TEMPERATURE SCANNING OF ELECTRICAL ROTATING MACHINES

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree of

MASTER OF ENGINEERING

in

ELECTRICAL ENGINEERING
(MEASUREMENT AND INSTRUMENTATION)

By

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CANDIDATE'S DECLARATION

I hereby, certify that the work which is being presented in the thesis entitled, TEMPERATURE SCANNING OF ELECTRICAL ROTATING MACHINE , in partial fulfilment of the requirements for the award of the Degree of MASTER OF ENGINEERING IN ELECTRICAL ENGINEERING, specialization in MEASUREMENT AND INSTRUMENTATION, submitted in the Department of Electrical Engineering, University of Roorkee, Roorkee (India), is an authentic record of my own work carried out for a period of about eight months, from August 84, October 85 to February 86 and September,88 to October 88 under the supervision of Dr. H.K. Verma, Professor, and Shri S. Mukherjee, Lecturer, Department of Electrical Engineering, University of Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

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ABSTRACT

The motor temperature can exceed the normal value because of number of causes as a) operation at line voltage (and frequency) different from rated value b) changes in the motor ventilation because of mounting arrangement or dust accumulation c) more frequent starting duty than was planned d) variation in loading caused by production tolerances of the driven machinery, normal wear, and field adjustment and lastly e) High ambient temperatures. To scan the temperatures at different points of the motor, it is essential that the scanner should be fast and should accurately reflect the temperature.

The present work was undertaken to develop a microprocessor based 7- point temperature scanner which measures the temperature of rotor winding by transmitting the value of temperature with radio link. Since no brushes and sliprings are involved in this scheme, the problem of wear and tear and the infirm contact in the brushes and sliprings is avoided. The developed software demultiplex the channels and gives the value of temperature accurately. The hardware, on the other hand, includes the transmitting circuit and receiving circuit. Since the output of the receiver is TTL compatible, the interfacing with the microprocessor does not require additional hardware.

The microprocessor based temperature scanner for rotating machines has been tested with different values of resistance simulated as temperature.

CHAPTER-1

INTRODUCTION

In modern production and processing plants, trouble-free operation of machinery largely depends on the electric drives. The requirements specified for the individual drives are so exacting today that it is in many cases no longer possible to provide an effective motor thermal protection system with conventional devices monitoring the current.

To maintain highest production rates and most efficent operation, "down time reports" are studied to uncover repetitive problems(1). Periodic review of this nature reveals the specific type of problems as well as their trends. Broadly speaking, equipment malfunctions can be classified as electrical, mechanical,or, as is some times the case, a combination of both. Because the electrical system of machines and equipment is a dual system - that is, it not only operates and sequences the machines, but also functions to protect both the machine and the operating personnel - all down time for maintenance, that is resolved by an electrician is usually reported as an electrical problem. Falling into this category is the protection of motors and the driven equipments.

A study of the motors used by an automotive industry resulted in some interesting conclusions about tripped motor overloads, as follows (1):

1) More than 70 percent of all overload trips were found

CHAPTER-1

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A study of the motors used by an automotive industry resulted in some interesting conclusions about tripped motor overloads, as follows (1):

1) More than 70 percent of all overload trips were found

to be " nuisance " trips, that is, trips not due to overtemperatures, but caused by dull tools, mislocation of parts, material hardness, or other mechanical factors.

2) Other " nuisance" trips experienced were generally caused by the fact that higher ambient temperatures within the control panel had effected the trip level of the motor overload.

3) When motor troubles did occur, a large percentage of these were mechanical, that is, involving bearings, shafts etc. rather than actual winding failure.

4) In those cases in which motor winding failure did occur, further study exposed the fact that most overload heaters were not properly applied.

The problem mentioned in preceeding paragraph and many other related ones, nececiates a reliable system for temperature scanning/monitoring of motor, thereby, giving trouble free operations. The temprature scanning system should invariably have following considerations.

1) It should accurately reflect the temperature of windings.

2) The operator should have preferably visual means to monitor temperature.

3) The monitoring should be continuous so that within minimum time the corrective measures can be taken. Optimum utilisation of machines is only possible when the winding temperature is continuously indicated.

4) It should determine the temperature occuring at relevent points and transmit them to an instrument which can indicate temperatures serially or with some

logic considerations.

1.1 Methods of Measurement

Continuous measurement of the temperature of rotor components can be effected in several ways(2).

a) Measurement of the winding resistance by the current-voltage method. This is particulary suitable for large turbo-type generators with excitation through sliprings.

b) Embedding of thermo couples or resistance thermometeres in the parts of the rotor winding to be monitored, the detecting elements being connected to sliprings.

c) The use of temperature sensors with varying resistance, which are connected to inductive or capacitive transmission devices.

d) Measurement of the temperature dependent change of the capacitance or inductance of components attached to the parts in the rotor, to be monitored. These methods usually work with r.f.bridges or special circuits.

e) Measurement of the temperature with resistance thermometers and conversion of the measured value into pulse train, the frequencey or pulse width of which is a measure of temperature. The pulses have to be picked off from the rotor by means of sliprings or brushless transmission elements, which can be used at the same time for feeding the transducer rotating with rotor.

f) Measurement of the temperature with resistance thermometer and conversion of the measured value into pulse train, the frequency or pulse width of which is the measure of temperature. The pulses can be transmitted by radio communications.

g) The use of the infrared detectors which measure the temperature dependent on radiated power from the surface of the rotor and stator.

An attempt has been made in the work reported in this dissertation to develop a microprocessor based system for scanning of temperature of electrical rotating machines using the principle mentioned in (f) above , that is, by using radiotelemetry.

1.2 Scope of Present Work

In the present work a microprocessor based 7-point temperature scanner using radio link for transmitting the measured value from the rotor has been developed. The work is devided into two parts, the hardware part prior to digital signal processing and the digital signal processing part. The sensor used for scanning is bead type thermistor. The scope of first part includes the transmitter and receiver circuits to transmit and receive the signals from the rotor. This signal is measure of temperature to be scanned. The second part consists of hardware and software developed for microprocessor which demultiplex , measure the pulses which are indicative of temperature and finally obtained the corresponding value of temperature from the lookup table thereby eliminating the non-linearity of thermistor sensor.

1.3 Organisation of Dissertation

All the methods mentioned in para 1.1 will be described in details in succeeding chapters 2,3,4,5 and 6 .

In chapter-7 hardware portion of the proposed screen before digital signal processing has been described. The digital signal processing is being described in chapter-8. The results / observations have been summed up in chapter-9.

CHAPTER-2

MOTOR THERMAL PROTECTION BY CONTINUOUS MONITORING OF WINDING RESISTANCE

This scheme is for detecting AC motor temperature by measuring the change in winding resistance with temperature (3). The scheme described in the literature is for protecting the stator winding, however, this principle can also be applied for measuring rotor temperature wherein it is difficult to incorporate the sensing device. This technique achieves the desired monitoring without additional motor wiring and responds rapidly to the average temperature of the winding.

The concept uses the fact that the resistance of Copper increases with the temperature and by measuring resistance, the temperature can be determined(4,5). Resistance is measured by means of a small direct current which is caused to flow through the a.c. motor winding. The method described here is practical, with relatively low cost, uses a non-linear resistor in series with motor winding, so that alternate half cycles of current are different. Thus a small direct current is developed in the windings.

To successfully use the concept, it is necessary to accurately measure the low value of d.c. signal present alongwith high amplitude a.c. signals, for example, 0.5.A. d.c. with 45 A a.c. and 0.4V d.c. with 220 V a.c. Simple circuits have been described here which can do this with sufficient accuracy and stability.

2.1 Principle of operation

The principle of operation is to cause a small d.c. current, typically 3 percent of rated a.c. , to flow through the motor winding by means of a series of asymetric resistance in one line. Measurement of the corresponding direct current and voltage enables the measurement of winding resistance and hence of temperature to be evaluated. The signal thus developed can then be used in motor overload and thermal protection circuits.

A practical form of the asymmetric resistance consists of antiparallel diodes (as shown in figure 2.1) Using available diodes, the equivalent of a mean d c voltage of about 0.4 V is injected in series with the a.c. supply. This is analogous to having a battery of 0.4 V in series with one line. It is to be noted that suitable single chip structures could be developed to replace the two diodes.

Refering to the figure 2.1 , it is evident that if the resistance of the 3-phase source is negligible as compared to the motor winding resistance, then voltage Vdc, which has a large ripple content, is approximately equal to Vdca, which has much reduced ripple content and hence is easier to measure. However, to develop a scheme for universal application, Vdc can be measured.

$$Vdc = Idc\ (rw + rw/2)$$

from which $rw = 2\ Vdc/\ 3\ Idc$

Therefore, winding resistance and hence temperature can be determined by measuring Vdc & Idc.

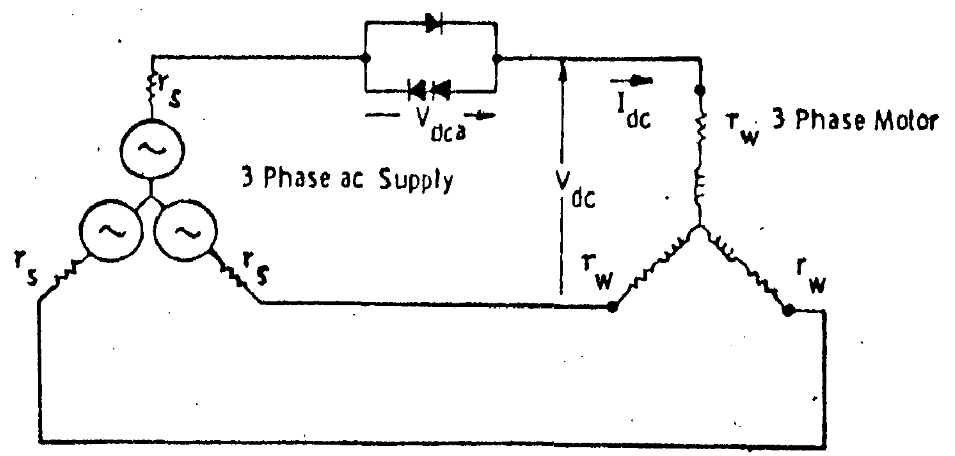


FIG.NO.2.1.METHOD OF D.C. CURRENT INJECTION IN TO MOTOR

2.2 Measurement Technique

In the proposed technique for measuring resistance and thus temperature of an a.c. load, only a small d.c. is caused to flow through it . To successfully implement the technique, it requires the ability to measure, for example 0.5 A d.c in a 45 A a.c signal and 0.4 V d.c. in a 220 V a.c. signal. The measurement must be accurate and should have long term stability. For example, to measure temperature within ± 5 Dg.C requires that resistance be measured with ± 2 percent accuracy.

The techniques that are used for doing this are illustrated in figures 2.2 . The principle of operation is quite simple, for example, a 1:1 current transformer CT is connected to subtract a.c. component of current such that the current flowing through Rc (which is the sensing element, eg, a magnetic amplifier winding) is almost ripple free, likewise a 1:1 voltage transformer VT is connected to subtract the a.c. voltage such that the voltage across Rcv, is substantially ripple free. The exact accuracy is dependent upon the transformer characteristics.

A practical tested circuit block diagram for 7.5 h.p., 220 V motor is illustrated in figure 2.3. An asymmetry is obtained by antiparallel diodes (type IN 11984) and the d.c current component produced is about 0.65 A. The d.c. current component is measured by a magnetic amplifier such that an isolated low drift output of about 8 V dc is obtained. The signal is compared with a dc signal produced by an operational amplifier from the voltage accross the

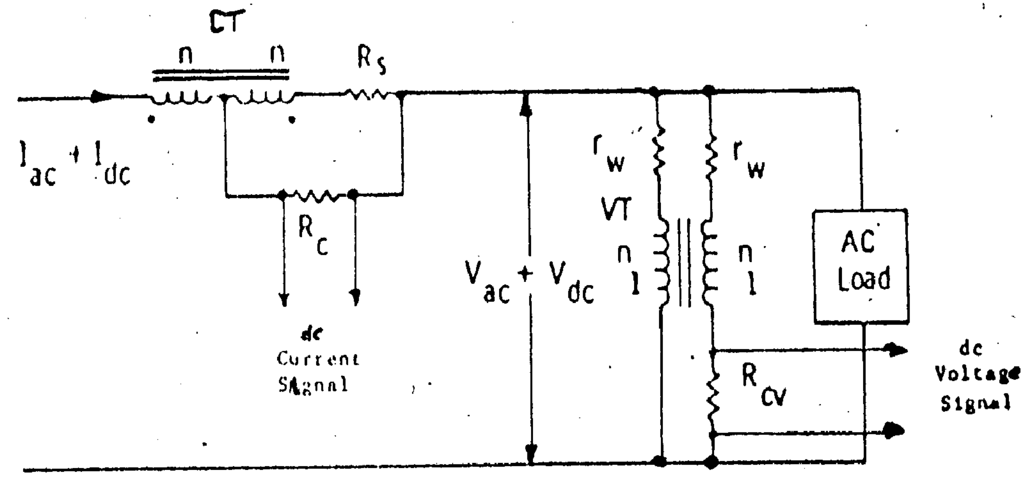


FIG. NO. 2.2 ARRANGEMENT FOR MEASURING D.C. VOLTAGE AND CURRENT WITH LARGE SUPER-IMPOSED A.C. SINAL

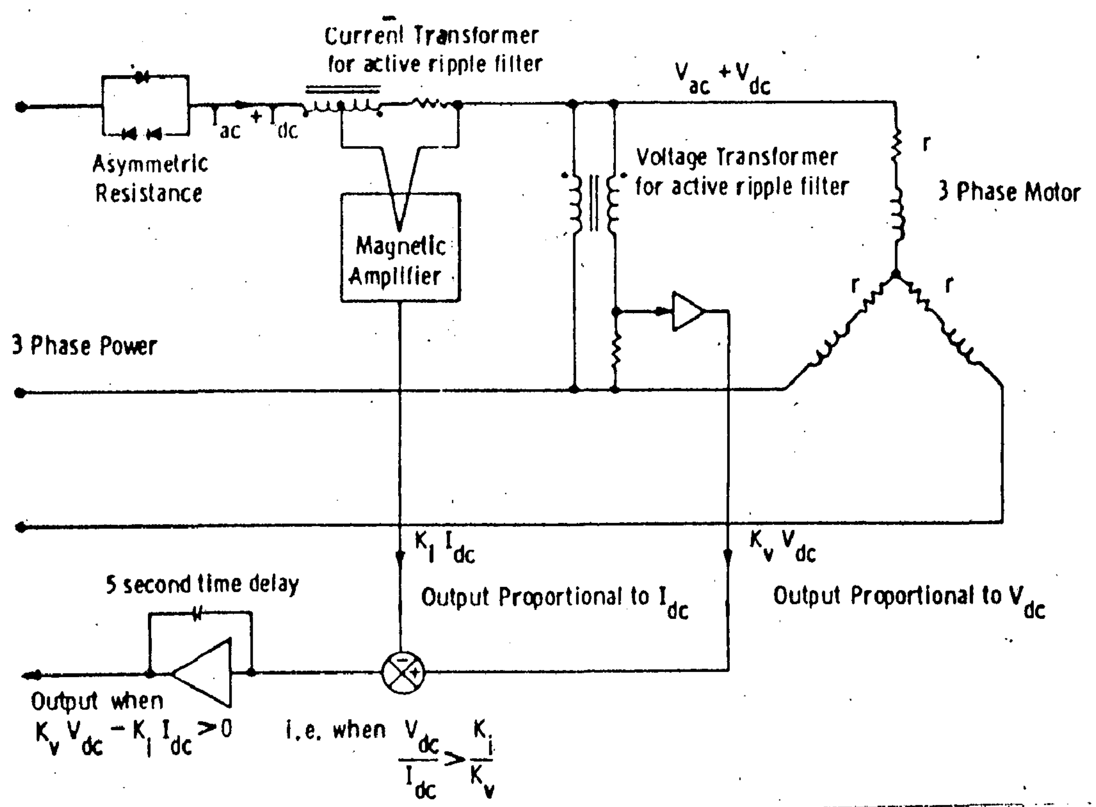


FIG.NO.2.3 MOTOR THERMEL PROTECTION BY WINDING RESISTANCE MONITOR

voltage transformer and active filter. The current and voltage signals developed are KiIc and Kvdc, (as shown in the figure) respectively. The two signals are added algebrically and applied to a high gain operacional amplifier such that an output trip signal is obtained when Kv Vdc − Ki Idc > 0, that is, when Vdc / Iac > Ki/Kv. Since Vdc/Idc is dependent upon the resistance of the motor windings it is possible to set a value of resistance of the motor at which a trip signal is obtained, by simple adjustment of the amplifier gain constant ki and kv. The resistance of the winding, will in turn, give the limit of the maximum temperature.

