_2$, as shown in the above referred figure, there can be no net flow of direct current.

The waveform in this case will be, as shown at C, with large positive stimulating impulses and a small negative voltage the rest of the time. Here, a satisfactory stimulating effect can still be found, with the small flow of current in the reverse direction over the longer interval simply preventing problems at the electrodes. A resistor may be placed as shown at position B in order to make possible the flow of this back current, but it can be omitted as well because the backward leakage through the diode and coil provides a corresponding path.

Such types of systems are convenient for the induction of power into the body overshort ranges. To overcome the grounding problems use can be made of high frequency transformer arrangement. In such a case the signal to be applied modulates a radio-frequency oscillator which is then coupled to the wires to the animal through a radio-frequency transformer having good isolation between windings.

In the case of a freely moving animal, the induction of signals involve the problem of amplitude control as well, if this parameter is of importance at all. Therefore the system is not omnidirectional, although with a trio of coils it can be made so. In some cases, it is convenient to place silicon diodes across this circuit to control the output voltage by limiting it to a particular value. In an alternative arrangement a large overall feedback loop can be arranged in which a small transmitter senses the voltage across the internal terminals and transmits a signal to the stimulator of such a form as to maintain the electrode voltage (or current) almost constant.

## Some Practical Applications

These methods are used for the stimulation of the ventricles of the heart for peacemaker applications. However, these have also been used to help with the emptying of the neurogenic bladder, for the stimulation of the baro receptors in the neck to help with the reduction of blood pressure, for phrenic nerve stimulation in connection with breathing problems, for attempting to block the path, and also for bypassing a defective ear in case of hearing loss. Another important application is the remote control of the stimulating impulses to various sites within the brain of an animal. It is possible here, by using radio techniques to separately control a number of animals in order to make observations regarding change of their social behaviour. For this, sometimes a small radio receiver is conveniently placed at the animal which closes a contact that activates a locally powered stimulator. Of course, the wide changes in the intensity of the radio signals, in this case, are tolerable. The circuitory of both the transmitter and receiver can be quite simple in this case.

## Long Range Telestimulation

At great ranges the same radio transmitter can be used to activate receiver and stimulator being carried by the subject by employing a far-field transmission.

However, these methods when employed in a laboratory with a high frequency of transmission may present some problems. Radio waves when reflected from walls and other objects can set up standing wave patterns. This will lead to "nulls" in which little signal can be picked up. Therefore, if an animal or subject comes by chance in one of these nulls when an impulse is transmitted, the expected effect may not be seen at all. This may become even more pronounced when several animals are being handled simultaneously on several frequencies. In this case, the walls should be covered with a highly absorbing material for radio waves so that reflections do not take place.

The telemetry transmitters for remote stimulation purposes can be turned on and off by inwardly induced signals, thus enhancing its battery life. This stimulation of a transmitter into activity is especially useful in short-term experiments in which case the animal is required to have some time to recover from surgery before observations are started. This is also useful in long term experiments in which case continuous observations are not needed. A bistable multivibrator arrangement can be used to either supply power constantly to a small transmitter or to switch it off, and this can be activated by external impulses as picked up by any simple receiving arrangement. In case the animal is approachable for switching on and off his transmitter, then a simple crystal-set receiver is enough.

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# SECTION

# THREE

# MEASUREMENT OF PHYSIOLOGICAL VARIABLES

# CHAPTER V

## OVULATION DETECTION

### General Description

Temperature measurements can be used to know the occurrence of ovulation. Conventional temperature measurements are made in the mouth or the rectum after the patient is awakened. These temperature measurements, however, sometimes fail to accurately predict the ovulation cycle in the case of those women who have even slightly irregular menstrual periods and also with regular menstrual period cases when a sudden disturbance such as a cold or an emotional upset can result in the minute temperature increments indicating the ovulation. However, the location of the sensing device and the method of measurement play an important part in accurately predicting the ovulation cycle. It has been found that rectal temperature is a very poor indicator of internal body temperature, while measurements of internal cranial temperature, i.e. measurements made in the external auditory canal, provide powerful responses even to small temperature changes (of the order of say $1/100^{\circ}C$). It has been further investigated that these internal cranial temperature records taken over a specific period can help in predicting the ovulation cycle and thus to detect accurately the occurrence of ovulation in the human female.

### Biological Aspect

The process by which a mature egg is released from the surface of the ovary is known as Ovulation. At birth of the human female, the lifetime supply of future eggs is present in the ovaries which is estimated at 250,000 to 400,000 of the eggs in both the ovaries. The eggs get matured from the time of birth to puberty. At puberty the eggs acquire a responsiveness to certain harmones circulating in the blood stream that are released by the pituitary gland located at the base of the brain.

The time of ovulation varies greatly during the menstrual cycle of the human female, occurring somewhere between eighth and seventeenth day of the usual twenty-eight day cycle in the case of most women. However, the ovulation occurs most frequently between the twelfth and fourteenth days.

As one of the pituitary harmones, known as the follicle stimulating harmone gets stimulated one egg matures for ovulation each cycle. Then, as a result of a balance of harmones derived from the pituitary gland as well as from the ovary itself the egg is released from the surface of the ovary. After this the egg enters the uterine tube.

One of the most common methods to determine the presence of ovulation is the measurement of oral or rectal temperatures. During the menstrual cycle of women the body temperature does not remain constant but follows a a fixed pattern. The temperature at these places remains low prior to ovulation, with a daily variation of 0.1°C to 0.3°C. Around the time of ovulation the temperature rises rapidly more than 0.5° and remains relatively elevated as compared to the daily fluctuations of temperature during the preovulatory phase. Only one day prior to the onset of menstruation the temperature acquires to normal range. Also, a low temperature at these places is often seen preceding the day prior to the rise in temperature indicating ovulation.

However, any interpretation from the measurement of oral or rectal temperatures to know the ovulation cycle has to be made with limitations. Because three-fourths of the time the rise in temperature is quite marked and definite and therefore the detection is not difficult. But in the remaining one-fourth, the temperature rising continues over a period of several days. Therefore, in these cases the detection of ovulation is more difficult.

## Location of the Sensing Device

It was found by Aronsohn and Sachs in 1885 that a part of the forebrain situated above the crossing of the optic nerve served as an uncomparable site for the control of temperature in warm blooded animals and man. This site has been called the "human thermostat"because it regulates the sweating and metabolic heat production. As this "human thermostat" does not depend on warm - impulses from the skin for its function but rather feels the variations of arterial blood temperature in the tissue of the brain stem, the temperature measurements taken as near as

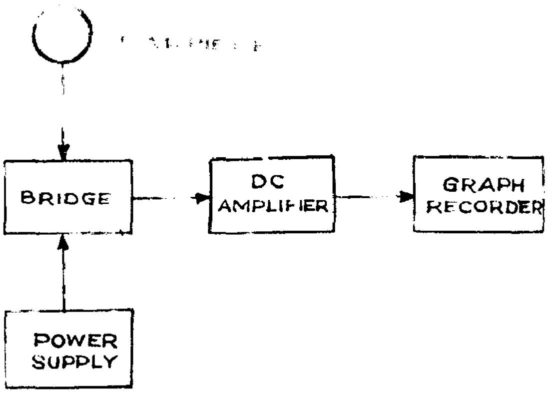


Fig. 5·1 Block diagram of measuring apparatus

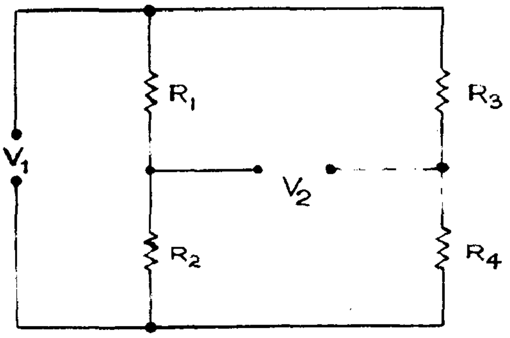


Fig. 5·2 Bridge Circuit

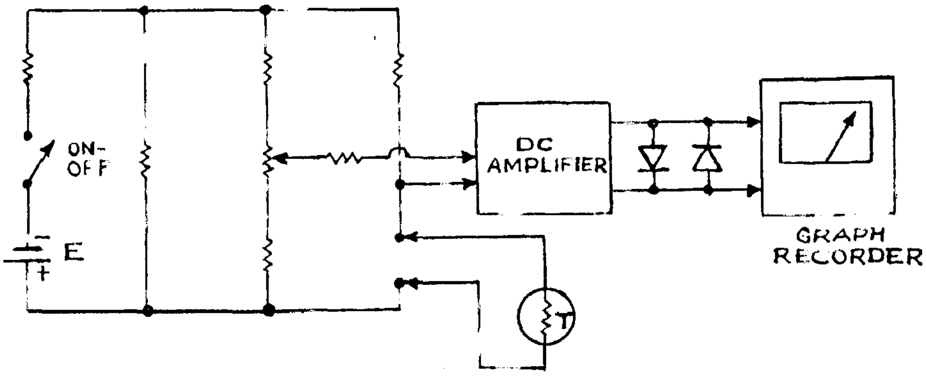


Fig. 5·3 Schematic of temperature measuring circuit possible to this thermostat give the best indication of the finer details of body temperature. Although measurements in the rectum are more accurate than those taken in the mouth or underarm, but for recording the minute changes of temperature associated with ovulation, they are insufficient. The rectum is surrounded by inert masses of body tissue that absorb heat and tend to hide the finer details of body temperature. Therefore, sometimes the rectal temperature measurements fail to predict accurately the time of ovulation. However, this difficulty can be avoided by choosing the site for location of the sensing device in close proximity to the "human thermostat", i.e. in the external auditory canal near the tympanic membrane and variations in temperature indicative of ovulation and the time of its occurrence can be measured precisely and recorded.

## Engineering Aspect

Figure 5.1 shows block diagram of the measuring apparatus.

(a) Temperature Sensing Device & Circuitry : A thermistor can be employed here as a temperature sensing device. This can be sealed in a glass capsule approximately 2 mm. in diameter and 1 cm. long. This device has a temperature coefficient of + 0.7 percent/$^{o}$C. A 1K-$\Omega$ thermistor, therefore, changes its resistance by 7$\Omega$ /$^{o}$C.

In order to detect a temperature change accurately in the 0.1$^{o}$C range, a wheat stone bridge circuit can be used as shown in figure 5.2. If a thermistor is substituted for a resistor in one arm of the bridge the output of this circuit is directly proportional to a temperature change. In this case, the output of a bridge $V_2$ is directly related to the potential $V_1$ applied to it and to the disproportionality of the resistance of the bridge, $R_1/R_2 \neq R_3/R_4$. Also, the output is a maximum when the resistance ratio $R_1/R_2$ or $R_3/R_4$ of adjacent arms is near unity. The potential applied to the bridge will be limited by the maximum saferating of the thermistor.

Figure 5.3 shows the circuit schematic of the entire apparatus.

(b) The Power Supply : The power supply potential $V_1$ for the bridge must remain very stable to enable comparision of data from several months of continuous operation. A mercury battery can satisfy this requirement because its voltage remains nearly constant throughout its useful life and it does not vary with small temperature changes. A resistor divider can be used to provide a constant low voltage as per requirement to the bridge.

(c) The D.C. Amplifier : It becomes necessary to amplify the weak signal from the bridge in order to drive the graph recorder. This amplifier should have stability characteristics similar to the rest of the circuit so that it would not drift with time or temperature changes.

The d.c. amplifier has a very high input impedance so it does not affect the output of the bridge. The input voltage and the gain can be adjusted so that the bridge output signal may be matched to the recorder input requirements.

(d) The Recorder : A continuous chart recorder can be used to make a permanent record of the data. Two silicon diodes as shown in figure 5.3 may be connected across the input of the recorder to protect it from excessive voltage from the amplifier. The chart in the recorder should be moved at a rate that data from a long time interval may be recorded in a short space and the graph may show a continuous average temperature level rather than momentary variations.

## Practical Aspect

The temperature measuring device should be stable and responsive to temperature changes of the patient but at the same time it should not indicate susceptibility to environmental temperature changes which are expected to occur during the experiment on the patient. In order to test its susceptibility to environmental temperature variations, a low temperature coefficient resistor should be inserted in place of the thermistor, and then the entire apparatus should be placed in an environmental test chamber and the temperature should then be varied from 60° F to 95°F. There should not be any significant change in the reading of the recorder if the device is less susceptible to environmental temperature changes.

The complete measuring system is required to remain stable in order to be able to compare daily temperature readings for a month or longer. For this, the thermistor should be connected to the bridge and placed in a constant temperature chamber. The resulting straight line graph on the recorder would then prove that the measuring system remained stable in time. When the measuring temperature changes, the variations recorded on the graph would indicate the temperature changes detected by the ear piece.

The graph should be calibrated in terms of temperature change in degrees Fahrenheit. This can be done by placing the earpiece in a water bath chamber and measuring the temperature with a thermometer.

Another important point is the fastening of the sensing device to the patients ear. It should satisfy two requirements - comfortability and steadiness. Any movement of the thermistor will cause significant change in the temperature measured due to a temperature gradient present in the ear canal. To satisfy these conditions the thermistor may be mounted in a plastic ear piece, suitable to the patients ear and ear canal.

<u>Discussion on Some Recordings</u> : The results of the experiments done by a team of Engineers are shown here in figures and in the form of graphs. Figure 5.4 shows the results obtained from one of the patients during a seven month period of experimentation indicating thereby the patients

Fig.5.4 Graph showing patients' morning ear temperature

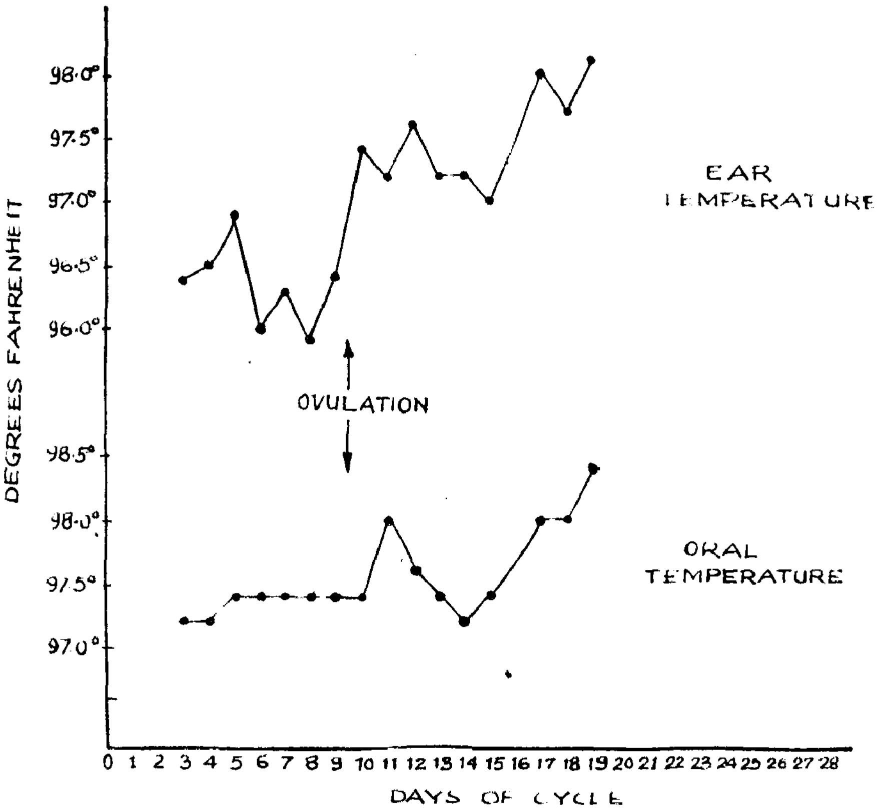


Fig. 5·5 Plot of morning ear temperature and Oral temperature

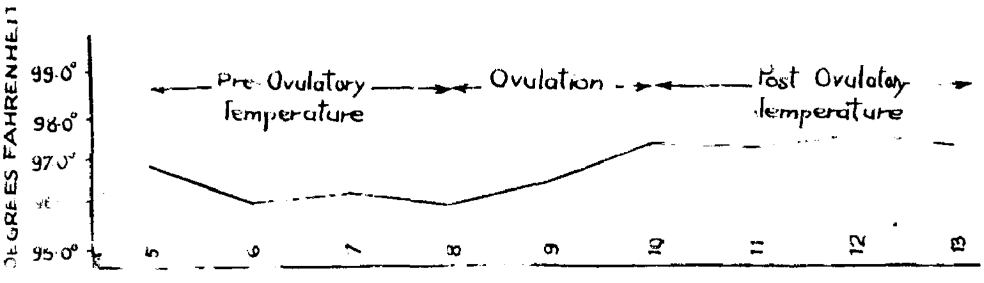


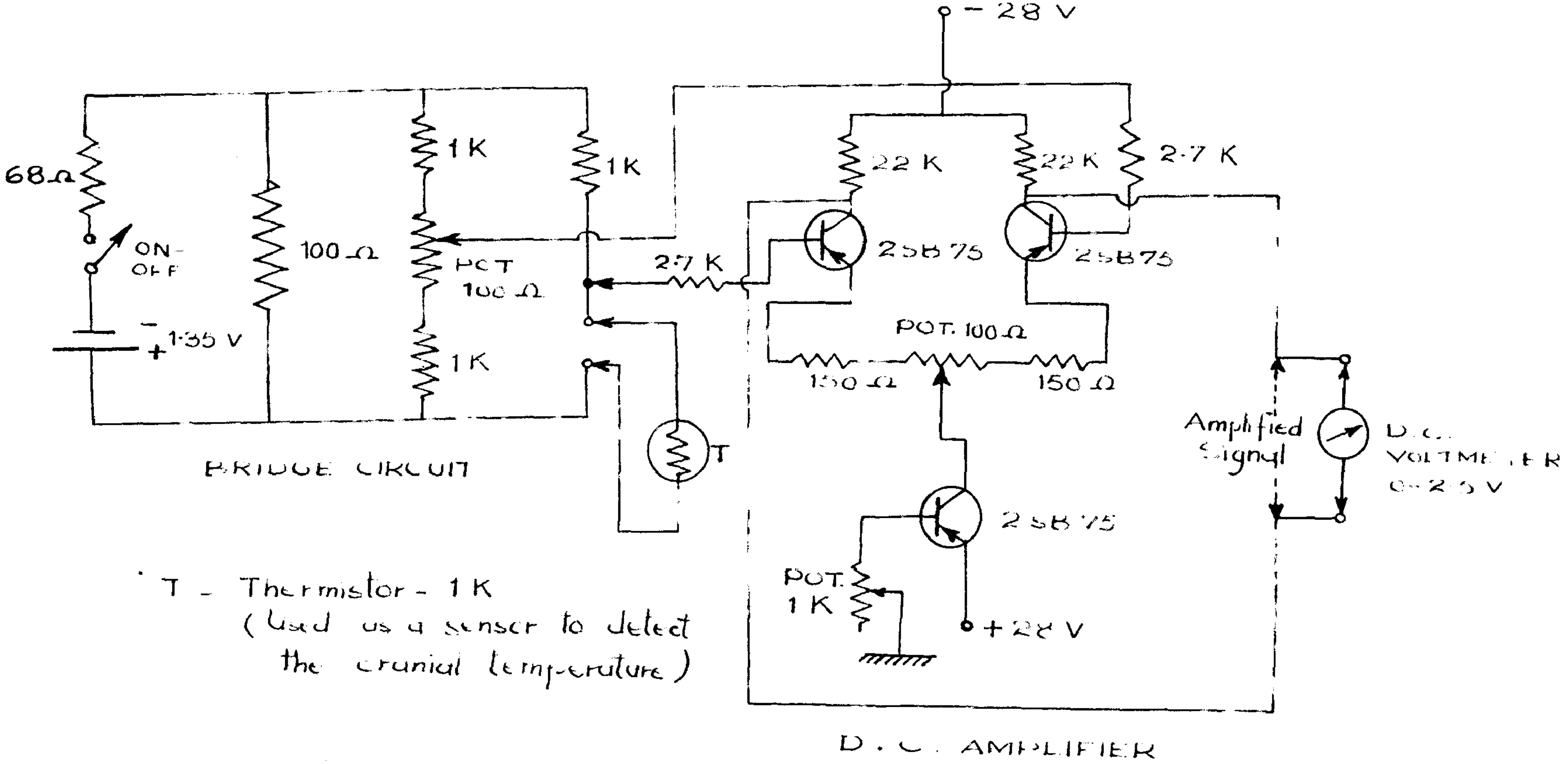
Fig. 5·6 Average morning ear temperature morning ear temperature as recorded on the fifth to the thirteenth day of a twenty-eight day cycle. The initial rise in temperature is the thermistor stabilizing to the patients' ear temperature. The readings here can be noticed of unequal duration because the patient did not record for exact hour increments each day. It can be seen from the graph that the lowest point in temperature occurs on the eighth day, followed by a rise of 1.5°F as recorded on the fourth day of the cycle. Figure 5.5 shows a plot for the period from third to nineteenth day of this cycle. An oral temperature plot has been shown directly below it.

The present theory says that the ovulation occurrence is indicated by a sharp rise in the oral and rectal temperatures. Also, a preceding low point can be observed on the day prior to ovulation. From figure it can be observed that the patients' ear temperature indicated a low point on the eighth day followed by a high temperature on the tenth day. Assuming that the temperature rise coincides with ovulation, it can be said that the ovulation occurred some time between the eighth and the tenth day. The tenth day reading would then be the indication for the occurrence of ovulation. However, the oral temperature does not give this indication until the eleventh day as is dlear from the graph of figure 5.5. The evidence of ovulation will also be shown by the daily ear temperature record of the patient.

Figure 5.6 shows a reproduction of the sample graph using average morning temperature equally spaced. The graph has been divided into three stages; preovulatory, ovulatory and postovulatory.

Referring to figure 5.5 it is observed that around the time of ovulation, ear temperature did not remain at a steady reading during the hour recording, but it gradually fell or rose depending upon its relationship to the occurrence of ovulation. The morning reading just prior to ovulation has a negative slope showing that the temperature slowly decreases during the recording. The temperature during the ovulatory stage has a positive slope and in the postovulatory state, a slope of zero. From this it can be interpreted that the time of ovulation can be known by measuring the changing slopes of a patients' morning readings.

A comparison of ear and oral temperature indicates the fluctuation of ear temperature to a considerable extent as compared to the oral temperature. From fifth day to the tenth day, the oral temperature stayed at about $97.4^{o}$F while ear temperature fluctuated an average of $\pm$ $0.2^{o}$ F and between the ninth and the tenth, rose by one degree. It is observed here that a day later the oral temperature followed by increasing $0.6^{o}$F. This difference might be due to an averaging effect of the mouth on temperature change. From these results it can be realized that the mouth does not respond as quickly as the ear to



T - Thermistor - 1 K
(Used as a sensor to detect
the cranial temperature)

Fig. 5·7 Circuit diagram of the Demonstrative Model for Ovulation Detection changes of internal temperature.

The ear temperature recordings done automatically have a further advantage over oral and rectal measurements in that a minimum of patient participation is required and human error is essentially eliminated. Moreover, the ear temperature method is rather comfortable and more sanitary than the oral or rectal ones.

## Demonstrative Model

A model was constructed for the purpose of demonstrating the principle of operation of the device used to detect the occurrence of ovulation. For this, a bridge circuit was made one arm of which had thermistor (three series having a total resistance of 600 ohms) as an element. This thermistor was used as a sensing element to sense the temperature changes occurring in the ear of the patient during the ovulation cycle. The bridge was powered by a single dry cell of 1.5 volt. The output signal of the bridge, as a consequence of the temperature variations sensed by the thermistor was of too low magnitude and, therefore, it was necessary to amplify this signal in order to make it interpretable using a voltmeter. A d.c. amplifier - differential type, using one stage only consisting of three transistors (p-n-p type, 2SB 75 were used) was added at the output side of the bridge. The signal now obtained at the output of this d.c. amplifier was found to be almost 80 times amplified as compared to that obtained without the use of the d.c. amplifier. The temperature variations could now easily be detected by using a voltmeter of low range. The complete circuitory of the model is shown in Fig.5.7.