The advantage of this technique is that it is more accurate than the measurement by thermocouples because of the measuring lags associated with the thermocouples. In contrast, the resistance monitoring scheme instantaneously measure the average temperature of the winding.

Secondly , this resistance measuring circuit will, under same conditions, detect other failures, for example, an open circuited supply line.

CHPATER-3

TEMPERATURE MEASUREMENT USING THERMOCOUPLES OR RESISTANCE THERMOMETER

The temperature of different parts of the rotor are generally measured by using thermocouples and resistance thermometers , These sensors give the output in the form of resistance change which is proportional to the change in temperature . The output of these sensors can either be taken from the sliprings or some coupling like inductive or capacitive can be used. These methods will be discussed in detail in succeeding paragraphs.

3.1 Delecting element connected to slipring

The temperature of different parts of motor can be measured by embedding the thermocouples or resistance thermometer in the winding and measuring the resistance change by r.f bridge or any other circuit. The resistance change can be calibrated for temperature of the winding. This method is being successfully used for measuring the stator temperatures but it has got inherent disadvantages in the case of rotor temperature measurement because of rotor being in motion and problems associated with the sliprings / brushes.

3.2Rotor temperature monitoring using inductive coupling (6)

The cage winding of an induction or a synchronous motor can be protected against excessive heating when the temperature of the cage is made available in motor control room. Numerous schemes, employing brushes and collector rings to get the information out from rotor have some inherent disadvantages because of undesirable brushes and collector rings. This method of direct sensing of rotor termperature can be efficiently utilized to protect rotor from over temperature. This system is capable of determining the temperature of cage bars, cage end rings, rotor field windings, or rotor armature winding, and can, therefore, be used on induction, synchronous wound rotor, and dc motors.

3.2.1 Protection Methods

Rotor protection on a normal motor application has always relied on some manifestation of stator temperature or stator current to initiate action and this frequently has meant a double role for the stator protection system. Many indirect schemes have been or are generally used can be described as ;

a) Induced field current relaying :

The frequency of the induced voltage and current in the field winding of a synchronous motor during acceleration decreases from a value equal to line frequency at standstill to zero at synchronous speed. By using a saturating transformer in the field circuit to feed a thermal type relay, a rotor temperature responsive system during accelaration can be achieved for a brush type synchronous motor. The thermal characteristics of the relay, however, can not closely correlate with the heating and cooling of the rotor or its ambient conditions so the method is not foolproof.

b) Induction type relay :

It is apparent that neither brushless type synchronous motor nor induction motor can utilise method described in a), and hence a more indirect scheme has been used based on the fact that while the stator inrush current of an induction or a synchronous motor during start remains fairly constant throughout accelaration untill about 80-90% speed is achieved , it does drop off markedly at higher speeds. By selecting an induction type overcurrent relay with inverse characteristics and by selection of relay tap, current transfer ratio, it is often, possible to obtain a system that will trip if the motor stalls and yet permit the normal start. Such a system again has no means of taking into account stored heat in the rotor from previous starts.

3.2.2 Direct sensing method

Aforementioned shortcomings can be overcome by the method described below for measuring rotor bar temperatures.

Thermo couple sensor

Accuracy of measuring actual cage bar temperature is largely dependent on the transducer used and the method of securing it to the cage. The transducer must have following characteristics: ruggedness, ability to mount on either a flat or a roundbar and a high dynamic response to reduce temperature readout error. The sensor used, therefore, is thermo couple junction.

To keep the time delay of the thermocouple low, it must be in the intimate contact with the bar. To best meet the condition of intimate contact, the thermocouple junction can be mounted in a small plug of copper which can then be screwed into the bar or, if tapered properly, can be pressed into a mating tapered hole in the bar. The plug thus becomes a part of the cagebar, keeping temperature gradients to a minimum.

3.2.3 Monitoring system

The block diagram of the temperature monitoring system is given in Figure 3.1. The rotating transmitter has a variable output frequency which is proporational to the temperature measured by the thermocouple. The measured information is passed to the stationary receiver through a set of windings on a rotary transformer. The receiver converts the variable frequency back to a variable voltage which is fed to a readout temperature indication. The readout meter has adjustable high and low set points which can activate the alarm when limits are exceeded.

To power the transmitter a stationary power oscillator, operating at a higher frequecy relative to temperature information, excites a second set of winding on the rotary transformer and the rotor power is then converted to dc for the transmitter.

In order to maintain a standard size rotary transformer, the rotating winding and the transmitter are moulded into one piece for mounting on the end of the motor shaft opposite the drive end. The nonrotating windings are supported from the end bracket of the motor. Where the transformer must be mounted on the shaft inside the

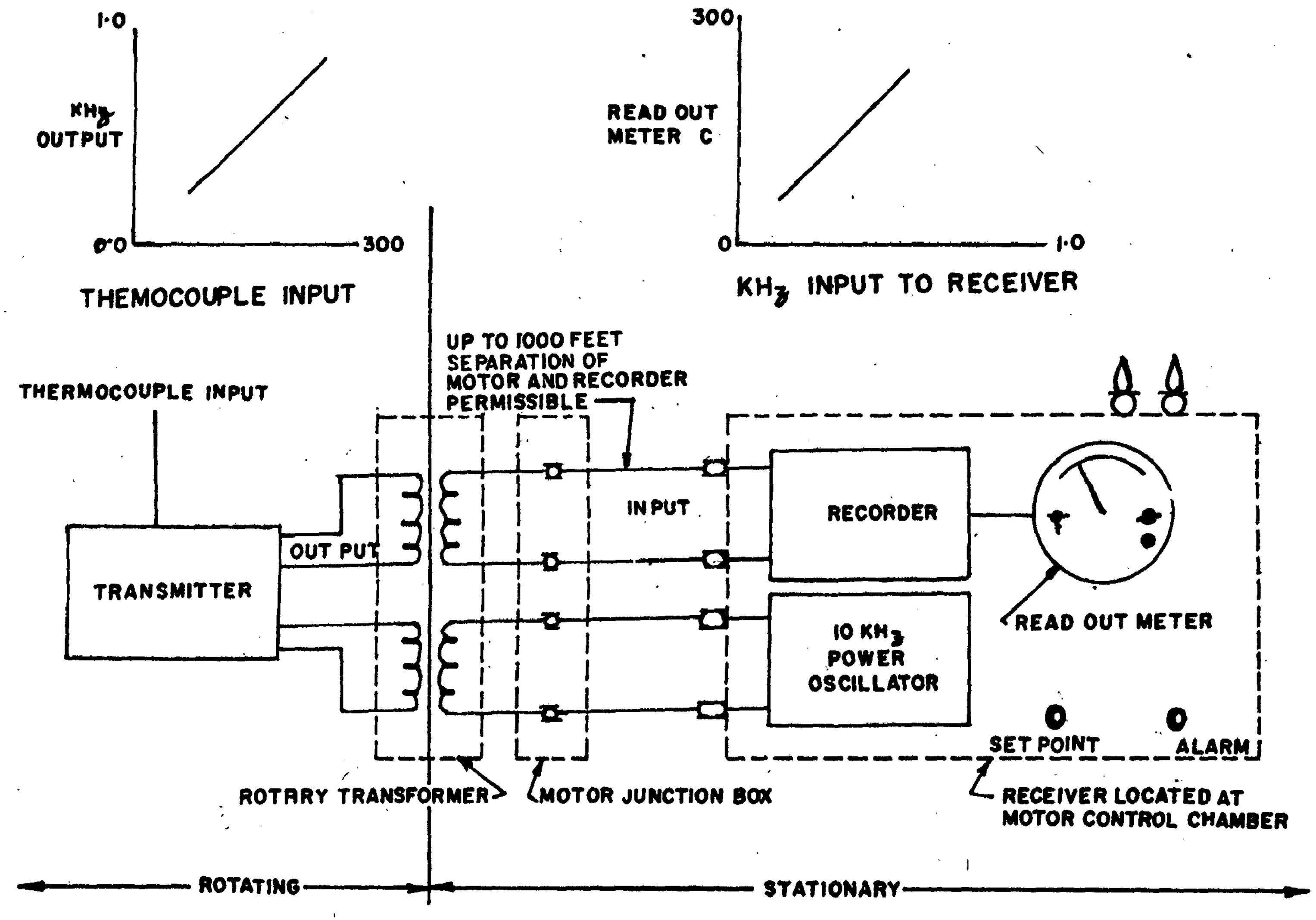


FIG. 3.1 SYSTEM BLOCK DIAGRAM

bearings. Calibration can readily be done in the field with a simple milivolt d.c supply used to simulate the maximum temperature change as sensed by the thermocouple.

3.2.4 Advantages

The rotary transformer has a number of non critical design characteristics. The signals are independent of shaft speed, shaft position end play, and concentricity of the airgap between rotating and non rotating windings. No iron core centre is required, but it will function normally with an iron centre. Also, no shielding is required between windings.

3.2.5 Disadvantages

In the applications, where it is desirable to monitor several temperature points with a multiplex transmitter, such a system has special problems, because a simple multiplex system requires a common thermocouples connection. Connecting thermocouples in common, with no isolation, to the cage introduces rotor cage bar voltages into thermocouple circuits. For this reason the system described relies on one thermocouple in the circuit although it may be any one of several available in different spots around the rotor.

CHAPTER-4

MEASUREMENT OF TEMPERATURE USING TEMPERATURE SENSITIVE CAPACITOR

The temperature can be measured by measuring the temperature dependent change of the capacitance or inductance of components attached to the parts in rotor. The resonant frequency of an LC circuit is determined by its inductance and capacitance(7). Therefore, if a temperature sensitive capacitor is used as a component of the resonant circuit, one can utilize this circuit as a temperature sensing circuit, or a primary transducer of a thermometer by measuring its resonant frequecny . This thermometer is especially convenient for high speed rotors because measurement of the resonant frequecny can be made without any direct connection to the sensing circuits. This thermometer employs a temperature sensing capacitor as an element of the resonant circuit. Simultaneous multipoint thermometering for the measurement of temperature distribution of the rotor can easily be made without any channel selector by arranging the sensing circuit in desired position.

4.1 Operating Principle

Curie -Weiss law in the para electric region gives the temperature dependence of the dielectric constant of a ferro electric material above the Currie point Tc. Therefore, capacitance C may be expressed by

$$C = Kc/\ (T-Tc) \qquad ....(i)$$

Where Kc is a constant and T the temperature. When this capacitor is combined with a temperature insensitive inductor to form a resonant circuit, its resonant frequency fo is given by

$$fo = Kr\ (T-Tc)^{1/2} \qquad ....(ii)$$

Hence, the temperature of the capacitor may be determined from resonant frequecncy. The measurement of resonant frequency without any direct contact may easily be made by observing the reaction of the resonant circuit, the method is that of the griddip meter. The measurement ciruit is shown in fig 4.1 . The output power of a variable frequency oscillator is fed to the bridge type measuring circuit and a part of the power flows into the resonant circuit through inductive coupling. In this case, the amplilude of the rf current Io, as shown in figure 4.1 can be obtained by simple analysis.

$$Io = \frac{Qk^2 E}{\left\{1 + Q^2\,[(1-k^2)\,(\frac{f}{fo}) - (\frac{fo}{f})]^2\right\}^{1/2}\ 2\pi foIp} \qquad ...(iii)$$

Where Q is effective quality factor of the resonant circuit k the coupling coefficient between exciting coil Lp and resonant coil Ls, f the oscillator frequecny, and E- the source voltage of a constant voltage supply. From Eq(iii) the maximum value of Io is obtained under the following condition.

$$fm = fo(1-k^2)^{-1/2} \qquad ...(iv)$$

When k satisfies the condition of k < < 1, fm is closely equal to fo. In this case , the resonant frequency can be determined with sufficient accuracy by observing Io a

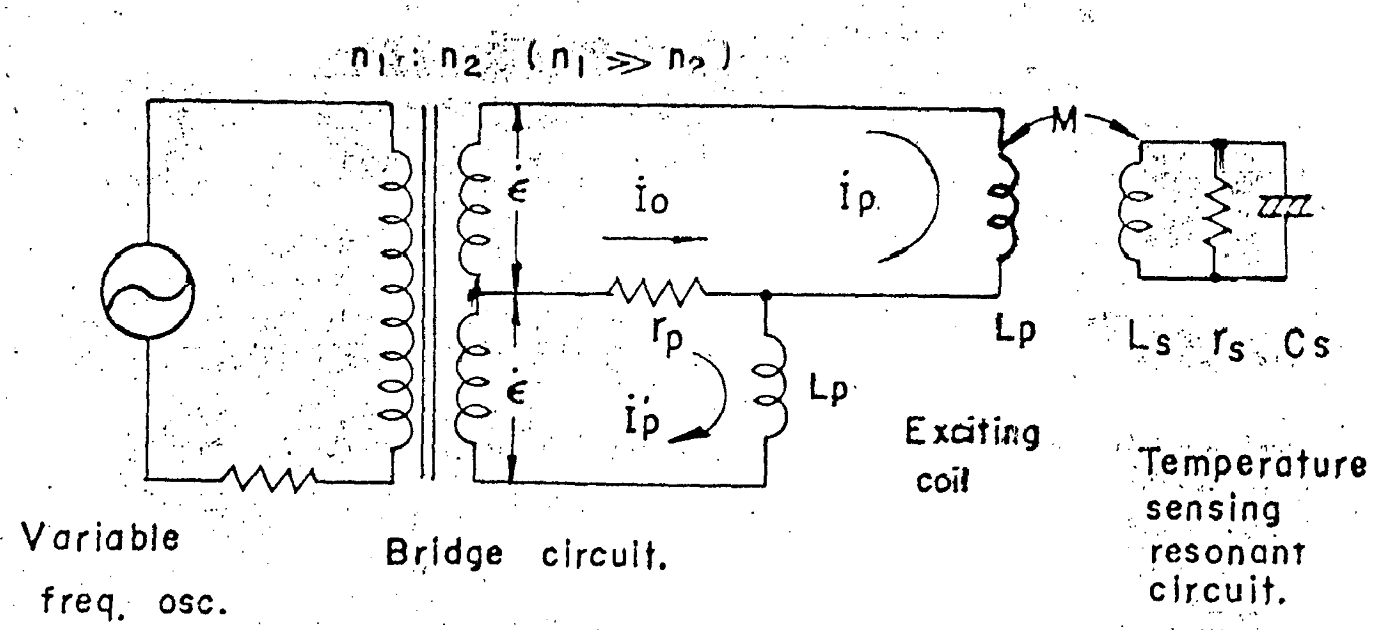


FIG. 4.1 Schematic of resonant point measuring circuit. $L_p = L_p'$, $\dot{I}_o = \dot{I}_p - \dot{I}_p'$, $\dot{I}_p = \dot{I}_p'$ at $M = 0$.

function of source frequecny. Since the value of k is less than 0.1 , this measurement is practically insensitive to spacing of coils, although the amplifier of resonant signal is quite sensitive.

4.2 Functional Describtion

A block diagram of the electronic circuit is given in figure 4.2, A number of capacitor Cs1, Cs2, ---- Csn are attached on or embedded in rotor, the corresponding coils Ls1, Ls2, ---- Lsn, are attached on the surface of the rotor at regular intervals so that all coils can couple to an exciting coil Lp during rotation when the sweep frequency of the oscilloscope is adjusted so as to synchronize with the revolution of the rotor, a number of resonant signals of the sensing circuits appear with regular spacing on the oscilloscope and resonant frequecny can be progressively observed by adjusting the source frequency without any channel selector. When many sensing circuits are employed, however, it is necessary to make use of some kind of marker to avoid confusing the sensing circuits. A position marker may be another resonant circuit composed of Lst and Cst whose resonant frequency is insensitive to temperature, and far below that of the sensitive ciruits with own power source. This position signal may be used as an external trigger signal to the oscilloscope. In addition, a time delay circuit and an intensity modulation of the oscilloscope may be utilised so as to selectively brighten each of the signal in turn.

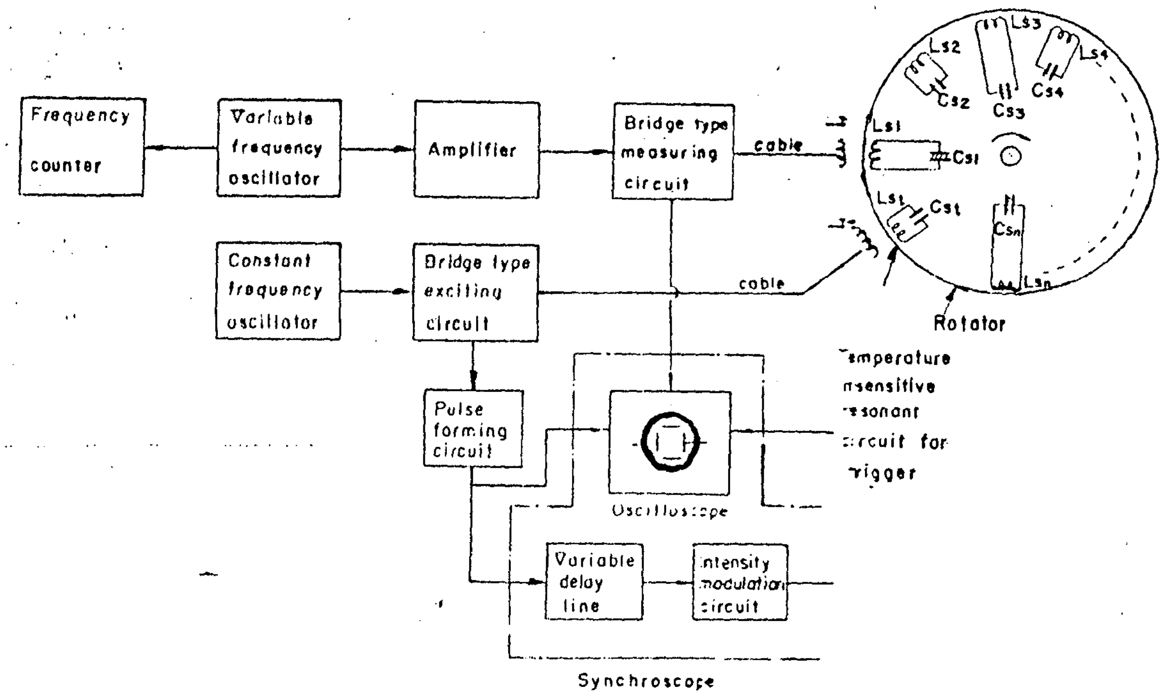


FIG.NO.4.2 BLOCK DIAGRAM OF CAPCITANCE THERMOMETER FOR ROTOR

4.3 Sensing Capacitance

In general, the dilectric constant of ferroelectric material shows remarkable temperature hysteresis characters below its Curie point.However, this hysteresis is reduced to an extremely small amount in the para- electric region above the Curie point, especially for the single crystal of the second order phase transition. Thus utilisation of a ferroelectric single crystal of the second order may be preferable to the usual temperature sensitive dielectric material, such as high polymer because of stable, high temperature sensitive and hysteresis free characteristics.

Ferromagnatic materials are also temperature sensitive but for the temperature measurement of an electric machine, the utilisation of ferroelectric material is more desirable, since the dielectric constant of ferroelectrics is not affected by the magnetic field of a machine.

Experiments show that error accompanied with temperature hysteresis of ceramic capacitors of Barium, Strontium , Titnate goes up to about $5^{\circ}C$ at $3^{\circ}C$ above the Curie point although the error should be reduced to about $0.5^{\circ}C$ by heat treatment at about $100^{\circ}C$ above the Curie point for 1 minute. Thus it advisable to choose a material whose curie point is about $50^{\circ}C$ lower than the lower limit of the operating range so as to give precise temperature measurement.

4.4 Coil

The resonant circuit coil should be light enough to endure to high centrifugal force. To eliminate the influence of magnetic field, an air core coil is desirable. The inductance of the coil should be determined considering the operating frequecny.

4.5 Frequecny

The operating frequecny should be chosen in such a way, so as to satisfy the following requirements:

a) The frequency should be chosen high enough so that one can use a small capacitor and coil as a sensing circuit.

b) The frequency should also take into account the stray capacitance or stray inductance of the lead wire between the capacitor and inductor and should keep these minimum. This requires the following relation :

$$L << c/f$$

Where L is the length of the leao wire and c the speed of light. If L is of the order of 1m, the upper limit of frequency may be about 10 MHz.

c) The frequency should be high enough so that the response time of the resonant circuit is shorter than the transit time d) High frequency will also be advisable because when there is strong environmental noise such as that produced by spark discharges in the commutator of an electric machine, the frequency should be chosen so as to minimise this effect, avoiding intense noise frequency bands.

Thus typical range would be 300 to 500 KHz. For accurate measurements, it is necessary to caliberate the capacitance - frequency characteristics at room temperature, using a precise variable air condenser as a stimulator for the sensing capacitor, with the coil and wires in position. Correction of the temperature dependence of the resonant frequecny can easily be carried out without increasing the temperature of the rotor.

CHAPTER-5

MEASUREMENT OF TEMPERATURE BY CONVERTING MEASURED VALUE IN TO A PULSE TRAINS

The temperature measured by thermocouples can be transmitted to the indicator by converting it to pulse trains by suitable circuits . These pulses can be transmitted from the rotor by using sliprings or brushless as transmission element or by using radio link. In the first case there are inherent disadvantages of wear and tear and infirm contacts due to sliprins and brushes . The second method, however , is free from these disadvantages . These methods are discussed in detail as follow :

5.1 By using sliprings or brushless transmission element (12)

For optimum utilisation of electrical rotating machines it is generally necessary to measure temperature continously and load adjusted accordingly. There is, therefore a need for the continuous measurement of the temperature of rotor windings. It should determine the temperature builtup at relevent points and transmit them to a recorder or indicating instrument. The coupling of the measuring system to the indicators or recorders and process computers requires great reliability and overall error of indication should not exceed $\pm$ 3% of the scale end value. Also the rotating components should be capable of withstanding the mechanical and climatic stresses occuring in service and of operating satisfactorily at all speeds.

Especially important is that indication should be maintained even at standstill so that the cooling down may be observed.

5.1.1 Principle

The principle of this type of monitoring system is the measurement of the temperature with the resistance thermometers and conversion of the measured value into a pulse train, the frequency or pulse width of which is a measure of the temperature. The pulse will be picked off from the rotor by means of sliprings which can be used at the same time for feeding the transducer rotating with the rotor.

5.1.2 Details of temperature measuring system

Platinum system resistance thermometers with 100 cold resistance at 0^{O} C are embedded in the slots. They can be placed in the insulating separator between outer and inner bars of the multi layer-windings. In the single layer windings they can be mounted under the slot wedge and with pole windings in the pole body insulation. The linear characteristic of these sensors is advantageous for temperature measuring system, as individual caliberation of the scale of the indicating instrument is unnecessary. If the semiconductor temperatures are, however, used it would be necessary to recaliberate the scale.

The system block diagram is depicted in figure 5.1 . The connections from the slot thermometers are taken to a terminal box on the rotor, which also accomodates the terminals for the slipring connecting leads and some power supply components.

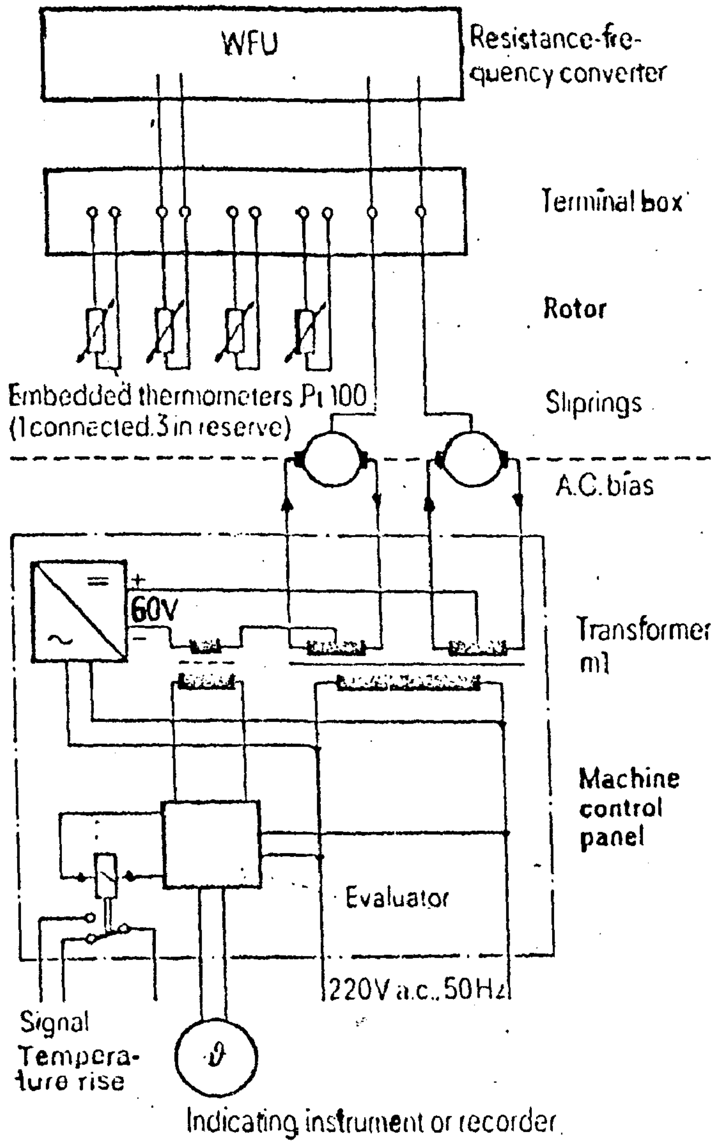


FIG. NO. 5.1 BLOCK DIAGRAM FOR ROTOR TEMPERATURE MEASURING SYSTEM

The resistance to frequency convertor, which is accommodated in a case of the same size, is also connected to the terminal box. These two boxes are of about the same weight and can be arranged symmeterically on the rotor to achieve balance.

The converter transforms the resistance of the embedded thermometer into a voltage proportional to temperature, which, inturn, controls the voltage to frequency converter. The two elements are so adjusted that the change in resistance from 100 Ω at 0^{O} C to 168.48 Ω at 180^{O} C corresponds to a frequecny change from 0 to about 1440 Hz. Thus the converter delivers an output frequency which is proportional to eight times the temperature and can therefore easily be indicated digitally.

The voltage to frequency converter controls a switching amplifier which superimposes current pulses of about 200μs duration and about 80m A (peak) at the output frequency on the supply current of the convertor. These pulses can be picked off by means of a pulse transformer connected in the negative lead and fed to the evaluating circuit. The evaluator operates digitally and indicates the temperature numerically after the frequency has been divided by 8. Alternatively, second possibility for evaluation is to use conversion of the pulse frequency into an analogue output signal and its subsequent transmission to a pointer instrument or a recorder (As shown in figure). In both the cases, the evaluator also includes one or two Schmitt triggers for signalling a temperature above the prescribed limit or for shutting down the machine. The evaluator can be accomodated together with the power supply components, for example, in a machine control panel.

5.1.3 Details of measured value transmission

Sliprings are used as transmission elements, as these are readily adaptable to the shaft dimensions and mounting conditions. Inductive (brushless) transmission devices are also used, but are only economical when the number of variants can be reduced.

At least two normal graphite brushes run on each brushes. They are biased by transformer m1 with an alternating current, so that the current density at the brush contact face is about 6 A/cm2.Conditions are therefore favourable for the formation of a good oxide skin on the sliprings so that constant low contact and small brush wear is assured. The supply current of the converter fed in symmetrically through the brush gear would not by itself be able to produce a good skin and thus constant transfer conditions on the sliprings. This form of slipring transmission described has been in satisfactory service for years under widely differing operating conditions. Most of the machines so equipped have sliprings peripheral speeds between 10 & 20 m/s.

5.2 By using Radio Telemetry (8)

The temperature of a rotor in running condition can also measured efficiently by telemetering the value of the temperature. Miniature telemetering circuits mounted in or on the rotor near the axis of rotation have been used to telemeter the temperature measured by a small thermistor which may be mounted anywhere on the rotor. In the rotor, in addition to meeting the small space requirement, the circuit must not be critically affected by centrifugal fields and must be as accurate and reliable as possible.