# CHAPTER VI

## MEASUREMENTS OF INTERNAL PHYSIOLOGICAL MOTIONS

### General Description

The motion within the human body in the presence of foreign metallic bodies can be measured by the use of an electronic device as discussed here. This particular method and the device has two principal advantages, namely -

1) It is free from any contact with the patients' body.
2) The patient's constitution does not affect the measurements made by this method.

### Basic Theory

If a coil forms a part of a tuned circuit of a self-excited oscillator, and this coil is kept in the proximity of metals or dielectrics thus subjecting it to external effects, then the frequency of oscillation will change according to the electromagnetic properties of the surroundings.

This system may be assumed equivalent to a transformer where the primary will represent the oscillator coil and the secondary winding will represent the metallic substances. This will represent the case of an air-transformer (where metal is involved), subjected to an inductive type of load. There will result a drop in effective inductivity in this case, in the primary winding and a corresponding increase in frequency will follow.

On the other hand, the presence of a dielectric will be equivalent to the application of a capacitive load which will result in a drop both in the primary current and in frequency.

This effect may be used for observation of changes in the proximity of the probe coil. However, to realize this, relatively high sensitivity coils are necessary. In this method two oscillators are employed which act simultaneously; one of them acts as a probe and the other as a reference system for determining the frequency changes of the former. Therefore, the basis of operation of the system is a frequency difference, which is converted electronically into voltage directly proportional to it. This device may be used for measurement and direct recording of the motions connected with various internal organs such as cardiac and muscular effects, arterial motion, etc. It can also be used for the accurate location of foreign metals embedded within the body where X-rays prove to be ineffective.

## The Apparatus

The apparatus to be used for the measurement of motion within the human body as discussed above is shown in figure 6.1 and consists of the following essential parts :-

1) A pair of Oscillators having a basic frequency of the order of 10 Mc/s. One of these oscillators will be fixed but the other one will be made variable about the basic level. The basic frequency is chosen so as to get maximum

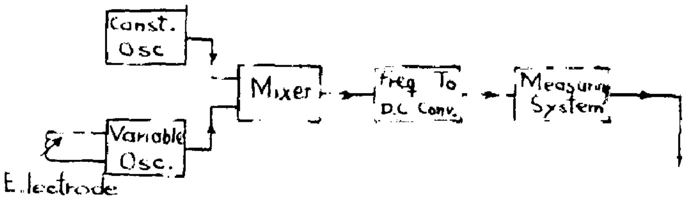
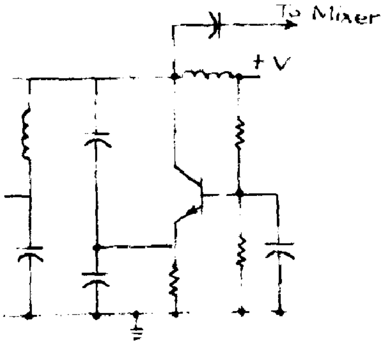


Fig. 6·1 Block diagram of complete set up for physiological motions measurement



Circuit diagram of fixed oscillator

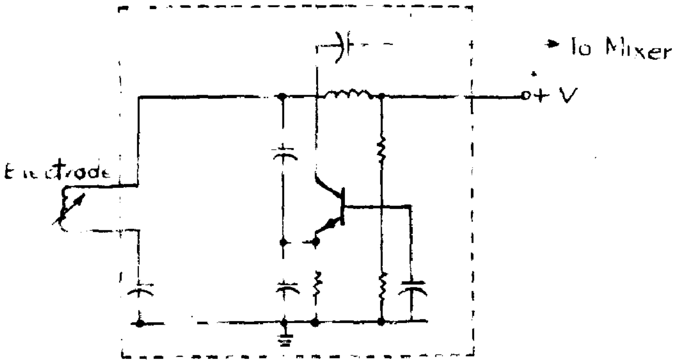


Fig. 6·3 Circuit diagram of variable oscillator

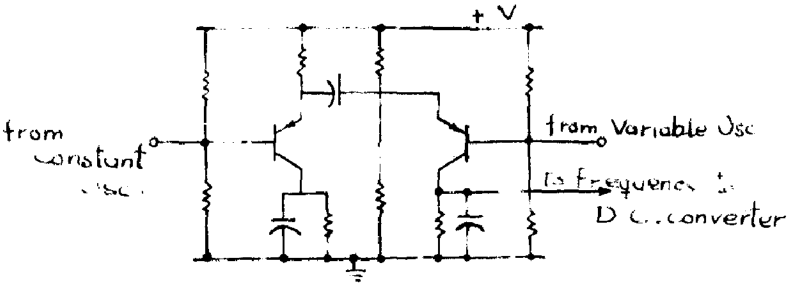


Fig. 6·4 Circuit diagram of mixer

accuracy in the readings of the frequency differences ( $\Delta f$) and to prevent at the same time the usual high frequency problems.

2) <u>The Mixer</u>, giving a voltage at the differential frequency ( $\Delta f$).

3) <u>The Converter</u>, having its output amplitude directly proportional to the frequency at the input.

4) <u>A measuring device to measure D.C. output voltage</u>

5) <u>A Recording device</u>.

<u>Various Components</u>

1. <u>The Oscillators</u> : As shown in the figure 6.2, the oscillators employed in the above apparatus are of the clapp type because of its high stability of the order of $10^{-5}$, which is essential in order to eliminate the voltages not due to actual environmental changes in the proximity of the variable coil. The variable coil in the tuned circuit permits zero adjustment before making measurements.

Referring to figure 6.2 for the circuit diagram of the fixed oscillator, where it is required that it should be tunable within the ± 150 Kc/s range in order to provide a zero prevoltage before the measurements of motion on the body are done. For this purpose a crystal device cannot be used because its frequency band is too narrow as compared to the above figure. However, the variation of the frequency with that of the capacitor is quite critical. As the circuit stability is governed by the Q factor of the coil, it should therefore, be as high

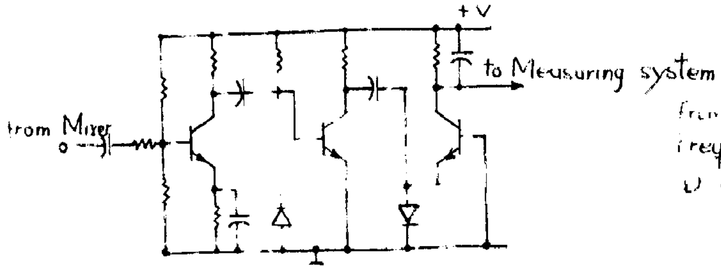


Fig. 6·5 Circuit diagram of converter

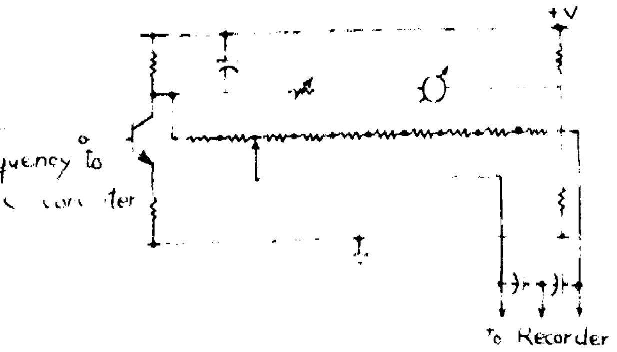
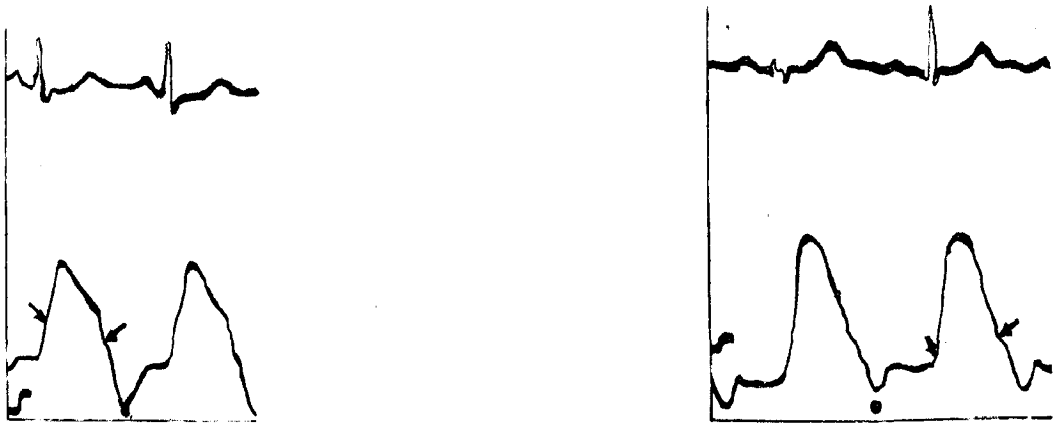


Fig. 6·6 Circuit diagram of measuring device


(a)

(b)

Fig. 6·7 Graph recordings showing normal displacement of the heart area the upex (1·5 cm. above the thorax) as possible.

The variable oscillator circuit diagram is shown in figure 6.3. It is like its fixed counterpart, except that there is no variable capacitor in this case. It should be constructed with very short connecting wires in order to avoid the problems of parasitic capacitance stability. The coil used here is of exchangeable type as per requirements. The sensitivity of the apparatus and its general stability depend on the size of the coil i.e. its Q factor. As the basic frequency of the tuned circuit is closely dependent on the inductance of the coil all coils should be so chosen as to have equal inductance.

2. The Mixer

This is shown in figure 6.4. Here the output frequency of the mixer will be either $\Delta f = f_1 - f_2$ or $\Delta f = f_2 - f_1$ (where 1 refers to fixed and 2 to variable oscillator). The mixer components can be chosen by assigning in advance a given range of operation.

3. The Converter : Circuit diagram of a converter suitable for this apparatus is shown in figure 6.5. This component is necessary for the purpose of obtaining a frequency to d.c. conversion.

4. The Measuring Device : This is shown diagramatically in figure 6.6. This will measure the current due to a voltage between converter outlet and a fixed potentiometer, which may be designed to give a zero reading at $f = 150$ Kc/s.

This arrangement is necessary in order to provide differentiation between metallic and dielectric surroundings. Here, a voltage divider consisting of 10 resistors is shown in parallel with the meter and its series resistance. This feeds a recording instrument, thereby allowing accurate callibration of the recorded voltage. A variable resistor in series with the meter as shown here, permits adjustment of its sensitivity, so as to avoid off-scale readings under wide environmental changes or, to magnify readings under small changes.

## Some Practical Applications

### 1. Detection of a metallic body in the bone

Sometimes during the process of setting a complicated fracture in the bones such as femur, a metallic screw is to be introduced. The removal of such metallic screws involves an operation. For this purpose, exact location of the metallic part within the body is essential. This, however, sometimes cannot be done even with X-ray methods as X-ray, photographs are projective views giving only the relative distances. With the method discussed above, the screw can be pinpointed by probing along the bone which will show a reversed deflection of the indicator as compared to the reading over sound bone.

### 2. Cardiac process measurements and recordings

The cardiac-kinetic measurements can also be made and recordings can be taken with the help of the measuring apparatus discussed above. Two such recordings of normal behaviour are shown in figure 6.7 which are known to be taken on two healthy subjects. The arrows here, denote the valve action and O - the start of the cycle.

### 3. Measurement of Muscular Motion

For the measurement of the muscular motion, the probe is simply placed in the close proximity to the muscle under examination and the patient is instructed to move the muscle and the movements are then recorded on a calibrated graph paper.

### 4. Near-surface tumors Detection

Near-surface tumors may be made detectable using this method and device. However, comparatively large tumors may be detectable through their relatively higher density compared with that of the adjoining tissue.