5.2.1 Description

The circuit diagram for the measurement of temperature of rotor is shown in figure 5.2(8).This circuit has been found not to be effected by rotor speed at least to 300 rps(10), which is generally the maximum speed required with standard size rotors. The unit has three subsystems consisting of a temperature sensor , a switch and a carrier frequency generator. The temperature sensing and encoding is performed by a blocking oscillator, whose pulse repetition rate is determined essentially by C4 and the combination of 20 K ohms thermistor and R4. In order to eliminate errors resulting from power supply variations or from change in component values because of age, magnetic fields, etc., two repetition rates are measured. The first, No, is determined by C4 and R4 alone and the second,N, by C4 and the parallel combination of R4 and thermistor Th. Ideally , the ratio of these two repetition rates is a function solely of the resistance of the thermistor, and thus of the temperature. Switching between these modes is accomplished by means of a transistor switch V6, which is actuated through an invertor V4 by a collector- coupled transister multivibrator circuit containing V5 and V6. The resistance of the transistor switch is sufficently large in the "off" state to eleminate any effect of the thermistor on the reference repetition

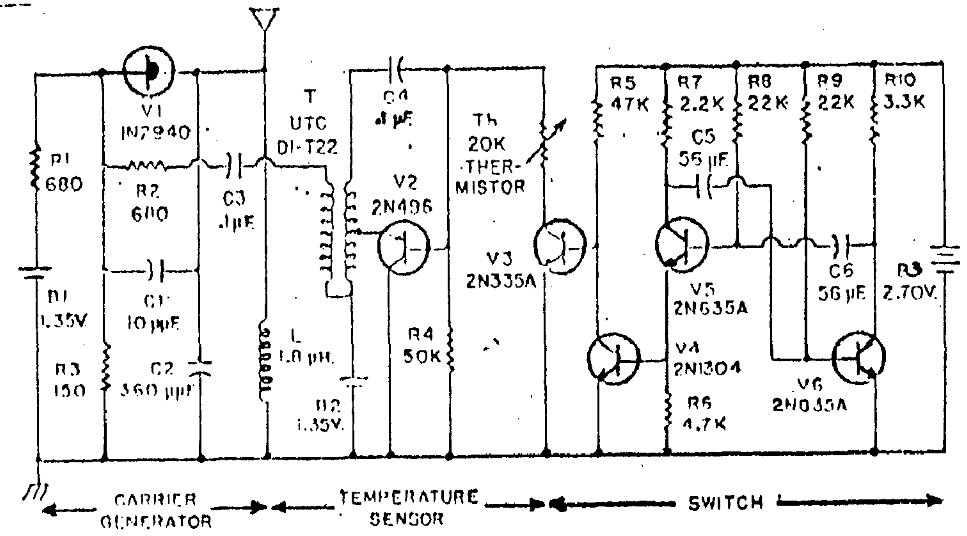


FIG NO 5.2 CIRCUIT DIAGRAM FOR CONVERTING TEMPERATURE IN TO PULSETRAIN TRANSMITTING IT BY RADIO COMMUNICATION

rate No. In the "On" state the switching transister contributes a small resistance in series with the thermistor. This resistance may be a slowly varying function of the temperature. Consequently, it is advisable to calibrate by measuring the ratio N/No with the unit held at various constant known temperatures. The carrier signal (5.5 MHz) is generated by a tunnel diode oscillator whose power output is approximately 0.04 mW. The transmitter is coupled to the oscillator by R2 and C3, which permits the pulses produced by the blocking oscillator to increase the bias of tunnel diode V1 sufficiently to drive it out of its negative resistance region and shut off the carrier frequency for the duration of each pulse. The transmitting antenna is wrapped around the base of the rotor while the receiving antenna is formed of several turns mounted concentric with the base of the rotor. Power is supplied by four mercury cells, which operate the unit continuously for more than 200 hrs.The total power consumption is roughly 6 mW / unit of time.

With the exception of the batteries, which are removable, the entire circuit is mounted in epoxy resin and supported by the rotor. THe batteries are insulated electrically from the rotor by using plastic. In its present form the circuit occupies the volume of slightly less than 2 in 3 and is mounted on the axis near the base of rotor.

5.2.2 Experimental Results

The transmitter used gave at room temperature No = 175 and N =540 also a change of 1 Dg C produces a change in N of over 10 Cps. This makes it possible to determine the temperature of the rotor to less than 0.01 Dg. C. It was also noted that circuit is not adversely affected by a 500 - G magnetic field and that it is shielded by the rotor.

Because of well known commutation difficulties with high speed rotors, radio telemetering should become useful for shaft mounted rotors as well as those which are magnetically suspended. In many applications, especially with very high speed rotors, the active transmitter circuit described above is too large and consumes too much power. In such cases, passive transmitters should be used. These transmitters carry no power source but only a resonant circuit whose frequency is sensed from out side. This characteristic frequency is altered by some circuit element which change in response to changes in the temperature. These passive circuits are to be preferred in the high centrifugal fields, and where the observations are to be carried out on small rotors over extended periods of time.

CHAPTER-6

TEMPERATURE SCANNING OF MACHINE SURFACE BY MONITORING INFRARED RADIATIONS

The surface of the rotor being metallic , emits the infrared radiations on heating . These radiations can be used to scan the surface temperatures. The radiations can be taken out from the rotor with the help of optical fibres. Pyrometer can also be used to measure the infrared radiations. These methods will be discussed in detail in this chapter.

6.1 By the use of optical fibres

For the purpose of systematic maintenance or to devise, improvements in existing designs, temperature distribution in the stator-bore surface and / or rotor surface of large machines is required. Monitoring of temperature distribution should preferably be carried out when machine is in operation, although it makes the measurement all the more difficult because of (i) the smallness of the gap between stator and rotor, (ii) the machine being in operation (iii) vast machine area to be scanned and (iv) the requirement of high accuracy and resolution of the measurement. Use of sliprings and brushes to collect signal from a transducer mounted on the rotor have disadvantages because of the wear and tear and infirm contact with the sliprings. The method described below overcomes these limiations by detection of the infrared radiation from the machine surfaces to be scanned for temperature.

6.1.1 Principle used

The temperatures of the surfaces to be scanned generally lie in the range of 0 to 200 ^{o}C (11) and hence the radiation would be in the intermediate infrared region and have the peaks in the wave length range of 6 to 11 micrometer. The infrared radiation from the stator-bore and rotor surfaces is directed to a detector through the seperate sets of optical fibres. (The speed with which the temperature is to be scanned is also quite high) . The infrared detector that can meet both the requirement of 6 to 11 μm and high speed are Zinc-dopped Germanium Silicon alloy cooled to 48 ^{o}K. and pyroelectric elements working at room temperature(12). The former is cheaper and has higher detectivity wheras the later has the advantages of faster response and requires no cooling. Thermal detectors though can work in this wave length, are not suitable because of much slower response and poor detectivity.

6.1.2 System Details

i) Optical Fibres

As mentioned earlier the radiation from the stator-bore and rotor surfaces are guided to the detector through two separate sets of optical fibres respectively. For the stator-bore surface temperature, a number of optical fibres are mounted on the rotor with their ends facing the stator, and the other ends coming out of the machine and facing the detector. Similarly for the rotor surface temperature, the fibres are mounted on stator with one end facing rotor and other end reaching the detector, which is placed at the stator end. In closed type machines, the detector should be accomodated inside the end cover and only two leads taken out from it. The detector collects the radiations from the fibres one by one through a mechanical scanning arrangement. The outer ends of the rotor and stator fibres are arranged in two seperate circles concentric with machine bore as shown in figure 6.1.

ii) <u>Scanning Arrangement</u>

When scanning the rotor fibres (which are mounted on stator), the detector stays opposite each fibre for the duration of one revolution of the rotor. The rotor area thus scanned is a circumferential ring opposite the inner end of the fibre in question. The width of the ring depends on the diameter of the fibre and its distance from the rotor surface. Larger the diameter or larger the distance, wider would be the ring. After scanning all the rotor fibres the detector is moved to the stator fibres mounted on the rotor. The detector is held in one position untill all the stator fibres have moved passed the detector, and then the detector takes the next position. In each position of the detector, the stator area scanned is an axial strip along the detector position. The width of the strip is again decided by the diameter of the fibres and their distance from stator surface. After completing the ring of the stator fibres, the detector moves back to the ring of rotor fibres. The scanning cycle thus repeats.

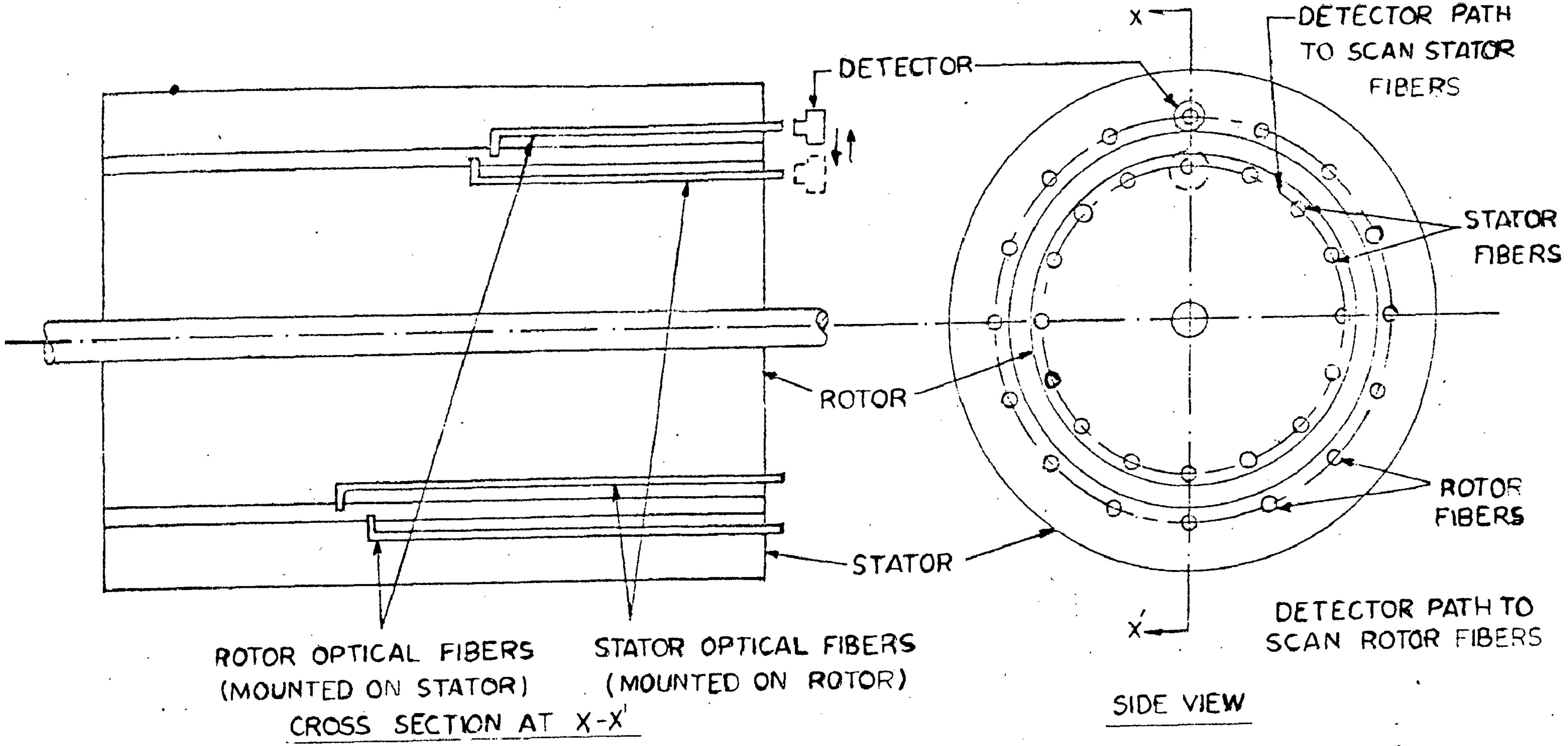


FIG.NO 61. MECHANICAL DETAILS: FIBER PLACEMENT AND SANNING ARRANGEMENT

iii) Focusing

To concentrate the radiations from the fibre openings on to the detector, a Germanium lens is interposed between the two. The lens is rigidly fixed to the detector at the appropriate distance from the latter. The spacing between the fibre openings and lens is also maintained constant when detector is moved for scanning the fibre.

iv) Synchronising

The movement of the detector is synchronised with the machine motion with the help of concentrated infrared radiations arranged to fall on the detector from suitably placed sources. These radiations are allowed : a) at the end of each rotor revolution, b) at the completion of the rotor fibre ring by the detector, and c) at the completion of stator fibre ring by the detector.

v) Electrical Signal Processing

The electrical output signal from the detector is amplified and demodulated to obtain d.c. voltage analogus to the temperature monitored. This voltage is fed to a suitable recorder. Block schematic diagram of the complete system is given in figure 6.2.

In case the temperature scanning is carried out for the maintenance purpose, it is considered very desirable to give an indication/alarm or relaying signal to open the machine breaker when the machine temperature exceeds a predetermined level. For this purpose a level detector finds out when the temperature anywhere on the rotor or stator bore surface exceeds the preset level.

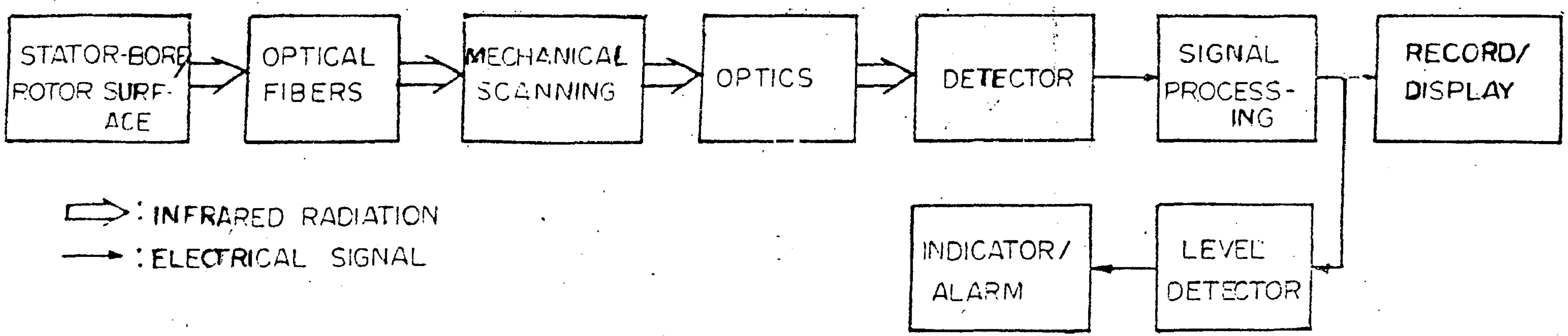


FIG. NO. 62. BLOCK SCHEMATIC

vi) Recorder

A high speed recorder such as storage CRO, magnetic tape, or photographic recorder shall be required for the present system. Operation of this recorder would be synchronised with the motion of the machine by the same concentrated radiations as used for synchronising the movement of the detector. These synchronisation signals would mark the end of : (a) the circumferential ring of the rotor surface or the axial strip element of the stator surface, as the case may be, (b) rotor surface scanning, and (c) stator bore surface scanning.

vii) Calibration

The instrument can be conveniently and accurately calibrated using an Eisenman calorimeter which is a fast responding miniature calorimeter built in the form of a conical cavity with an absorption coefficient approaching unity (typically 0.995)(13). Infrared radiation from an object under controlled heating is monitored on the proposed instrument and is also absorbed in the said calorimeter. The temperature in the cavity of the calorimeter is measured with a platinum wire thermometer that has an acuracy and resolution of the order of 0.001 $^{\circ}$C. The instrument is then calibrated by comparing its response with the thermometer reading.

Since the detector used in the proposed instrument is of quantum type, its response depends only on the radiated wave-length and hence on the temperature of the object, and is independent of the intensity of radiation. As such, the calibration once carried with the above arrangement would hold good when the instrument is put to use for temperature scanning of machine surfaces.

6.1.3 Advantages

a. The disadvantages of contact measurement (where measuring device is in physical contanct with the object under measurement) are no longer here because it enables measurement without disturbing thermal conditions of the object. Whereas in the contact method a thermal drain is caused on the object thereby affecting its temperature, specially at contact point.

b. In the contact methods, it is necessary to mount or embed detectors such as thermocouples or thermistors in large numbers thereby making measurement difficult and expensive.

c. A much finer temperature scanning of the machine surface is obtained.

d. Since only one detector is used, the calibrator is much simpler and accurate and can be checked up frequently.

e. No electrical signal is required to be brought out from the rotor and hence no sliprings, inductive coupling or radio links are necessary **(14)**.

f. Contrary to monitoring only a few selected points with the help of embedded temperature detectors, the entire surface is scanned here in much smaller area elements.

g. The motion of the machines is used to have advantage in the mechanical scanning of the fibres.

h. The response time of the quantum detectors proposed here would be less than 1us as against a few seconds for the thermistor and thermo couples.

6.2 Use of pyrometer for monitoring of roto. temperatures of large squirrel - cage motors.(15)

In the case of large three phase motors, monitoring of the stator temperature alone is not always sufficient to ensure the degree of protection for all operating conditions . The stator temperature can be measured normally by three or six resistance thermometers embedded between the top and the bottom layers of the two layer windings. A thermal overload of the stator winding during steady state operation will be detected quickly and safely enough by this method. This method can , however, pose problems for scanning of rotor temperatures.

Large squirrel cage motors are almost exclusively rotor-critical . Therefore, thermal monitoring of the stator alone is not sufficient.

The principle of infrared radiation measurement is employed ,that is, detecting the radiant energy, which is closely related to the surface temperature. For mesuring the rotor temperature of motor a pyrometer must have various special characteristics, which are following :

The device must be :

a) Small and easy to fit to in the motor.

b) Insensitive to magnetic field strength at the point of installation.

c) Resistant of high housing temperatures.

d) Insensitive to vibrations.

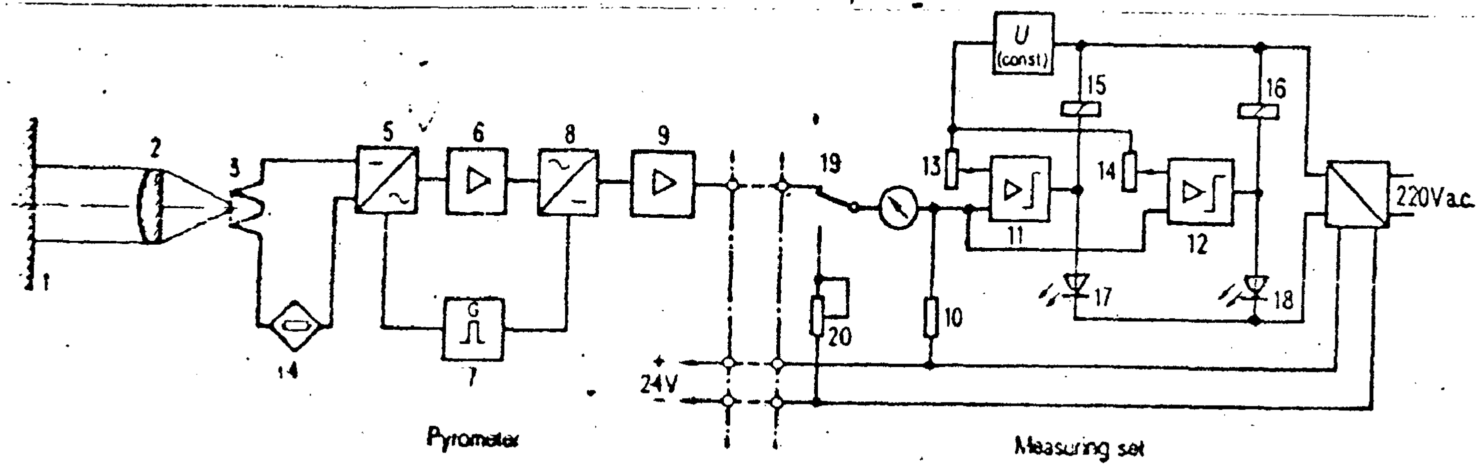
e) Designed for long-term stability.

6.2.1 System Details

The mode of operation of the pyrometer and measuring set is shown in the figure 6.3. The image of' the object being measured is formed on the thermo-couple radiation receiver by a CaF2 lens system . The receiver converts the radiation density through the lens into an EMF propotional to the incoming radiant frequecny. The radiation receiver is connected in series with resistance bridge in order to compensate for the temperature of the pyrometer housing. The following amplifier modules include a chopper which converts small d.c. voltage from the receiver into a.c. voltage . The a.c. voltage amplifier stage, increases the measuring signal from approximately 0.2 mv to 0.2 V. The voltage is passed through demodulator and is converted into a load-independent output current of 0 to 20 mA in the output amplifier. The chopper and demodulator are controlled by square wave generator.

The pyrometer is connected to the measuring set by means of a three-core cable. In the measuring set the output current from the pyrometer produces a voltage at the input resistor which is compared with the adjustable voltage of the potentiometer by bistable amplifier .

Depending on the voltage accross the resistor or the potentiometers, the bistable amplifier trigger and the contacts of the relay switch over. At the same time, the



1 Object to be measured
2 Lens system
3 Radiation receiver
4 Ni resistance bridge
5 FET chopper
6 A.C. amplifier
7 Square-wave generator
8 Demodulator
9 Output amplifier
10 Input resistor
11, 12 Bistable amplifiers
13, 14 Potentiometers
15, 16 Relays
17, 18 Light-emitting diodes
19 Changeover switch
20 Potentiometer

FIG. NO. 6.3 PRINCIPLE OF MEASURING DEVICE FOR PYROMETER THERMOMETER light-emitting diodes lightup red. In order to set the desired response temperatures, the input of the bistable amplifiers is switched from the pyrometer to potentiometer by means of a changeover switch.

6.2.2 Scanning Arrangement

Pyrometer is fitted into motor parallel to its axis preferable into the end-shield (fig.6.3) and aligned with the rotor-cage end ring. The ring must be painted dull black on the side facing pyrometer in order to increase the radiation capacity.

6.2.3 Advantages

Since the temperature is equalised very quickly because of the high thermal conductivity of the conductor material and the internal brazed connections between the bars and rings, with the result that the bar temperature can be determined with sufficient accuracy and relatively quickly.

CHAPTER-7

PROPOSED TEMPERATURE SCANNING SCHEME BASED ON RADIO LINK

The scanning of temperature of the rotor winding while machine is in operation is quite a difficult task due to smallness of the gap between the rotor and stator, the machine being in operation, accuracy and resolution of measurement is required to be high. The problem of wear and tear in the use of the sliprings and brushes to collect signal from a transducer moving in conventional methods , necessitates an instrumentation system which can overcome these problems. The proposed system on the other hand helps in reducing errors / problems associated with wear and tear and infirm contact with the slipring beacuse the signal is transmitted with radio link.

A scheme for measuring the temperature of rotor using radio telemetery has been developed by the author and is being reported in this chapter.

7.1 Principle

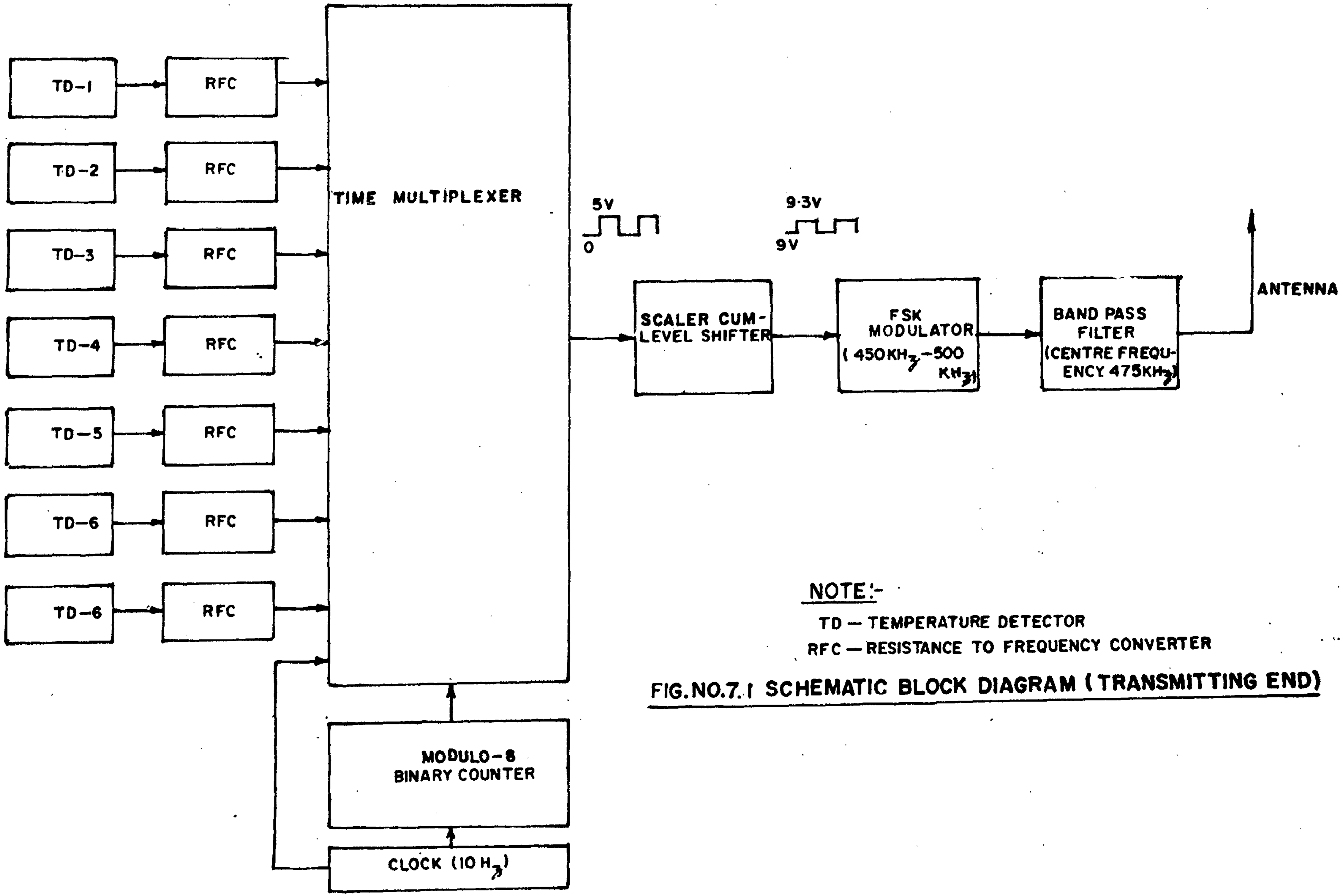
A seven- point temperature scanner has been developed here. The temperature scanning in the proposed instrumentation scheme is based on radio transmitting the value of temperature from the rotor . The temperatures of different points measured with the help of thermistor sensors are converted into pulses, the frequency of which is proportional to the temperature to be monitored. The pulses after being time divisionally multiplexed are transmitted by radio communication link using frequency shift keying (FSK) modulation. The thermistors used in the proposed scheme are negative temperature co-efficient (NTC) type, that is, the resistance decreases with the increase of temperature. These sensors are smaller in size, cheaper and have higher sensitivity than resistance temperature detectors. The major drawback of non-linearity has been overcome by using Microprocessor.

At the receiving end the pulses transmitted by FSK are demodulated and then fed to a microprocessor which counts the time period of the transmitted pulses and gives the temperature by using a lookup table. The microprocessor also serves as a demultiplexer for the seven channels.

7.2 System Details

7.2.1 Block schematic

The various stages of 7-point temperature scanner are shown in the block schematics in figures 7.1 & 7.2 . This scanner scans the temperature at different points with help of thermistor embedded in the rotor winding the resistance of which changes with the change in temperature . The resistance outputs of all the seven channels is converted into pulse trains by using an astable multivibrator circuits. The frequencies of these pulses are the measure of temperature scanned by the thermistors. These pulse trains are time division multiplexed before being transmitted by frequency shift keying (FSK) modulation. FSK modulation is performed using a voltage controlled oscillator (VCO) circuit which gives traingular



NOTE:-
TD — TEMPERATURE DETECTOR
RFC — RESISTANCE TO FREQUENCY CONVERTER

FIG.NO.7.1 SCHEMATIC BLOCK DIAGRAM (TRANSMITTING END)

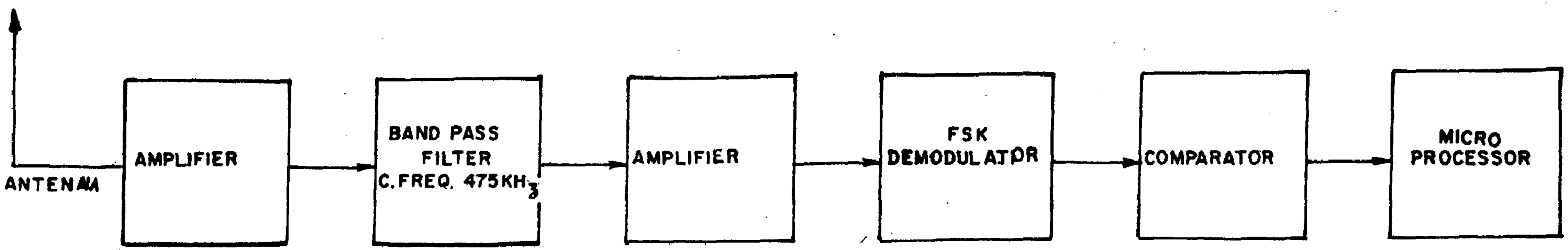


FIG.NO.7.2 SCHEMATIC BLOCK DIAGRAM (RECEIVING END) wave trains of two different frequencies (in Kilo Hz frequency) for two different voltage levels of the square wave pulse. The triangular wave trains are then passed through a band pass filter which filters out all harmonic frequencies and amplifies the two fundamental frequencies which are finally transmitted in the air using an antenna. Filter also converts triangular waves to sinusoidal ones.