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# CHAPTER VII

## MEASUREMENT OF RESPIRATION RATE

### Introduction

The respiration rate in the case of critically ill patients can be determined by measuring the central venous pressure. This venous pressure is transmitted to a strain gauge transducer by means of a catheter which is inserted into the patient's right atrium or superior vena cara. Then a signal conditioning method is used by employing a low-pass filter to remove the pulsatile variations related to heart action which are superimposed on the low-frequency respiratory changes. The output of the respirometer can then be sampled by means of a control system computer and the results can be made to print on an output typewriter.

Central venous pressure measurement may be helpful in the case of critically ill patients because it provides a sensitive indication of cardiac failure. Venous pressure variations are partly function of respiration and can, therefore, be used as inputs to the signalconditioning circuit.

However, the problem of irregularity of the waveforms and variations in their duration and amplitude with the use of signal conditioners for the determination of respiration rate will be there. The rate and amplitude of respiration may become extreme in the case of seriously

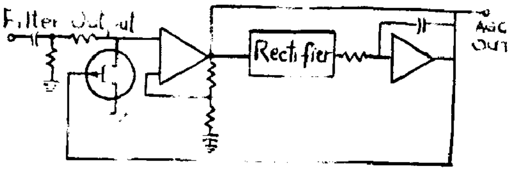
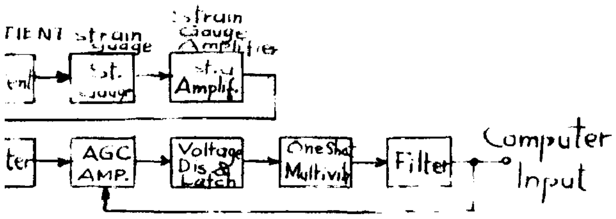


Fig. 7.2 Simplified AGC Circuit



·1 Respiratory rate meter block diagram

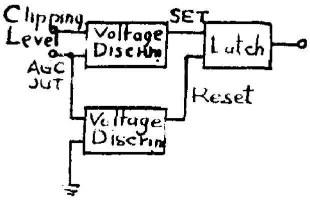


Fig. 7.3 Block diagram of discriminators and latch

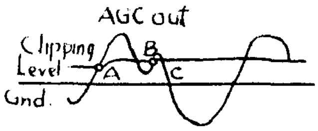
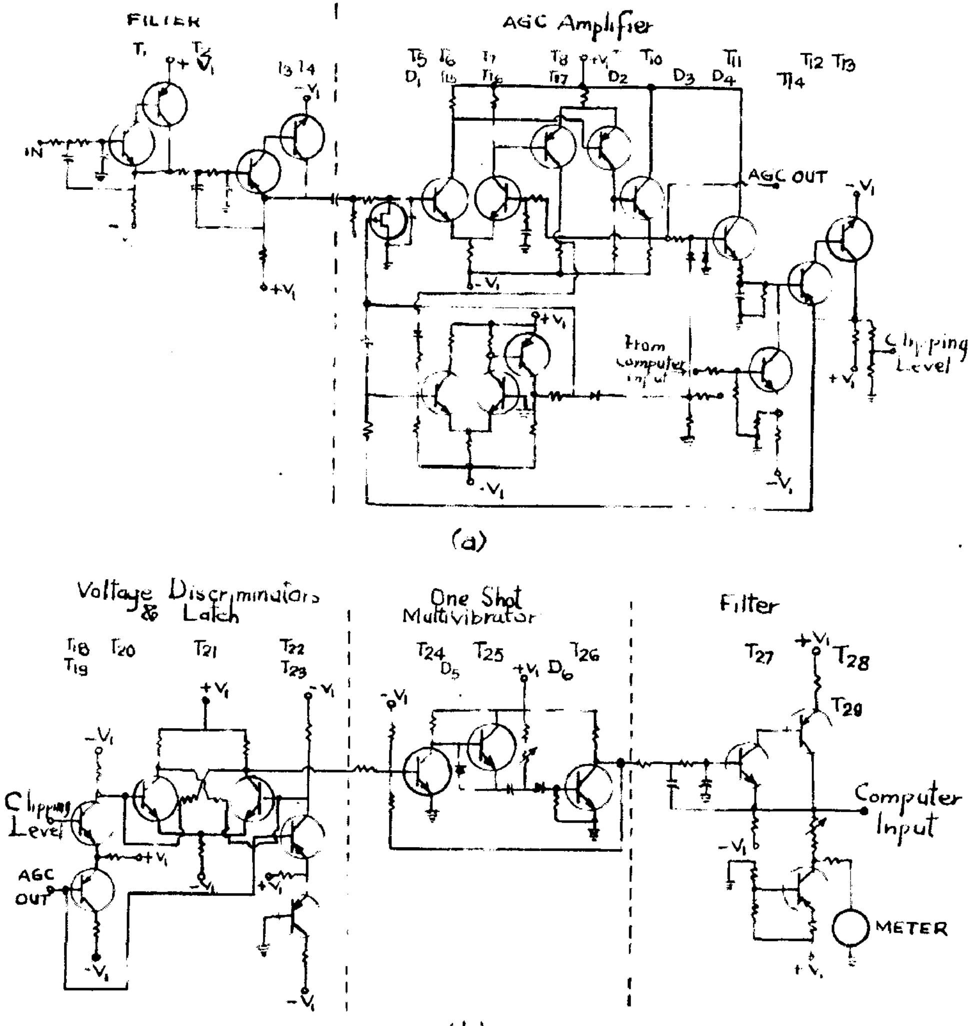


Fig. 7.4 Waveforms representing the AGC output and Clipping level



(a)

(b)

Fig. 7.5 Circuit diagram of the measurement system for respiration rate ill patient. Also other irregular waveforms are associated with coughing and swallowing in such cases. Ratemeters usually work quite well during normal respiration but may fail for high rate measurements due to the reason that short duration and low amplitude waves cannot be differentiated from small variations superimposed on normal amplitude waveforms. Therefore, the rate with rapid respiration is too low because some of the low amplitude waves are not detected by the rate meter with its normal sensitivity. However, in cases of slow respiration small variations within one waveform may be wrongly understood as indication of individual breaths, and a high rate may be recorded wrongly.

## General Description

Figure 7.1 shows a block diagram of the system for the respiration rate detection.

With respiration, the changes in intrathoracic pressure occur which are transmitted to the veins. Also the superimposition of the pulsatile variations related to heart action on the low frequency respiratory changes takes place. The signal conditioning is done to separate respiration from the higher frequency signals. This is done by low-pass filtering method. The waveform thus obtained will be similar to the output of other respiratory sensors. Wide amplitude range of respiration signals is normalized by means of a low frequency automatic gain control amplifier shown in figure 7.2. The effect of short-term amplitude variations and noise can be minimized by using a variable clipping level circuit. The ratemeter consists of a one-shot multivibrator circuit followed by an active filter. The output of the filter is sampled by means of an analog-to-digital converter. The computed output can be recorded on a typewriter.

## The Components

A typical circuit diagram for different components of the measuring system as discussed above, is shown in figure 7.5. The components include the filters, A.G.C. amplifier (automatic gain control amplifier) and the ratemeter.

## The Input Filter

The active input filter consists of two similar sections in cascade, operating at a cutoff frequency of 0.8 c/s. $T_1$ and $T_2$ are used here to provide an isolating stage in the first filter section, $T_3$ and $T_4$ perform the same function in the second section. The transistors used in the two filter sections are chosen so as to have complementary characteristics in order to minimize the d.c. shift. This makes it possible to use the filter output for other measurements where d.c. shift is comparatively large.

## The Automatic Gain Control Amplifier

The output of the filter is fed to the capacitor-coupled, automatic gain control amplifier. This amplifier employs a field effect transistor $T_5$ as the element to control the gain. Transistors, $T_6$ to $T_{10}$, as shown in the figure form a high input impedance amplifier to amplify

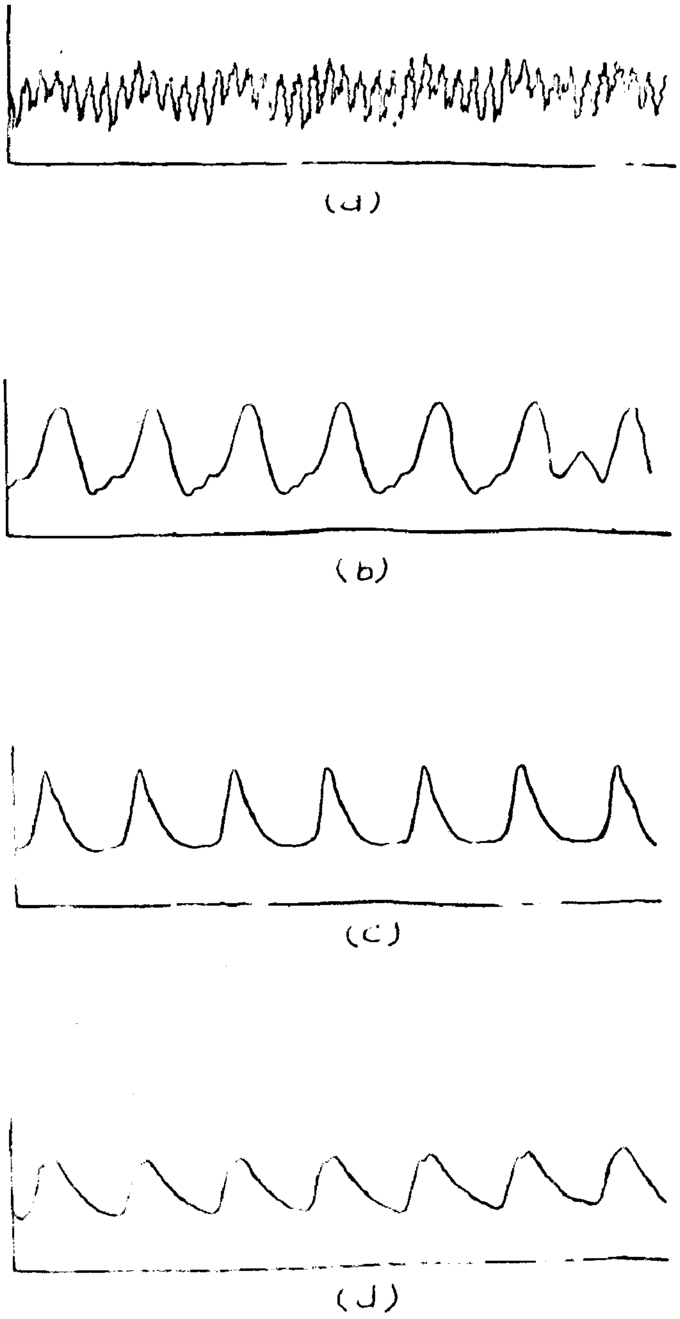


Fig. 7.6. (a) Venous pressure (b) AGC output
(c) Thermistor temperature variation with air flow
(d) Airway pressure

the output of the field effect transistor. The amplifier output is rectified by $T_{11}$ and is followed by $T_{12}$ and $T_{13}$ to provide isolation for the rectified signal. The transistor $T_{14}$ provides the discharge of the capacitor $C_1$ in the rectifier circuit and is controlled by the ratemeter output, thus discharging the capacitor at a rate proportional to the respiration frequency. Transistors $T_{15}$, $T_{16}$ and $T_{17}$ amplify and filter the rectified output, and thus provide the control signal for the field effect transistor.

### The Detector and the Ratemeter

The clipping stage as shown in the figure is meant to improve tolerance to noise. The clipping level in this case is obtained from the output of the rectifier circuit in the automatic gain control amplifier. Clipping level changes, therefore, compensate for short-term variations in amplitude. When the output of the amplifier goes above the clipping level, a latch is set, as shown in figure 7.4 (point A). When the amplifier output goes below ground, the latch is reset at point C. However, the peak following B is ignored.

The ratemeter consists of a one-shot multivibrator which is followed by an active filter stage. The reason for choosing this filter instead of a simple RC network, is that it improves the response time of the ratemeter to a change in the input frequency. The transistors shown as $T_{27}$ and $T_{28}$ in the figure perform the necessary isolation for the active filter. The transistor $T_{29}$ is used as a voltage shifting element

<u>Some Waveforms</u>: Some of the typical waveforms are shown in fig. 7.6, which are the outcome of this type of measuring system.