At the receiving end, the signal received from the motor rotor is first amplified and then filtered before being demodulated using a phase locked loop (PLL) circuit. The demultiplexing, measurement of the time period of pulses and finally conversion into the temperatures is performed by the microprocessor , which not only measures the time period accurately , but also takes care of the nonlinearity of the sensor. The pulses from the demodulator are shaped using a comparatar so that the input pulses to the microprocessor are TTL- compatible.

Different blocks of the transmitting end and receiving end before the digital signal processing scheme will be discussed in detail in this chapter and digital signal processing carried out in the microprocessor will be discussed in the next chapter.

7.3 Transmitting end details

7.3.1 Detector

The scanning system depends, in large measure, on the size and type of thermal sensors used in the applications(16). Over the past several years, a number of thermal sensors have been developed for a wide range of applications. Not all are suitable for motor temperature scanning/monitoring due to their large size, resistance characteristics and dielectric properties.

Resistance temperature detector and thermistor are perhaps the most familiar and have been associated with the temperature detection and control for many years. For proper sensing the sensing element should be closely coupled to the actual source of heat, that is, with the motor winding. In this way, the sensing element is responsive to the conditions of motor over-temperature accurately. Thermistors can easily be placed close to the heat source because of the small size and appropriate shape and have an important advantage of higher sensitivity over resistance temperature detectors.

a) Thermistor Construction & Types(17)

Thermistors are thermally sensitive resistors that exhibit a resistance change with the change in temperature.(say 4% per ^{o}C). These thermistors have a stable ceramic like structure consisting mostly of metallic oxides. They have high temperature coefficient -10 times that of typical metals. The temperature coefficient of a thermistor can be either negative, that is, resistance decreases with the increase of temperature or vice versa. In first case they are termed as NTC and in second case, PTC.

In many respects a thermistor resembles a conventional resistor. It is usually a two terminal device, having resistance as its fundamental property , it often looks like a resistor and is generally installed and operated in the manner of an ordinary resistor. But its distinguishing difference is the material from which it is made. Whereas conventional resistors are made of special wire, an evaporated film, Carbon or some composition containing Carbon, thermistors are made of special mixtures or compound, usually semiconductrs. Some substances used are selected oxides of Cobalt, Magnesium, Manganese, Nickel, or Uranium. Thermistors are supplied in various types of packages depending upon make and model, electrical ratings and end applications. Common configurations in use are rod, disc, washer and bead. Size, response time, maximum rated temperature and precision of manufacturing are some of the factors involved in selecting the proper type. Bead type is smaller in size & response is fastest. Also in terms of temperature accuracy, discs , rods and washer type are usually furnished with given resistance within about , $2^{o}C$ of specified temperature whereas bead type is specified within $0.05^{o}C$. The maximum rated temperature depends on whether a unit is glass coated or it has attached leads. The glass coated leads can withstand temperature upto $300^{o}C$.

b) <u>Basic Thermistor Characteristics</u>

The thermistor has several characteristics that are of interest. These include cold resistance, hot resistance and resistance Vs temperature, voltage Vs current and current Vs time characteristics.

The term cold resistance denotes the resistanc measured at room temperature (25 ^{O}C) by some method whic does not cause appreciable heat producing current to pas through the thermistor. The accepted technical designatioi of cold resistance is zero power resistance.

The opposite of cold resistance, on the other hand, is resistance of the heated thermistor. In a directly heated thermistor, the heat results from the temperature of the air (or other medium) surrounding the thermistor and / or from current through the thermistor. In a negative - temperature coefficient (NTC) thermistor hot resistance is lower than cold resistance and PTC vice versa holds.

The E-I (Voltage Vs Current) conduction curve of a thermistor is shown in figure 7.3 (16). The voltage drop across the thermistor increase to as relatively high level E2 (depending upon type and size) as the current through thermistor is increased from zero to a certain level I1.Then as the current is increased further, the voltage drop decreases for each new current increment, until it falls to level E1 at which the current has reached its maximum permissible value. This decrease in voltage drop, in response to an increase in current, indicates a negative resistance between points I1, E2 and I2, E1.

Thermal lag appears in some thermistor action. In particular, the maximum steady state value of current corresponding to a given voltage is not reached

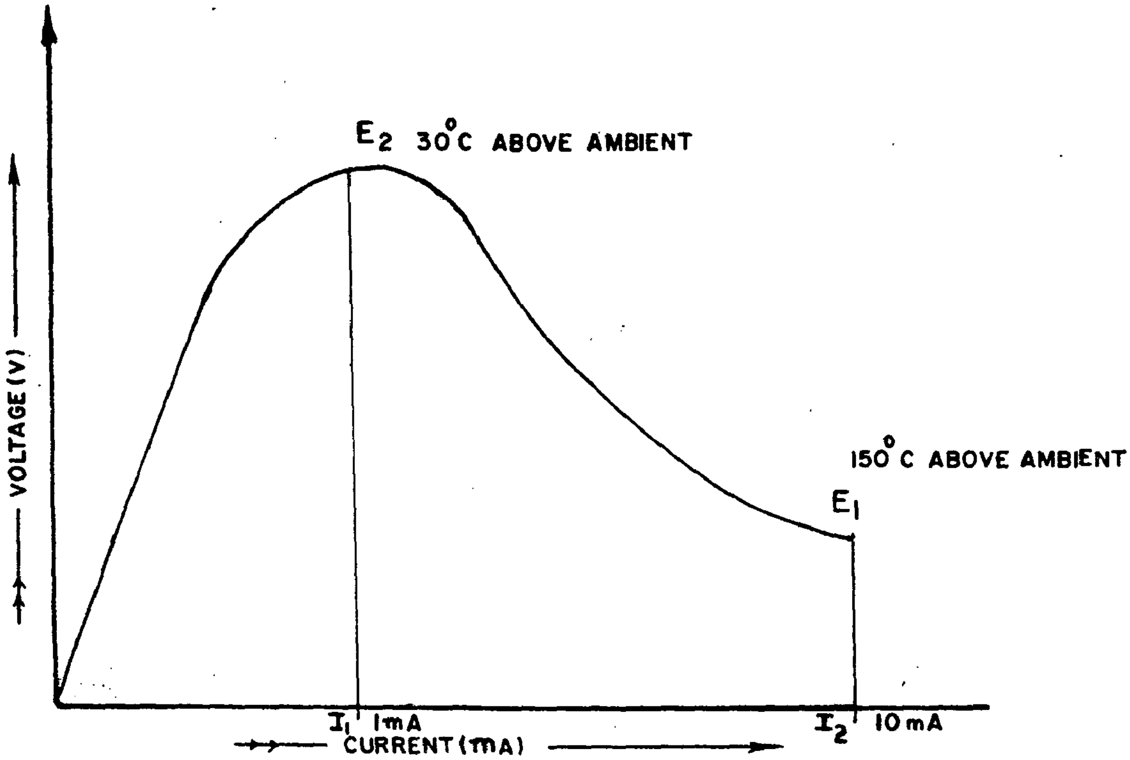


FIG.NO.7.3 VOLTAGE V/S CURRENT CHARACTERSTIC

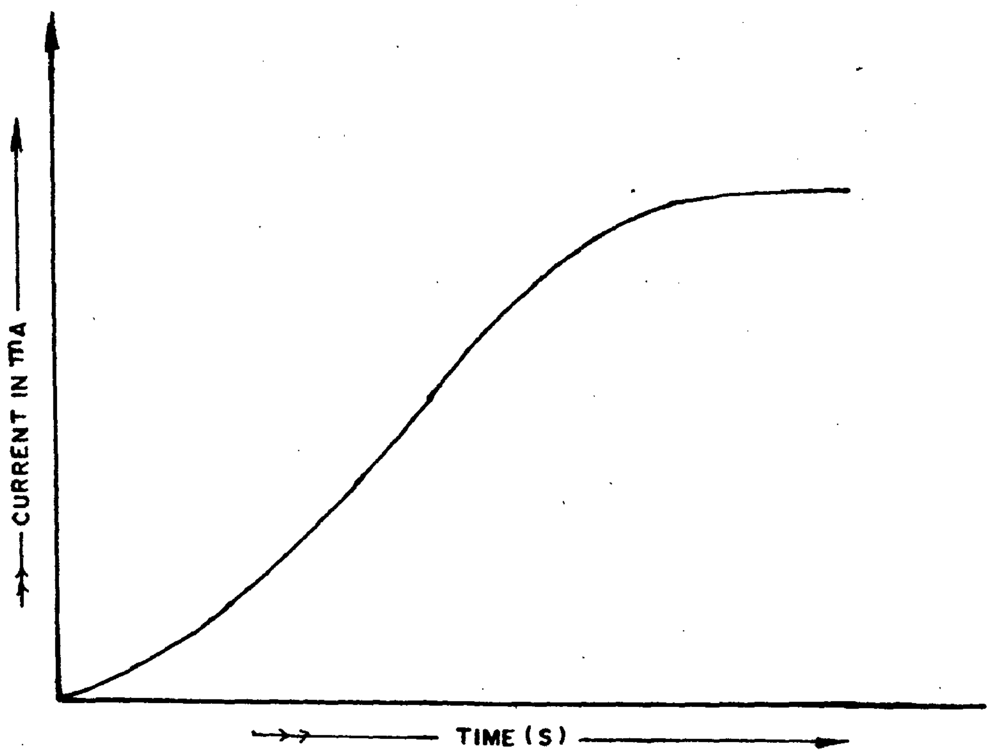


FIG.NO.7.4 CURRENT V/S TIME CHARACTERSTICS

instantaneously when that voltage is applied to thermistor, but only a short time later figure 7.4(16). This action is due to a cummulative effect. When the voltage is first applied to an NTC thermistor, the added resistance limits the current to a relatively low value. But this current causes internal heating which, after an interval, lowers the thermistor resistance, and this lower resistance allows more current to pass. This increased current, in turn, lowers the resistance further causing still more current and so on until further the maximum current is attained.

c) Resistance Vs Temperature Characteristics of the thermistor used .

Two different bead type thermistor have been used to draw the resistance Vs temperature characteristics. The value ratings of the two thermistor were 4.7 KΩ and 10 KΩ at room temperature . The 4.7 KΩ thermistor is an ordinary bead type while the 10 KΩ thermistor is glass coated one. The thermistor were heated in the water bath and resistance measured with each degree rise in the temperature as in Appendix. The graphs of two thermistor are show in figure 7.5 and 7.6. The non-linearity of these characteristics does not pose any problem because of the scheme being microprocessor based.

7.3.2 Temperature to Frequency Conversion

The temperature measured by each thermistor is converted into the square wave pulse train by using an astable multivibrator circuit. The astable converts resistance into pulse frequency. The temperature to

FIG NO.7.5 47 KΩ THERMISTOR CHARACTERSTICS

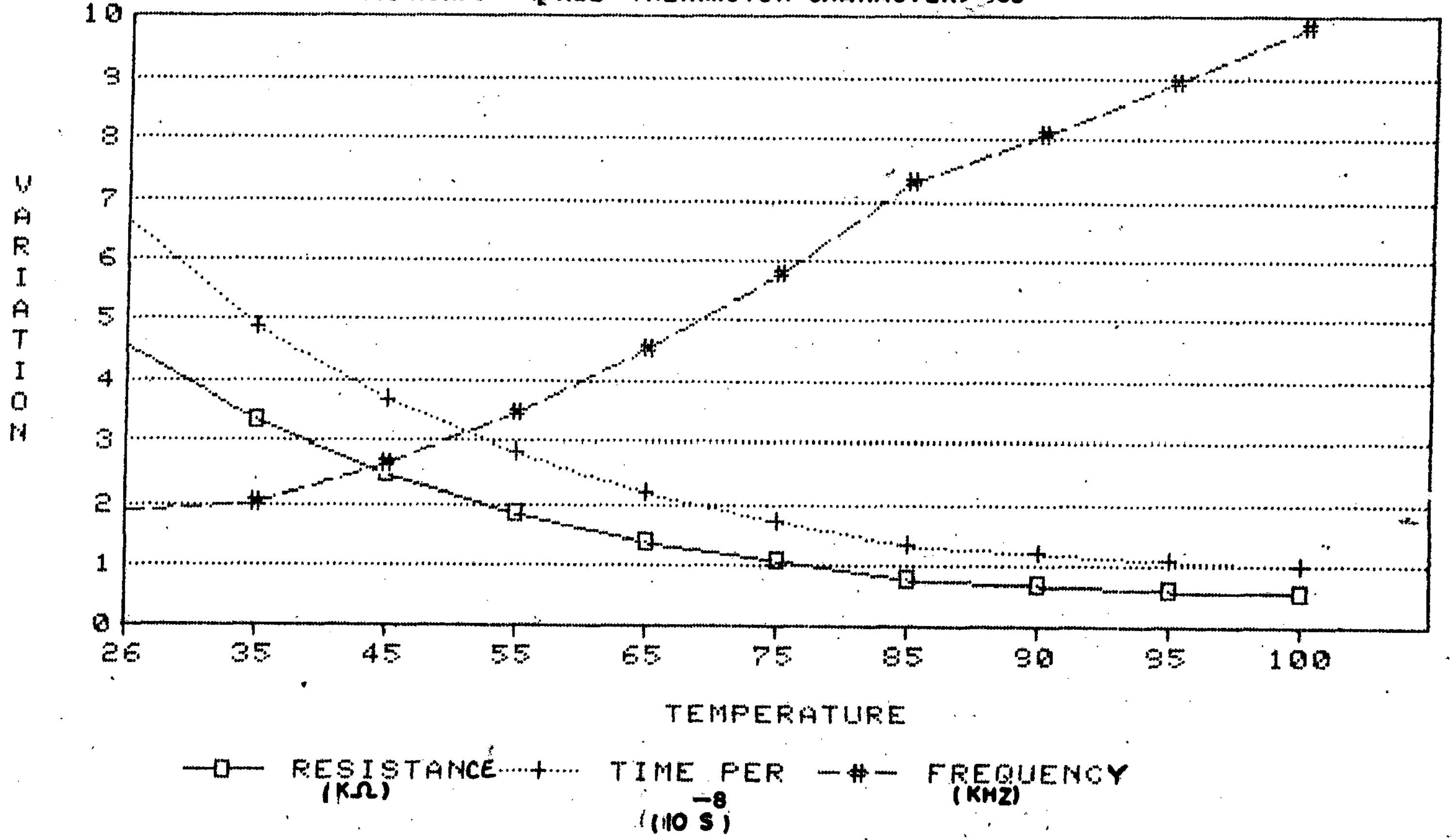
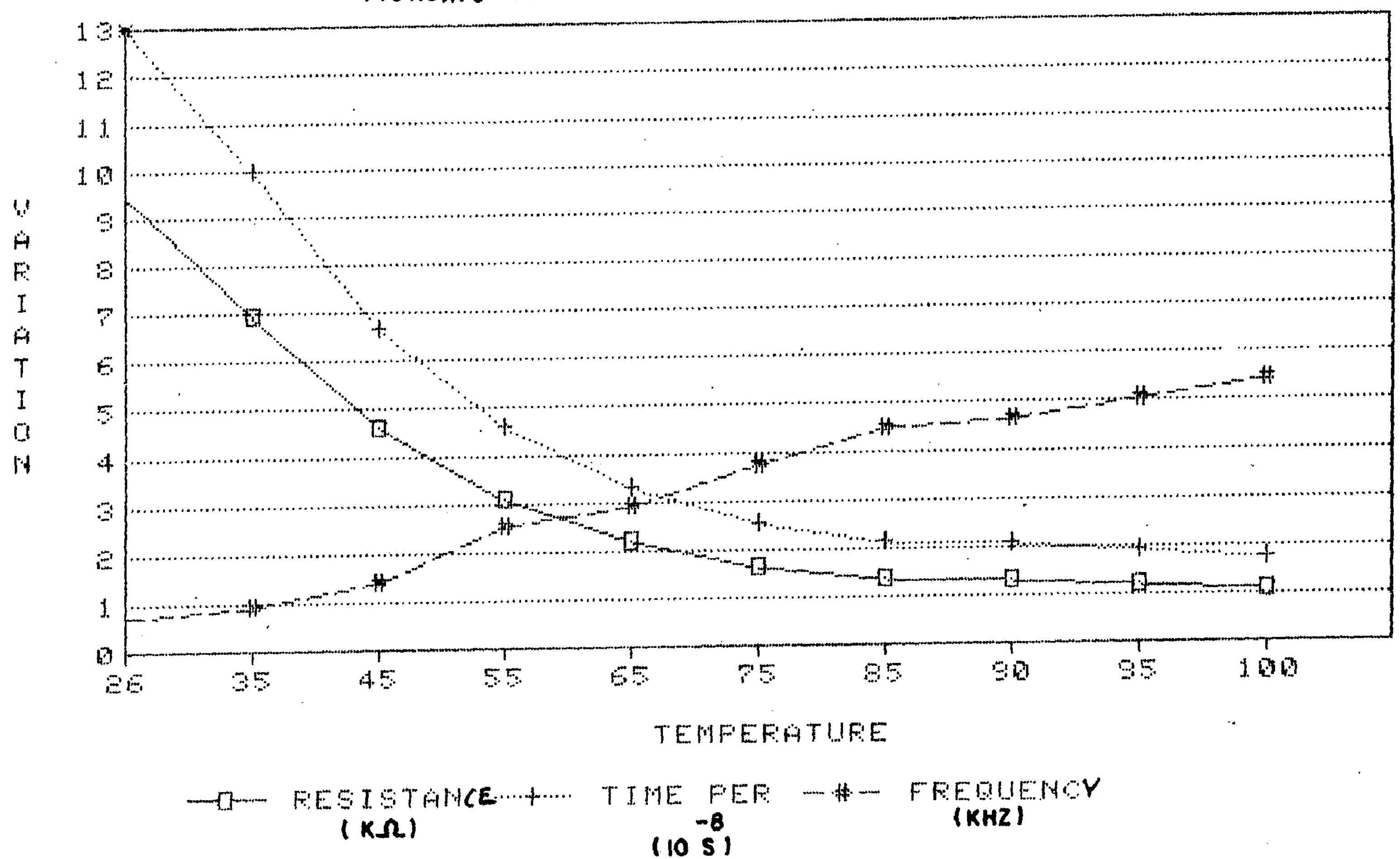


FIG NO.7.6 10-KΩ THERMISTOR CHARACTERSTICS



frequency conversion in the proposed scheme is done by using IC 555 timer.

The frequency of oscillation of astable multivibrator circuit built around 555 timer and shown in figure 7.7 is given by (18).

$$f = 1/T = 1.44/ (RA+2RB)C \text{ ------------(1)}$$

The external capacitor charges through RA and RB and discharges through RB only. RB is the temperature-dependent resistance of the thermistor.

The thermistor used is 4.7 K bead type. Its resistance varies between 4.595 KΩ and 0.560 KΩ for temperature varying from 26 °C to 100 °C (Appendix). Selecting RA = 220Ω, C = 0.1 μF and RB1 = 4.595 KΩ and RB2 = 560Ω

f1 = 1.53 KHZ

f2 = 10.75 KHZ

Thus pulse frequency will vary from 1.53 KHz to 10.75 KHz for temperature varying from 26 °C to 100 °C.

7.3.3 Multiplexing

The proposed scheme is able to measure temperature of seven different points and will have 8 signal channels. That is, the temperature from 7 thermistors fitted in the rotor winding will be transmited in 7 different signal channel and the eighth channels will be used for the sync pulse. The seven signals from the thermistors after being converted into the pulses are time division multiplexed. The circuit used for digital multiplexing is shown in figure 7.8. This circuit has been designed to

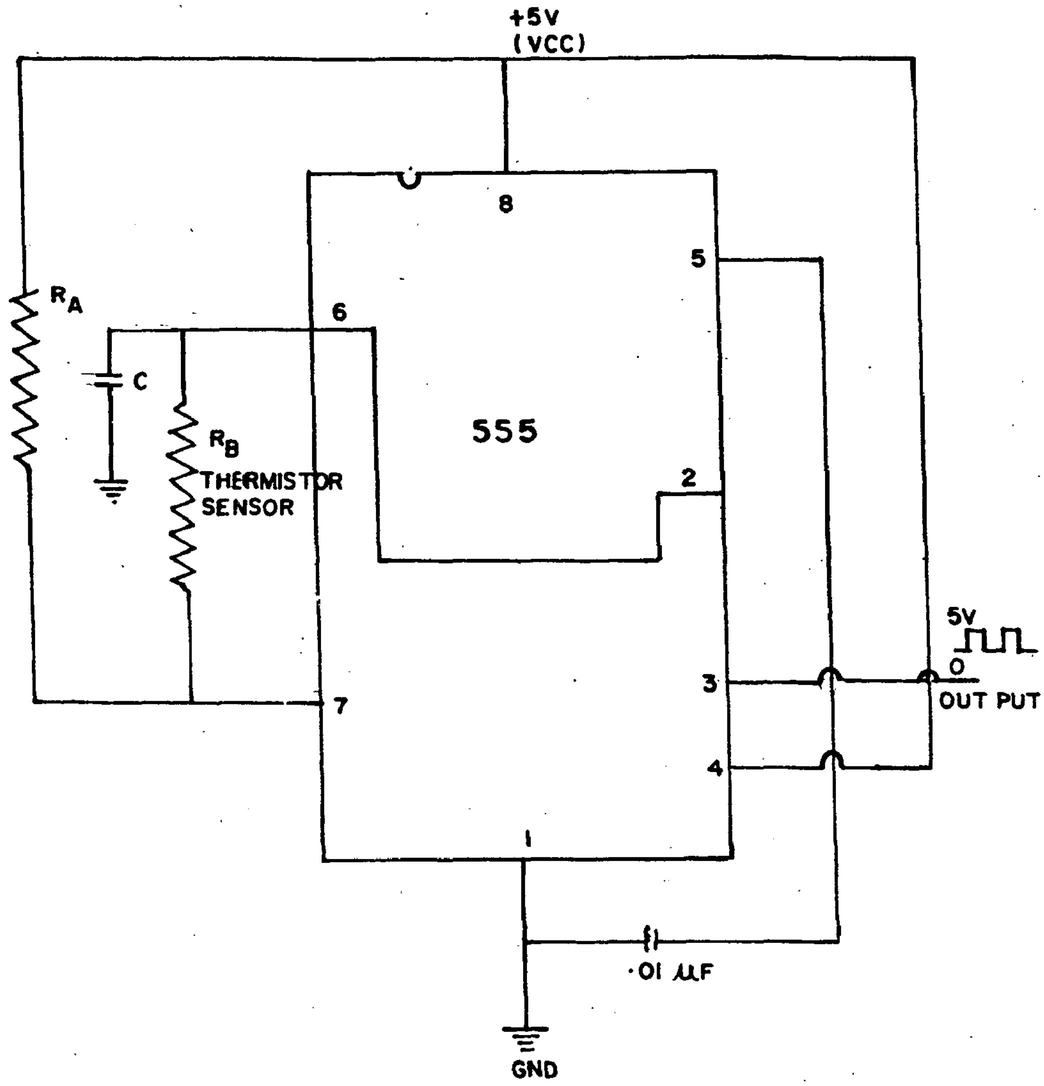


FIG.NO.7.7 TEMPERATURE TO FREQUENCY CONVERSION CIRCUI

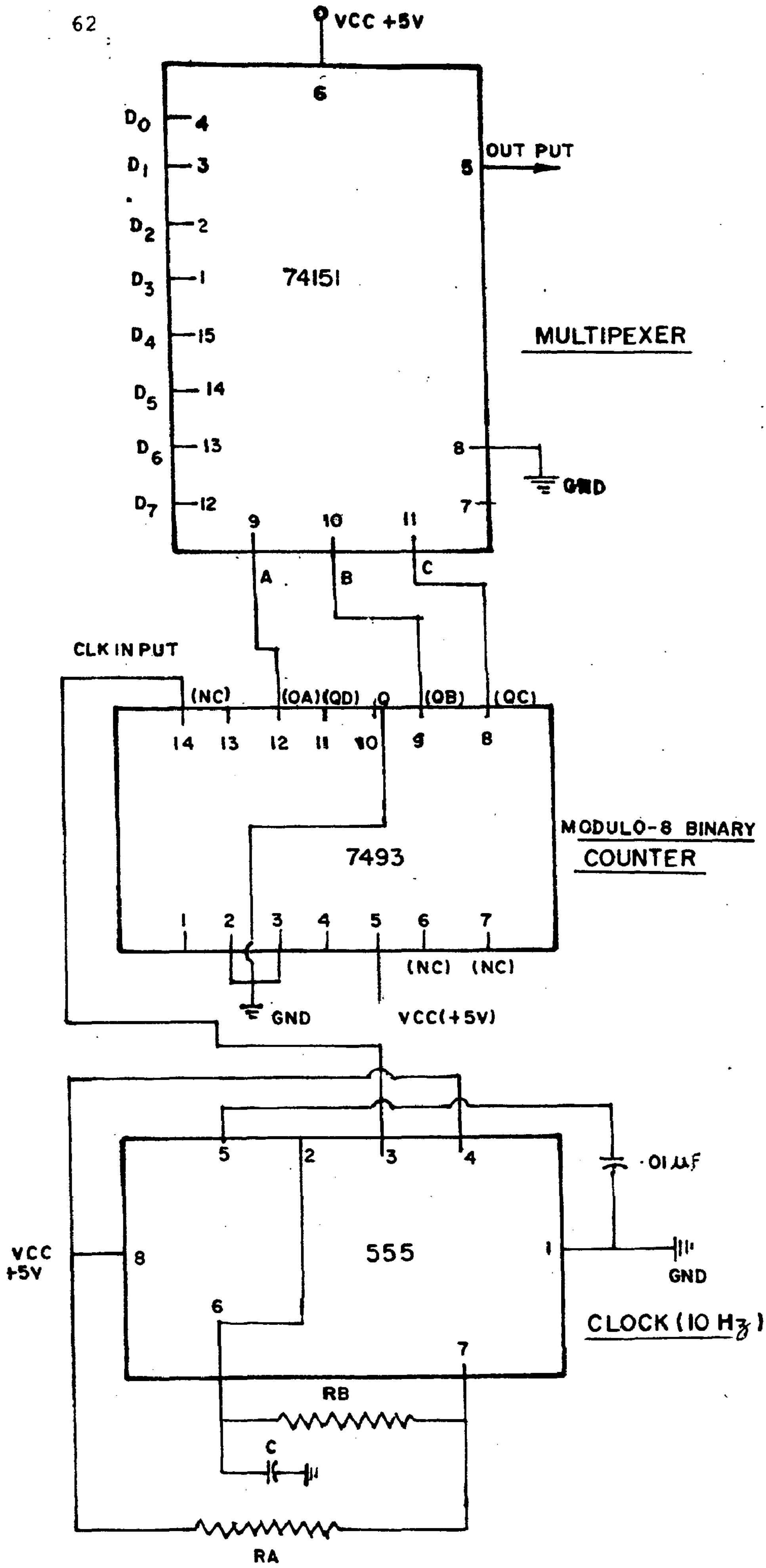


FIG.NO.7.8 TIME DIVISION MULTIPEXING

transmit each channel for 100 ms with help of a digital multiplexer 74151 whose channel are selected cyclically by a module-8 binary counter (3 flip-flops) of a 7493 counter are used for this purpose, (19). The rate of channel solution is controlled by a 10-Hz clock made from a 555 timer as shown in the diagram.

The seven out of total eight channels will be having the pulses measure of the temperatures at different points. Whereas the eighth channel will have sync-pulse (square) whose frequency is very much lower than the frequencies of pulses in other channels. The sync-pulse is used for detecting the starting and finish of one frame of measurement. In this scheme the sync-pulse channel has been connected to the clock of the counter and hence the sync pulses and the clock are automatically synchronised.

The frequency of oscillation of 555-based astable multivibrator is given by.

$$f = 1/T = 1.44/(RA + 2RB)\ C.$$

Taking RA = 330 ohms, R3= 71 $K\Omega$ and C = 1 micro farad,

$$f = 10.117\ HZ.$$

7.3.4 Frequency shift keying modulation

For radio-transmission of signals from the rotor to the stationary receiving end instrumentation , the modulation technique is frequency shift keying. The two different levels of the pulse signals will give two different high frequency waves after passing through a scaler end shifter, a voltage controlled oscillator (VCO) and a bandpass filter.

(A) Voltage controlled Oscillator

The function generator used for the modulation is IC NE 566. The 566 device is a general purpose VCO designed for linar frequency modulation. It provides simulataneous triangular and square wave output at frequencies upto 1MHz. If a sinusoidal waveform is required, as in this application , the wave has to be shaped using an external circuit.