# CHAPTER VIII

## MEASUREMENT OF ORAL AND NASAL AIRFLOW

### General Description

Unimpaired oral and nasal airflow during speech can be measured with the help of an integrating flowmeter, described here. Warm wire velocity sensors arranged in the form of two independent arrays are used to sample the oral and nasal flow fields. The indications of these velocity samples, which are linear, are added in order to determine the oral and nasal flows. Frequency response of the order of 250 c/s can be achieved by means of short pieces platinum wire used as sensors. By means of feed-back control each sensor can be maintained at a relatively constant temperature. In order to minimize the error caused by small changes in temperature of the exhaled air, an operating temperature of 200°C is used.

The pattern of airflow from the nose and mouth determines the features of consonants. Therefore, simultaneous recording of flow and audio is of considerable use and importance for speech specialists. The type of air-flow during speech is controlled mainly by the respiratory effort, and by oral valve system, which controls and directs the breath stream. The measurement of unimpaired oral and nasal airflow is, therefore, useful to speech physiologists.

### Principle of Operation of Integrating flowmeter

The principle on which this particular integrating flowmeter works is that if exhaled air is allowed to move freely rather than capturing and channelising it, a flow field is established. But flow is the surface integral of the normal component of velocity. Therefore, on this basis, it is seen that if the sampling of velocity is done at a number of "points" uniformly spaced within the area of airmovement, and approximately equidistant from the orifice of flow, the addition of velocity samples provides a close representation of flow. For this purpose, it is observed that a minimum bandwidth for the flowmeter system should be of the order of 250 c/s due to the reason of lips and tongue tip movements taking place within 4 to 5 ms.

## Constructional Details

To obtain the frequency response, as mentioned above, short pieces of platinum wire maintained at constant temperature may be used.

The flowmeter consists of 28 similar and independent channels. Each channel is designed so as to keep the temperature of its sensor constant. The sensors of 24 of these channels are placed in a uniformly spaced array on a curved surface at a distance of 1 to 2 cm. from the lips of the subject. To separate oral and nasal flow, a thin metal plate is attached to this array. Above the plate, the four remaining wires are so arranged in order to be able to sample nasal flow. The edge of the separator may be padded with rubber in order to achieve a tight fit.

As velocity sensors, pieces of platinum wire are used. A typical size of the platinum wire suitable for this purpose is 12.7 micro in.diameter and 9.5 mm in length. A very large ratio of length to diameter is required to minimize errors due to heat conduction to the supports. Also, a further consideration requires that the length should be relatively short compared to distances in the velocity field so that notable changes in velocity take place.

The curvature of the surface for placing oral and nasal velocity sensors is determined by noticing the changes in facial set up. However, the size of the mounting surface is determined by measuring air velocity around the mouth during speech using a warm-wire sensor. Sensors for oral flow are placed in a uniform array for detecting oral flow. Similarly, by observations of smoke flow during speech, an approximate placement for nasal flow sensors can be determined.

The desired frequency response is obtained by means of feedback control of the temperature of each warm-wire sensor. In this case each warm-wire sensor is made one arm of a bridge circuit. When airflow cools the sensor, its resistance decreases thereby making the bridge unbalanced. This unbalance can be detected by means of a high-gain amplifier which will also increase the voltage applied to the bridge. This warms the sensor, thereby making the temperature and resistance to regain their original values, and thus the voltage imbalance is reduced. As the wire does not change appreciably in temperature, good frequency

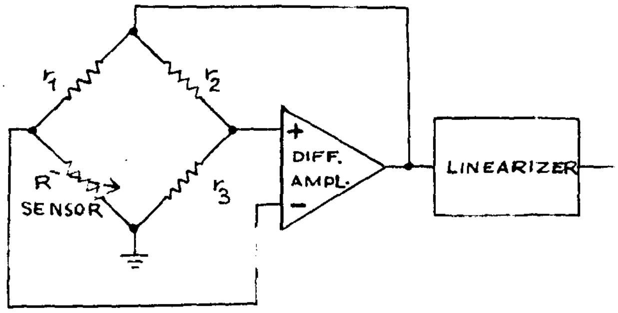
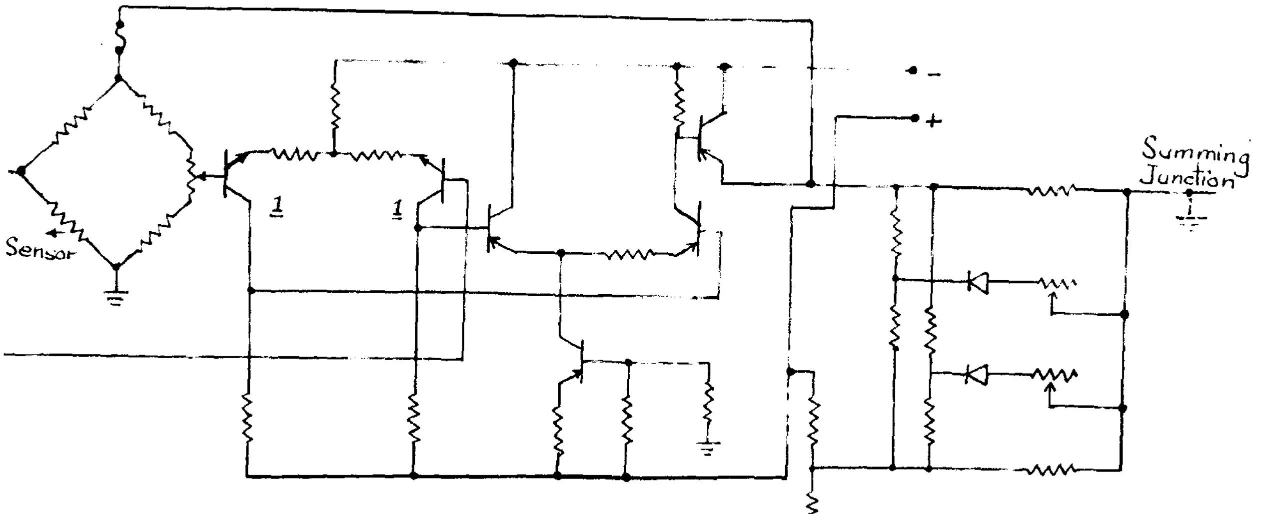


Fig. 8·1 Simplified block diagram of a single velocity measuring channel.



1 Input transistors have their cases heat-sinked together

j. 8·2 Schematic diagram of one channel of a typical integrating flowmeter
"Summing junction" refers to the input of an operational amplifier

response is obtained which is not limited by heating and cooling lags. The only limiting factors for the frequency response so obtained are the amplifiers gain and phase shift. The error due to small changes in temperature of the exhaled air can be minimized by performing the operation at 200°C.

Figure 8.1 shows the block diagram of a single velocity-measuring channel. Here, each channel consists of a sensor in a bridge circuit, a differential amplifier, and a linearizer. If one channel is considered and it is assumed that the amplifier's input impedance is infinite, the voltage varies in such a fashion that

$$\frac{R}{R+r_1} - \frac{r_3}{r_2+r_3} = \frac{1}{A}$$

where A is the amplifier's gain.

If A is large, then $\frac{1}{A} \approx 0$

and therefore, $\frac{R}{R+r_1} \approx \frac{r_3}{r_2+r_3}$

$$\text{or} \quad R \approx \frac{r_1\, r_3}{r_2}$$

Here, $r_1$, $r_2$, $r_3$ are constants, therefore, the feedback will tend to keep the resistance (and therefore the temperature) of the sensing element constant. The output of the differential amplifier, however, increases when heat is taken away from the sensing element by air flow. This results in sufficient heat to be generated in this element in order to replace that carried away. Therefore, the time delays associated with passive change of temperature are minimized. This makes the frequency response dependent mainly upon the speed of corrections in supply voltage. This, however, is given by amplifier gain and phase shift.

In order to obtain airflow, the voltages representing the velocities at several points of measurement are required to be added. For this, these voltages must be made directly proportional to the velocities. This can be done, by means of biased-diode function generators. However, the curved current-vs-voltage characteristic of germanium diodes can be used with advantage due to the small range of voltages.

Because the velocity sampling here is uniform and the outputs of each channel are made directly proportional to the velocity, by adding the outputs using an operational amplifier, it can be made equal to integration. Therefore, in that case, the output of the operational amplifier is directly proportional to airflow given by units of volume per unit of time.

Figure 8.2 shows a typical circuit consisting of the bridge, amplifier, and linearizer components of the block diagram shown in figure.8.1.

## Remarks

The airflow during speech is modified due to the respiratory, laryngeal, and palatopharyngeal valving as well as due to the size and shape of mouth opening. In other words, the complex physiological changes which are responsible for speech production cause noticeable variation in the volume velocities of oral and nasal flow with respect to time. This integrating flowmeter gives satisfactory response to the normal range of flow produced during conversational speech, which is given as 0 to 1200 ml/s. Some nonlinearity of response, however, occurs when high velocity turbulent flow is created as a result of allowing air to diffuse.

The short comings of this flowmeter are : 1) the nonlinearity due to high velocity, turbulent flow and 2) the transit time delay. These might be considered inevitable in free-field flow recording systems. The warm wires which are used here, as velocity sensors introduce another drawback, because the warm wires are insensitive to the direction of flow, that is, forward or backward flow. However, the angle of incidence of airflow does affect the response of warm-wire sensors. Therefore, to account for the individual variations in facial contour, an optimal placement of sensors is necessary as the sensitivity changes due to changes in the angle of incidence.

The problem of transient-time delays and variations in sensitivity which result from differences in the angular direction of flow, can be solved by minimizing these by placing sensors on a flexible frame. Individual positioning of sensors in close proximity and at proper angle with respect to the nose and mouth of the speaker, is achieved by the use of such a frame.

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# CHAPTER IX

## MINIATURE PRESSURE TRANSENSOR

### Introduction

A method for measurement of intraocular and other physiological pressures is described here. This method consists of a displacement transducer contained in a distensible pillbox small enough to be implanted in the eye of a small animal suitable for laboratory tests. In this method no element or part of the device touches globe of the eye. This passive resonent transensor absorbs energy from an oscillating detector coil outside of the animal at a frequency which will depend upon the pressure in the eye. Due to passive type of operation of this transensor its life is increased but at the same time it limits the useful range of the device to approximately 10 times the diameter of a single transducer.

This pressure transensor can be used for continuous sensitive pressure recordings in the case of conscious and responsive animals under test because of its (1) fine pressure resolution of the order of 0.1 mm $H_g$, (2) milli-second response, (3) small size of the order of say 0.015 $\mu l/mmH_g$, and (4) no loss of fluid from the eye during the measuring process.

The size reduction problem here is solved by the introduction of a novel transensor principle which requires only one electronic part and no batteries. With this device the pressure information is telemetered outside of the eye by a frequency modulated very high frequency radio link. In this case the head and eye movements are not restricted during the measurements and therefore the continuous pressure records can be obtained from animals when they are alert and physiologically responsive.

### Working Principle

The intraocular pressure is sensed by introducing into the eye a bubble of gas and then observing itsvolume. The bubble is encapsulated in a rigidly suspended flexible film so as to prevent absorption of the gas in it. The size of the bubble can be seen optically in an anterior chamber.

A more sensitive method of measurement for deeper and opaque structures is by employing the novel strain gauge transensor principle to know the size of the encapsulated bubble. In this case, a pair of parallel, coaxial spiral coils gives a high Q distributed resonant circuit whose frequency varies sensitively with relative coil spacing. The pressure acting on the capsule brings these coils closer to each other, resulting in the increase of the capacity between the spirals as well as of their mutual inductance which lowers the resonant frequency of the system. The resonant frequency of this transducer is detected through the intermediate tissue which absorbs the electromagnetic energy. To detect the bubble tonometer at a distance, an external inductively coupled oscillating detector may be

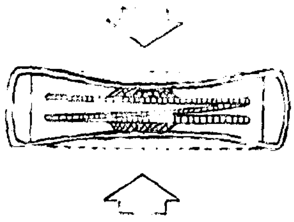
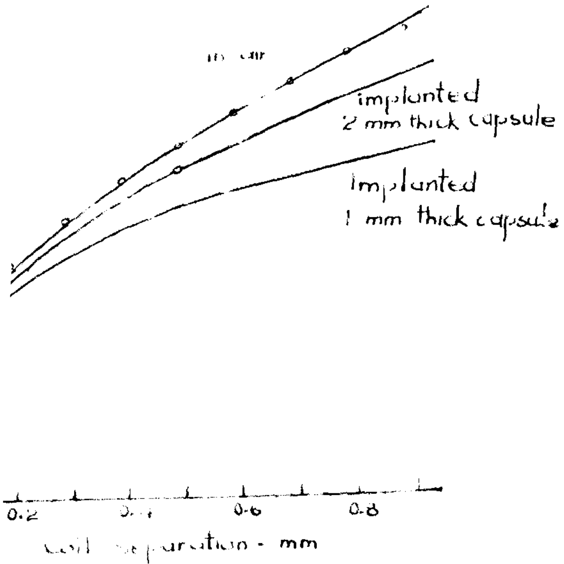


Fig. 9·1 Cross section showing the plastic bubble tonometer



aph showing variation of resonant sensor frequency with coil separation

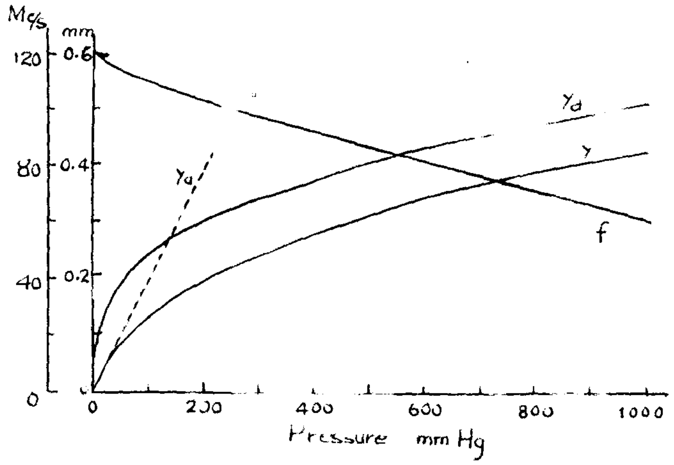
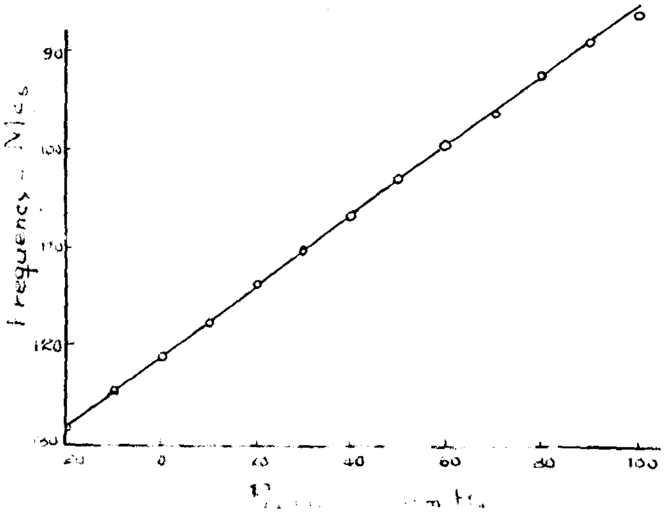


Fig. 9·3 Graph showing the variations of y, yd, ya and frequency f with pressure



9 [illegible]

employed. The energy absorbed by the transducer at its resonance can be continuously observed by repeatedly sweeping the external oscillator frequency. This can be converted to a voltage to drive the recorder and thus continuous records of intraocular pressure are obtained. Figure 9.1 shows the cross-section of a plastic bubble tonometer.

<u>The Implanted Capsule</u>

The pressure sensing implants can be made very small since they are required to contain only one compact circuit element and also since they need not store energy for longer periods. The lower limit on the size of a passive transensor is determined by its desired working distance from the detector.

The implantable transducer is kept in a short, thin-walled glass tube and polyester diaphragms are stretched tightly over its ends. Glass is used as the supporting structure of the transducer due to its rigidity and firmness with respect to the shape. To avoid shielding between the spirals and the detector coil, nonconductors must be used for constructing the pillbox.

The unconnected spiral coil-pair will work as a displacement transducer, whereas the coils are connected at the periphery, the resonant frequency of the circuit is reduced to approximately half when the coils are closely spaced. Therefore, this is useful when working at very high frequencies which also doubles their displacement frequency modulation range. The coils, here, are joined so that the rotation takes place continuously in one direction forming a single inductor, the mutual inductance of which will increase as two halves of spiral more towards each other. This increases the pressure sensitivity of the transducer. Closer spacing increases the pressure sensitivity of the unit at the expense of pressure range. Optimum inter coil spacing, however is approximately one tenth of the spiral coil diameter.

Mathematical Analysis

The transensor can be considered as equivalent to a spiral-coiled half-wave dipole antenna, where the length of the winding of each coil, taking into account the retardation due to surrounding dielectric, will approximately be equal to one-quarter wave length at its resonant frequency. For analysis purpose this device may be considered as a jumped constant tuned circuit, or a coiled transmission line. Considering here the lumped constant approximation, the analysis can be done in the following manner.

The electromagnetic resonant frequency of the spiral transensor can be calculated from its physical dimensions and is given by :

$$f = (4 \pi^2 LC)^{-\frac{1}{2}}$$

where $L = L_1 + L_2 \pm 2M$

$C = 0.00885 \, K \, 4 \pi a^2 S^{-1} + C_o$

$L_1 = Zn^2 a$, inductance of one spiral coil

$M$ = their mutual inductance

$n$ = number of turns in each spiral

$Z$ = a constant = $1.33 \times 10^{-3}$

$C$ = the capacitance between the coils

$C_o$ = fixed stray capacitance

$K$ = 1, for air

$a$ = mean radius of spiral coils in mm.

$s$ = spiral coil separation in mm.

The sensitivity depends less on the variation of mutual inductance as compared to the variation of capacity between the coils. The coupling coefficient between the two spirals under normal operating conditions is of the order of 10 percent, and the variation is also slow, so that L can be approximated as

$$L \cong 2.2\, Zn^2a \quad \text{micro-Henry}$$

Due to the fact that the resonant frequency varies as the inverse square root of the capacitance between the coils and this capacitance varies inversely with the separation of the coils, the resonant frequency of the transducer will be approximately proportional to the square root of the coil separation. Therefore, for the above case

$$f = 168 \times 10^6 \left(\frac{S}{1+6\times10^{12}\, C_oS}\right)^{\frac{1}{2}}$$

In air, $C_o \cong 0$

and therefore, $f = 168 \times 10^6\, S^{\frac{1}{2}}$.

However, practical resonant frequency of a transensor after implantation is lowered due to the added stray capacitance which is given by the separation of the coil from tissue, i.e. the pill thickness. Figure 9.2 shows the calculated and measured values of these functions from comparison point of view.

The pressure sensitivity of the plastic bubble tonometer is governed by the mechanical stiffness of the capsule, the stiffness of the diaphragm being added to that due to the air enclosed in the bubble. For a circular diaphragm with edges held, and uniformly loaded, the displacement of the centre of the diaphragm is given by,

$$Y_d = 0.662\, b \left(\frac{pb}{Et}\right)^{1/3}$$

$$Y_d = \gamma_d\, p^{1/3}$$

where b = radius of the diaphragm

E = modulus of elasticity

t = thickness of the diaphragm

p = pressure applied

$\gamma_d$ = diaphragm compliance

(a typical value is 0.05)

For large pressures, the stiffness is controlled by the diaphragm. For small pressures, upto about 30 mm $H_g$ , the stiffness of the capsule is controlled by the enclosed air cushipn . The air in the capsule behaves approximately as a linear spring. For low pressures, the diaphragm deflection can be written as be seen here that the measured pressure calibration is linear within 2 percent over the physiological range of intraocular pressure.

Very high pressure sensitivity of pills can be achieved by using thin diaphragm material and spacing the coils closely. Transducers having pressure sensitivities above the value of 1 Mc/s per mm $H_g$ are possible by this method. This sensitivity is achieved, however, at the expense of a mechanically limited steady-state pressure range and to some extent reduced mechanical frequency response.

For practical purposes diaphragms having thickness of the order of say 0.0025 inch are used for 1) rugged construction, 2) a wide range of pressure operation, 3) small vapour permeability, 4) longer life, and 5) higher frequency response, giving a pressure sensitivity of the order of a few hundred Kc/s per mm $H_g$.

A gas permeability time constant for these capsules is given by the product of semipermeable membrane resistance and the bubble compliance (due to the combined effects of the diaphragm and the volume of air enclosed in the bubble).

Due to its time constant it takes nearly three weeks for achievement of steady-state conditions in the radio-pill following its implantation. Because of their passive nature and the time taken in establishment of equilibrium, these transduders have a rather long life of the order of six months or more.

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$$Y_a = \gamma_a p$$

where $\gamma_a =$ $h/p_o$, compliance of the enclosed air. (a typical value is 0.0026)

$h$ = pill thickness

$p_o$ = ambient pressure.

Considering the combined effects of diaphragm and air stiffness, the deflection can be expressed as the parallel combination.

$$Y = \frac{\gamma_a p \quad \gamma_d p^{1/3}}{\gamma_a p + \gamma_d p^{1/3}}$$

$$= \frac{1.5 \times 10^{-4} \; p^{1.33}}{0.0026p + 0.05p^{0.33}} \text{, for a typical case.}$$

The diaphragm deflection curves are shown in figure 9.3. The coil separation with applied pressure is then given by,

$$S = S_o - Y$$

and the resonant frequency as a function of pressure can be written as

$$f = 168 \times 10^6 \left[ \frac{S_o - \dfrac{1.5 \times 10^{-4} p^{1.33}}{0.0026p + 0.05p^{0.33}}}{1 + 2\left(\dfrac{1.5 \times 10^{-4} \; p^{1.33}}{0.0026p + 0.05p^{0.33}}\right)} \right]$$

which is also shown in figure 9.3. It is seen here that the mechanical and electrical function nonlinearities of the transducer at higher pressures tend to disappear. Figure 9.4 shows the measured pressure calibration of a typical pressure transensor operating in this way. It can be seen here that the measured pressure calibration is linear within 2 percent over the physiological range of intraocular pressure.

Very high pressure sensitivity of pills can be achieved by using thin diaphragm material and spacing the coils closely. Transducers having pressure sensitivities above the value of 1 Mc/s per mm $H_g$ are possible by this method. This sensitivity is achieved, however, at the expense of a mechanically limited steady-state pressure range and to some extent reduced mechanical frequency response.

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# SECTION

# F
# O
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# BIO-CONTROL SYSTEMS

# CHAPTER X

# PARALYZED MUSCLES CONTROL

## General Description

The problem of Myo-electric control of Paralyzed Muscles is discussed here. A muscle or its motor system is said to be paralyzed when its neural connection to the brain is broken. A motor neuron disconnection is named as lower motor neuron lesion, whereas a disconnection in the spinal chord or brain is called an upper motor neuron lesion. However, in both of these cases the contractibility property of the muscle is preserved in the initial stage but after some time of disuse the muscle looses this property. This loosening of the contraction property is delayed to a greater extent in the case of upper motor neuron lesion. For many years, the medical practitioners have been using electrical stimulation to prevent and delay the loosening of the contraction property of the muscle due to lower motor neuron lesions. However, recently electrical stimulation was used for restoring the paralyzed muscles functions.

In figure 10.1 the mechanism of conscious movements has been shown in a simplified way for a two-axis motion in the plane of X and Y. The mechanism can be understood in this way that when a man decides to perform a motion from $P_1$ to $P_2$ the command is passed to a cerebral center shown as C in the figure, which commands the subcenters such as $C_1$, $C_2$, $C_3$,$C_4$. These centres then send neural

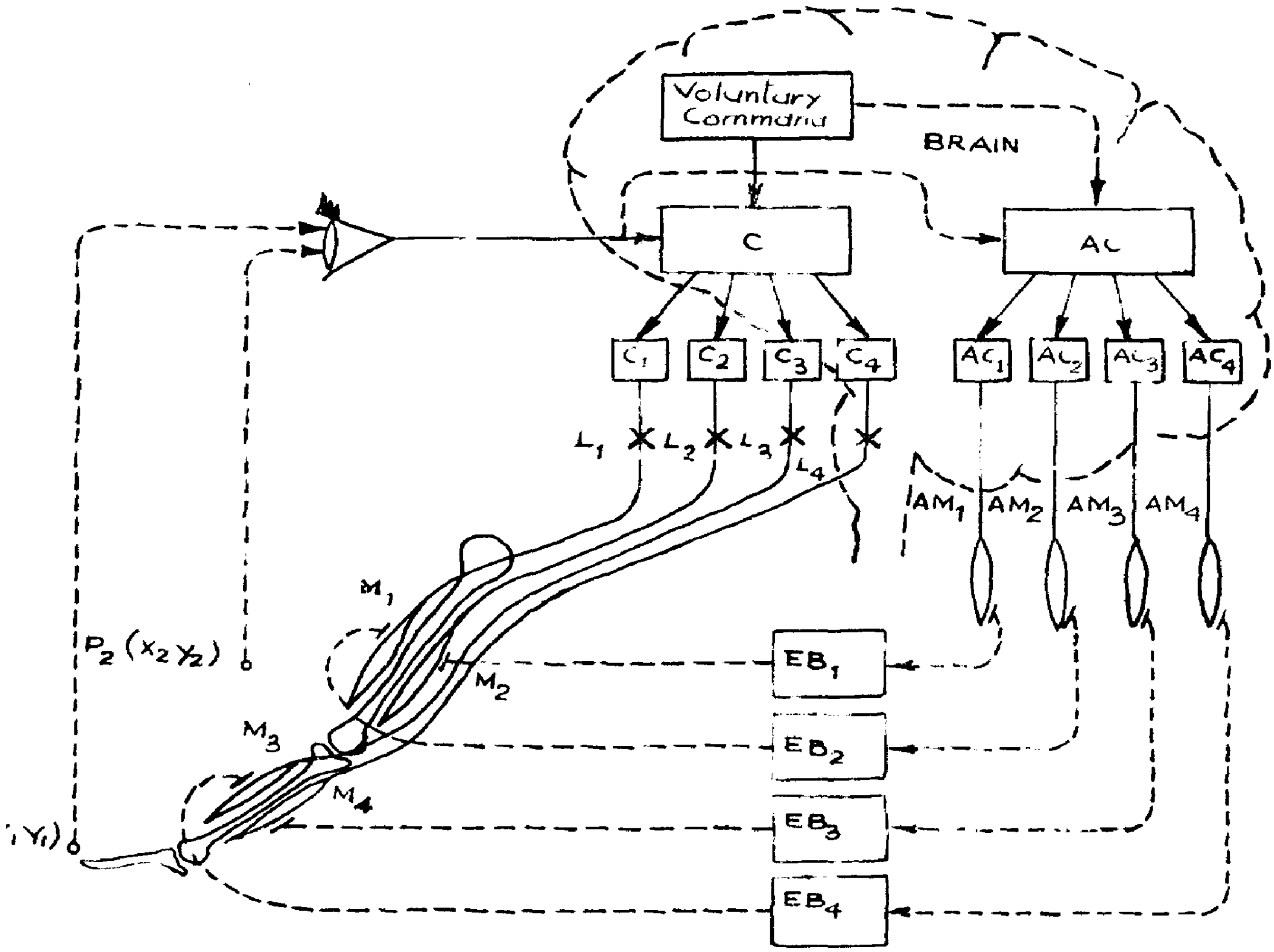

Fig. 10·1 Simplified diagram of the mechanism of Concious movements.

impulses to the respective muscles. The movement is observed by the eye which serves as the measuring device in the feedback loop. Also, the signals known as the proprioreceptive from muscle, tendon, and joint sensors are sent to the central nervous system. When due to some disease, lesions $L_1$ - $L_4$ come in the efferent and afferent pathways, the extremity gets paralyzed. Here the assumption is made that four other muscles shown as $AM_1$ - $AM_4$ in the figure remain in normal function and these are not used in every day activities.

If the cerebral pathway could be moved from C to AC by means of, say learning and if external bypass connections such as $EB_1$ - $EB_4$ could be made, the patient would resume control over his paralyzed muscles voluntarily. This example can be extended to any number of muscles. The limitations to this are - 1) the number of useful auxiliary muscles AM is low in a paralyzed person, and 2) the learning process may require the repatterning of too many auxiliary muscles and, therefore, may become prohibitively long or impossible. However, computers may help to overcome these problems.

## The Stimulator

The stimulator which will be of the EMG controlled type for controlling the paralyzed muscles is discussed here. Control signals may be picked up from the peripheral nerve path or brain centres. Also movements due to contraction of an auxiliary muscle may be transformed in resistance changes of a potentiometer but this will

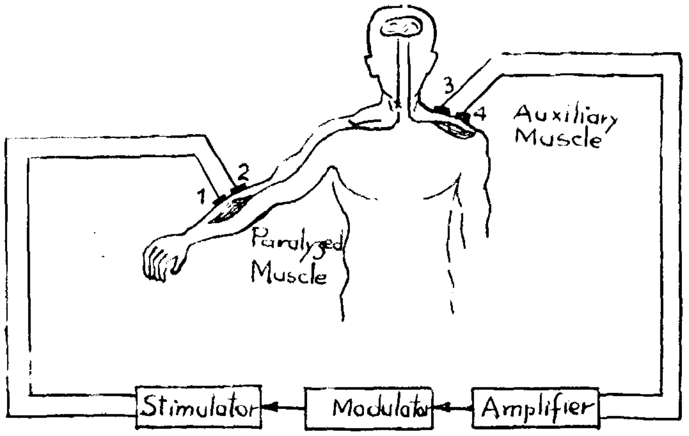

Fig. 10·2 Block diagram of EMG controlled Stimulator

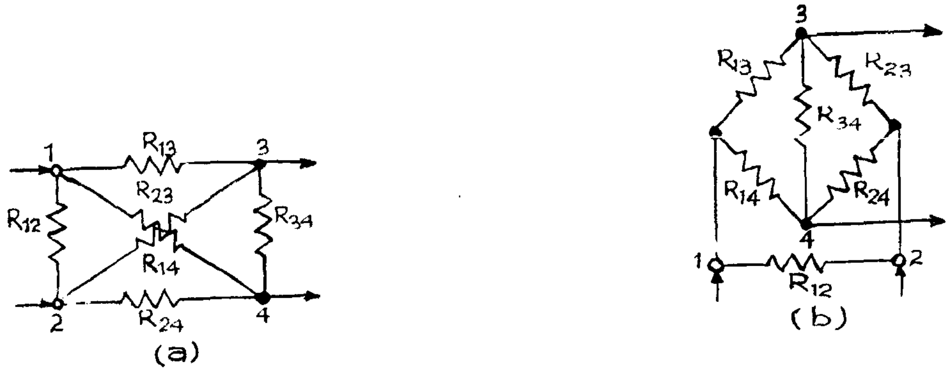

Fig. 10·3(a) Human body representation by approximate Equivalent Circuit. (b) Redrawn circuit of Fig. 10·3(a)

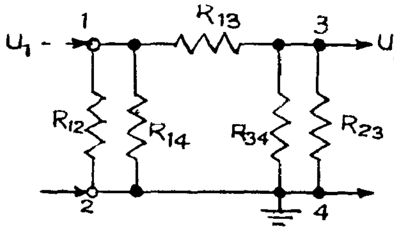

Fig. 10·4 Approximate equivalent network of the human body if a common lead between amplifier and stimulator exists require a mechanical transducer, and to make it sufficiently small may further put a difficulty. Strain gauges, however, are suitable for this purpose but the technique of using these devices on the human skin is perhaps not well-defined to this stage. Considering all these possibilities, the use of action potentials of the auxiliary muscle as control signals remains as the only alternative. Figure 10.2 shows the block diagram of the system, which may be used for controlling the paralyzed muscles. Here, it is shown that from the left trapezius muscles of a C4-5 patient the electromyographic voltages were picked up, amplified, rectified, short-time integrated, and then used to modulate the output pulses of a stimulator. The stimulation current is applied to the right extensor digitorum muscle.

Here, the problem of feedback from the stimulator electrodes through the body to the EMG electrodes is a major one. The stimulation voltages may be about say 30 volts and the EMG potentials about 1 mV, then it is seen that the EMG electrodes may pick up stimulator voltages and thus cause the oscillations of the stimulator. This may result in danger for heart damage if stimulation current flowing through it is of an appreciable amount. The volume resistance of the body can be approximately represented by the net work as shown in figure 10.3. This represents the volume resistance of the body with respect to the stimulator and EMG electrodes. Here the points 1 - 4 are equivalent in figures 10.1 and 10.3(a). Considering 1 and 2 as the voltage source, the pick up voltage at the input of the amplifier is nothing but the voltage which appears across the diagonal of a loaded wheat stone bridge. This is shown in figure 10.3(b). However, resistances $R_{13}$, $R_{14}$, $R_{23}$ and $R_{24}$ are approximately equal as may be proved by measurements. Thus, theoretically, a negligible voltage should appear across 3 and 4. However, if amplifier and stimulator have a common lead the situation will be different. If it is assumed that 2 and 4 are common, the network of figure 10.3 will change into the circuit shown in figure 10.4. Referring to figure 10.4, the ratio $U_2/U_1$ is given approximately as 1/3, if $R_{34}$ is assumed of the same magnitude as $R_{13}$ and $R_{23}$. Therefore, the feedback transfer function will increase from theoretically zero to theoretically one third value if the input and output are galvanically coupled. The feedback transfer function will depend on the common mode rejection of the amplifier, however, if the zero line of the differential amplifier is connected to one of the stimulator electrodes. In that case, the feedback transfer function will be greater than in figure 10.3 and smaller than in figure 10.4.

## The Control System

The complete control system for the paralyzed muscle, as discussed above, will consist of an amplifier, a modulator and a stimulator together with two pairs of electrodes one pair to pick up the myoelectric potential developed across the auxiliary muscle and the other pair to stimulate the paralyzed muscle. The diagram of the actual circuit for this purpose is shown in figure 10.5.

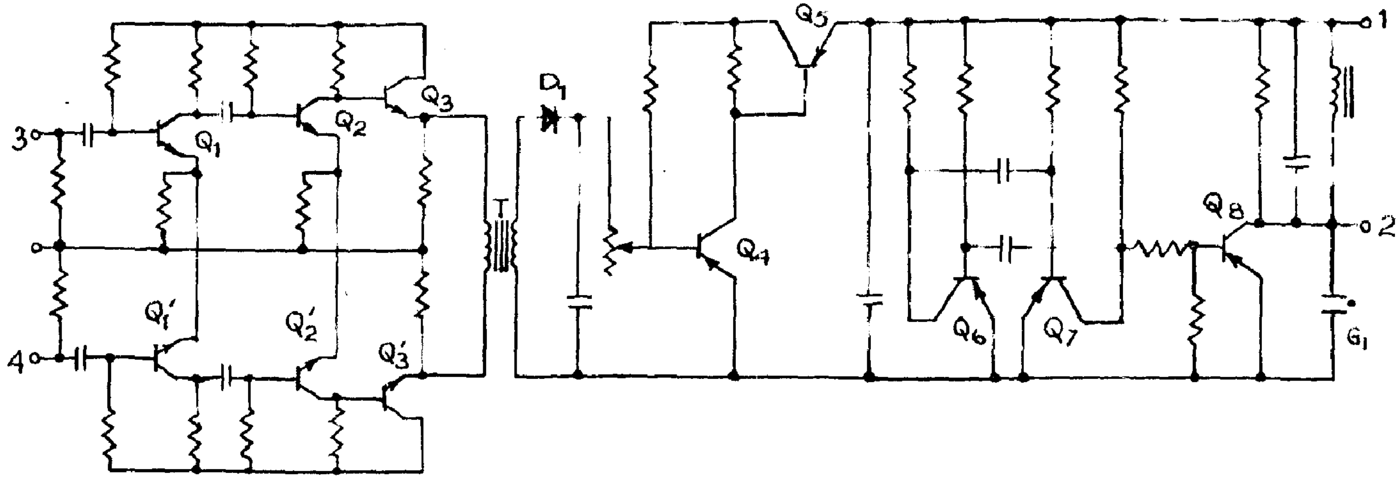

Fig. 10·5 Circuit diagram of the complete system for controlling the paralyzed muscle

Here, the differential amplifier should be constructed by using high-gain transistors. The first two differential stages of the amplifier should produce a gain of the order of 10,000 or so. These stages are then followed by an emitter follower in order to reduce the output impedance of the amplifier.

For decoupling purposes a transformer is used here between the amplifier output and the rectifier. The transistor shown as $Q_4$ in the figure normally remains in the full on condition. The collector current of $Q_4$ transistor is decreased when a rectified and filtered positive myoelectric potential appears. This decreases the usual high resistance of the regulator transistor $Q_5$ and therefore, the multivibrator, shown by $Q_6$ - $Q_7$ transistors, gets higher input voltage. This will result in higher pulses, faster switching will occur in $Q_8$ transistor, and higher induced pulses will appear across the output terminals 1 - 2. In this way the muscle action potential supplied at the input terminals 3 - 4 controls the stimulator pulses at the output. The reception rate of the pulses may be round about 50 pulses per second.

Here, the input and output characteristics are not perfectly linear and depends on the sensitivity adjustment $P_1$. The condensers used here for filtering purposs in the rectifier and after $Q_5$ transistor give a smooth control of the stimulator, but in addition they will cause a delay between the command signal and the desired results. However, for practical purposes this delay if not of higher order will not diminish the utility of the system. The nonlinearity of the system is compensated by visual feedback of the patient. For example if the problem of patients paralyzed right hand muscle is controlled by stimulating it from the patient's active left shoulder muscle, then after a few weeks of training the patient will begin to contract his shoulder muscle without conscious effort in order to open his right hand. This also proves to a certain extent the assumptions of transfer of the command from one brain center to another as discussed earlier and shown in figure 10.1.

However, regarding the smoothness of control there are no limitations, but there will result jerks in the hand position (considering the above cited example), because of difficulties encountered in holding the shoulder muscle on certain levels in the contracted position. Still the patient may be made to open his hand in a number of different levels without much difficulty, thus proving the utility of the control system for all practical purposes.

This device is powered by two sets of batteries. By carefully choosing and adjusting the components, the device may be made quite small, say having the dimensions of 4 by 5 by 6 inches. This will make it easy to mount the device behind the patient's wheel chair.

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# CHAPTER XI

## NEUROMUSCULAR CONTROL SYSTEM

### General Description

A human subject performs rapid skilled movements at such a rate that conscious control involves the strategic selection of a set of detailed plans of control which have been learned by the subject previously. The roles of spinal reflexes, rutines of motor impulses from the central nervous system, and conscious voluntary control can be observed separately by the use of transient changes in the force applied to various muscle groups and then obtaining a computer analysis of the results so obtained.

### Basic Theory

The sensing elements as contained by muscle, skin, and tendon include force, position and velocity-sensitive components. The sensing elements are part of feedback loops which affect the muscle behaviour. Some of these feedback loops, that is, "reflexes" include only the spinal chord while others involve higher centres in the brain. Apart from all these loops there is the feedback which results from visual observation, and from other organs such as those of hearing smell or balance which carry information to the operator about the consequences of a muscular movement.

The information is transmitted in the nervious system in the form of bursts of unit impulses. The size of these unit impulses carries no information. The transmission speed of these impulses is more than the required one when compared with the possible speed of movement produced by muscles, but still it is relatively low and in the fastest human nerve fibres it is approximately one third that of the sound in air. Therefore, if a group of muscles is made to oppose a constant force, then by suddenly changing the force there results a short period in which a displacement of the muscles and the connected mechanical system (used for investigation) occurs without the feedback operation. The system behaves during this period as though all the loops were open. This period is followed by a time when only the spinal reflexes will be acting, but the transport lag to and from the brain will still be present. Then a response from the brain will occur and as a result the subject will consciously find that a change has occurred. The subject may perhaps observe a movement by visual means. However, this complete operation takes about one third of a second.

## The Apparatus

The measurements on the various flexor muscles of the arm such as biceps in the upper arm and brachioradialis in the forearm can be made using this apparatus. These measurements, however, cause the elbow to bend, in which the subject is made to lie down comfortably on his back with his elbow being bent at right angles. The applied force is carried to his wrist through a cuff. A meter or an oscilloscope is provided in the range of easy vision of

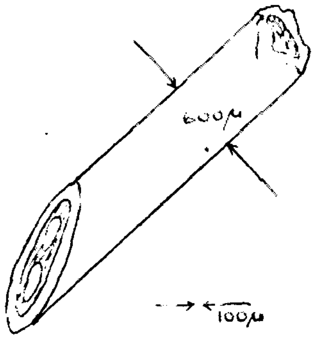

Fig. 11·1 A needle electrode

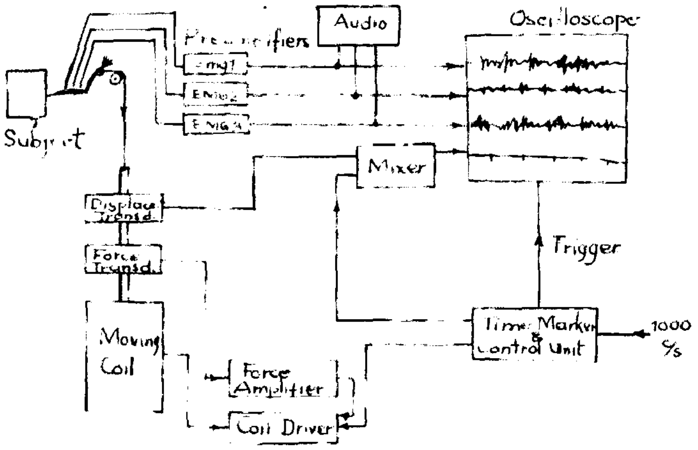

Fig. 11·2 Block diagram of muscle loading apparatus the subject which records any displacement produced by his arm. An index mark is provided in the oscilloscope to give him visual position feedback.

One or more sets of recording electrodes are then inserted into the muscles under test. The electrodes consist of hypodermic needles, generally 2 inches long. A pair of silk and enamel insulated nicrome wires passes through the needle. The ends of the two wires serve as the actual electrodes, the wire being set in position in the needle by means of a setting material. This is shown in figure 11.1.

When these "bipolar" needles are used in conjunction with a differential amplifier, the electrical activity in the muscle can be recorded within a range of about 2 mm from the tip. The needle diameter is considerably greater than that of individual fibres, so the needle will not enter a single fibre in the actual sense. As the needle will be inserted, a slight prick will be felt as its tip will pass through the skin, but after wards no more sensation will arise as the needle will enter the muscle.

The force generator, in this apparatus, consists of a large moving coil electromagnet, similar in looking to a loudspeaker. A typical force generator will produce a force of 1 K.gm. for a current of 58 milliamperes. The coil position is detected by a linear potentiometer which occupies a position in the central pole piece and the force developed is detected by means of a strain gauge which responds to the deflections of a steel bar kept at the

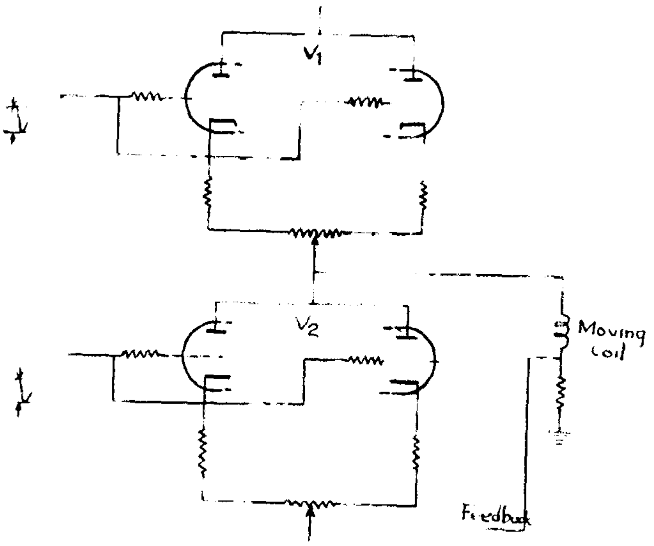

Fig 11·3 Driver output stage

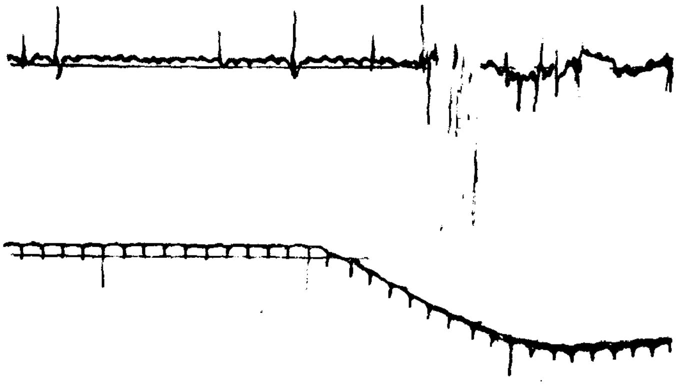

Fig 11·4 Biceps motor unit potentials, displacement, and time markers (10 and 100 ms) top of the coil.

Figure 11.2 shows the general arrangement of the control and recording circuits. The output from the displacement transducer is added to that of a time marker generator and is then seen on an oscilloscope using its one of the beams. Other beams of the oscilloscope are used to record the electrical activity in the muscles. The output of the force transducer may also be displayed on an oscilloscope. It is also compared with a reference signal and the difference is fed to the moving coil driver amplifier. This will result in force feedback. However, the force delivered remains almost constant irrespective of the acceleration in the moving coil system. As a result, the inertia and friction in the coil system are reduced.

For coil driver amplifier, a vacuum-tube direct-coupled, "single-ended push pull" circuit, as shown in figure 11.3 may be used. In this case, a great amount of power is dissipated in the cathode resistors required to force load sharing between the two halves of each tube, but this improves the linearity. Overall, current feedback is also applied over the complete driver amplifier. The power supply in this case for the output stage and magnet exciting coil may consist of a three-phase full wave rectifier, with capacitive filtering only.

## Some Recordings

Figure 11.4 shows some recordings as given by this apparatus.

If a constant load representing, say, 5 percent of the force a muscle can exert, is applied to it and the electrical activity is recorded by using a needle electrode as discussed above, the tracing consists of a regularly repeating pulses of a small number as is seen in figure 11.4. These pulses are about 100 microvolts in amplitude, and have a duration of about 4 millisecs. and are repeated at the rate of about 8 per second. In a normal subject the fine structure of a single pulse is almost constant. Each of these pulses shows more or less synchronous discharge of a number of muscle fibres in the proximity of the needle. This discharge is of synchronous nature due to the reason that this group of fibres is supplied by branches of a single nerve fibre. Such a group is known as a motor unit. The muscle fibres which are adjacent to each other generally belong to different motor units and the fibres of one motor unit may be widely scattered through a muscle. When the activation by this electrical discharge takes place, a muscle fibre starts contracting, a contraction may last about 150 milliseconds.

As the load is increased on a muscle, two things happen - (1) motor units increase in repetition rate, upto a maximum of about 25 pulses per second, and (2) new motor units appear. Due to the combined effect of these two mechanisms, there results an increased developed force.

The incoming information to the muscle may be studied by seeing the motor unit potentials. Figure 11.4 shows a typical record of displacement and the corresponding muscle activity.

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