Figure 7.9 shows the block diagram of the internal components of a 566 function generator(18).It consists of a current source which can be controlled by an external resistor R1, a Schmitt trigger and a pair of buffer amplifiers. The frequency of the oscillation is determined by the external resistor, R1, an external capacitor, C and the d.c. voltage applied to the control terminal (pin 5). R1 should normally lie between 2 K and 20 K while pin must be biased externally so that the control voltage Vc lies between 3/4 V+ and V -. The typical connection diagram is shown in Fig.7.10(20) in which R2 and R3 provide bias for pin 5. A small capacitor say, 0.001 uf, should be connected between pins 5 and 6 to eliminate possible oscillations in the current source. The frequency of the oscillations can be varied over 10:1 range by varying R1 . It can also be varied over a 10:1 range by a signal applied to pins via coupling capacitor C2 . The modulating signal can be coupled directly as well if appropriate dc bias voltage is applied to pin 5. The frequency of oscillation fo is given by.

$$f_0 = 2(V^+ - V_C)/R1\ C1\ V^+$$

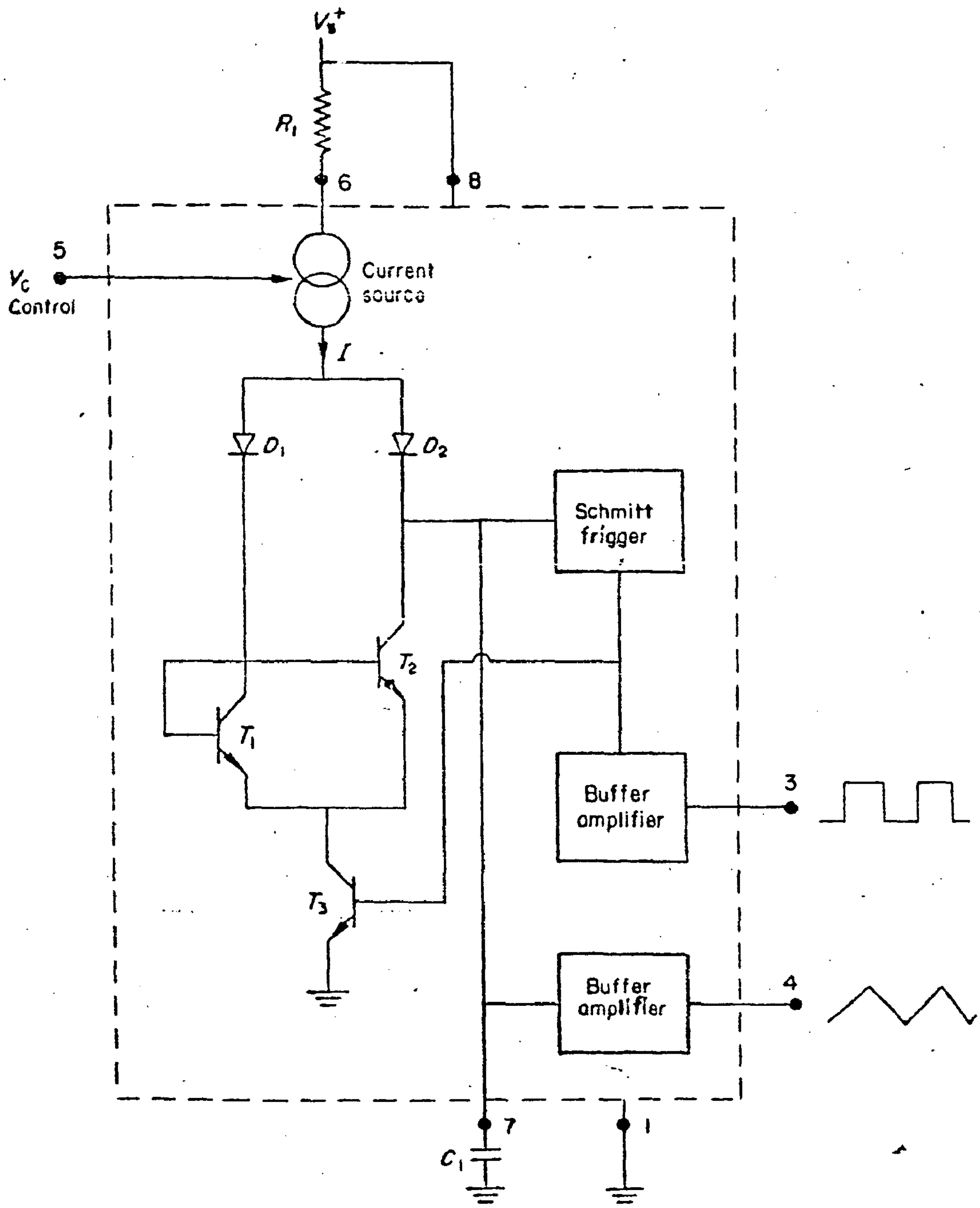


Fig. 7.9 566 waveform generator; simplified functional schematic

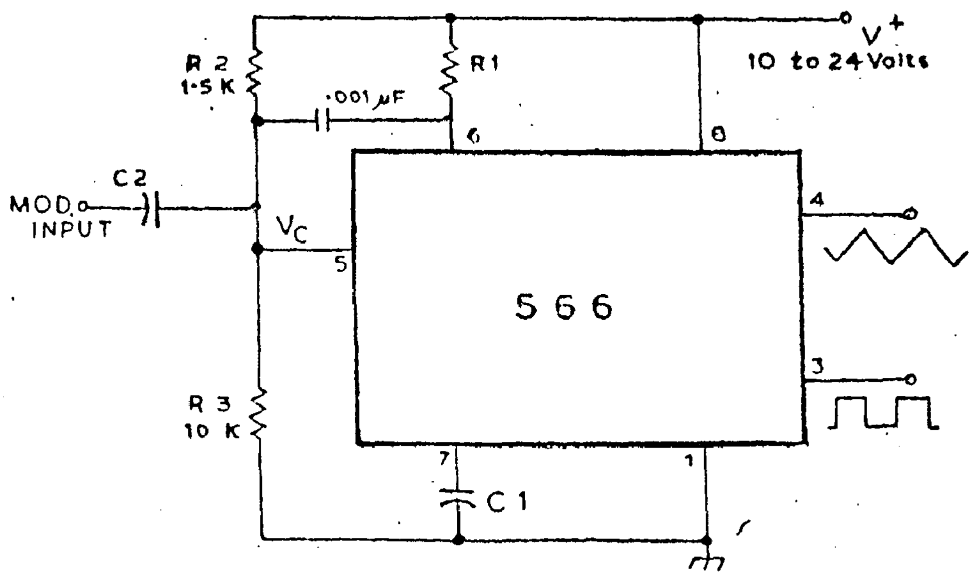


Fig.7.10 Typical Connection Diagram of 566.

Value of Vc must be in the range $3/4\ V^+ < V_c < V^+$ and value of R1 in the range $2\ K \leqslant R1 \leqslant 20\ K$

This square wave having 0 and 5 V levels will have to be scaled and level shifted in order to have frequencies 450 KHz and 500 KHz corresponding to them respectively. Therefore if in one case Vc1 is 9 V we know

$$f_1 = \frac{2(V^+ - V_{c_1})}{R_1 C_1 V^+} \quad \text{and} \quad f_2 = \frac{2(V^+ - V_{c_2})}{R_1 C_1 V^+}$$

$$\text{or} \quad \frac{f_1}{f_2} = \frac{12 - 9}{12 - V_{c_2}} \quad \text{or} \quad \frac{500 \times 10^3}{450 \times 10^3} = \frac{3}{12 - V_{C_2}}$$

ie VC2 = 9.3V

Now taking connections as per figure 7.11 and if C2 = 47pf, C2 = .001pf, R1 = 10K, R2 = 2.2 K and R3 = 10 K

C1 can be computed as under

$$C_1 = \frac{2(V^+ - V_{c_1})}{R_1 V^+ f_1}$$

$$= 100\ pf$$

(B) Scaler-Cum Level shifter

In order to have two frequencies of 450 KHz and 500 KHz the two levels of pulse output, namely 0 and 5V, will have to be scaled and shifted so as to get 9.3V and 9V levels respectively. This block will be used before the voltage controled oscillator.

The device used for this purpose is the IC 741 operational amplifier, acting as an adder(21). The configuration used is depicted in figure 7.12.

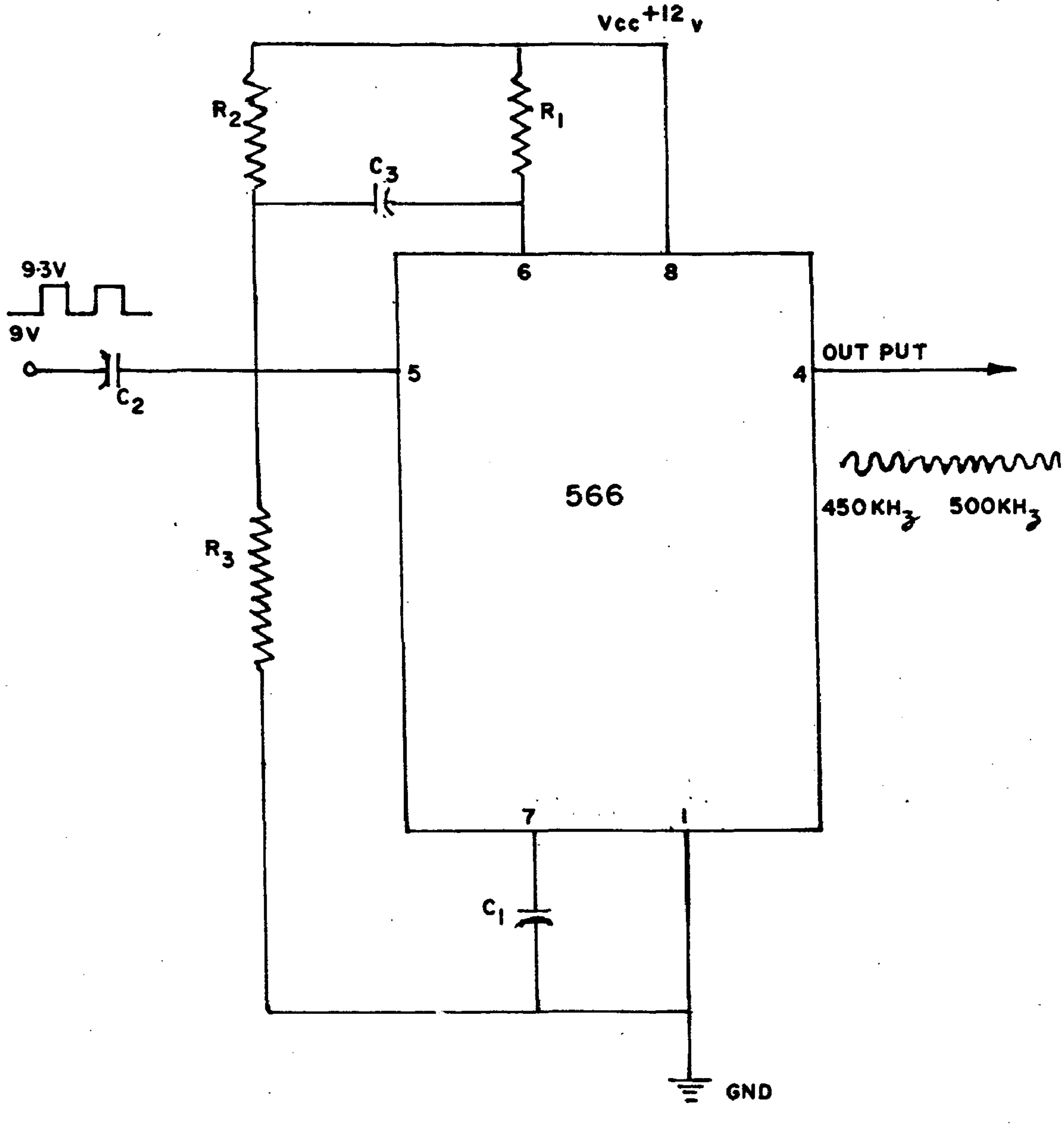


FIG.NO.7.11 FREQENCY SHIFT KEYING MODULATION
(VOLTAGE CONTROLLED OSCILLATOR)

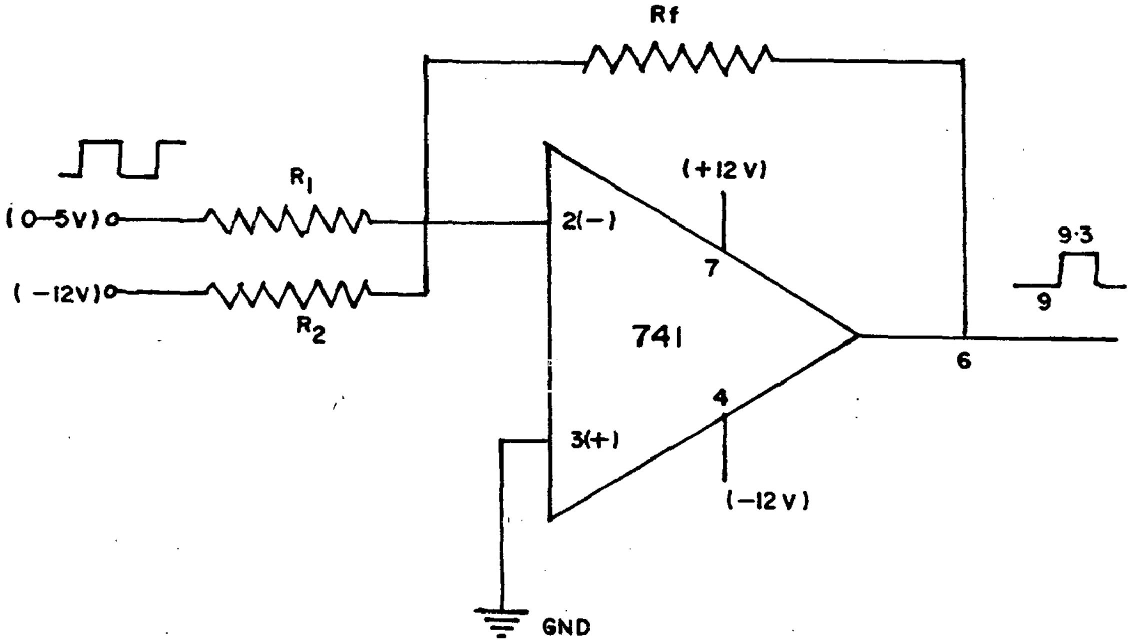


FIG.NO.7.12 LEVEL SHIFTER

The pulse signal and a negative voltage of 12 V are applied to the inverting input pin through resistance R1 and R2 respectively. The feedback is provided through a resistance Rf.

Now using following equations the values of different resistance can be foundout.

$$-\left[\frac{5}{R_1} + \frac{(-12)}{R_2}\right] R_f = 9 \qquad \text{---- (i)}$$

$$\text{and } -\left[\frac{0}{R_1} + \frac{(-12)}{R_2}\right] R_f = 9.3 \qquad \text{---- (ii)}$$

Taking Rf = 8.2 KΩ, we get

R2 = 10.58 KΩand R1 = 136.67 KΩ

(C) Bandpass Filter

The output of VCO in this case is triangular, and hence there is a necessity to convert it into sinusoidal wave train to have an effective transmission. An active VCVS (voltage controlled voltage source) band-pass filter has been used here. An ideal VCVS is a voltage amplifier with infinite input impedence, zero out impedence and high stable gain. The high input impedence, low output impedence and stable gain of an operational amplifier, when connected in the inverting feed back configuration, allows its use as a close approximation to the ideal VCVS.

A VCVS circuit with a second order band pass transfer function is shown in figure 7.13(17). A general expression for a second order band pass transfer function may be written as.

$$A(s) = \frac{A_0 b \omega_0 s}{s^2 + b\omega_0 s^2 + \omega_0^2} \qquad \text{where } b = \frac{1}{Q}$$

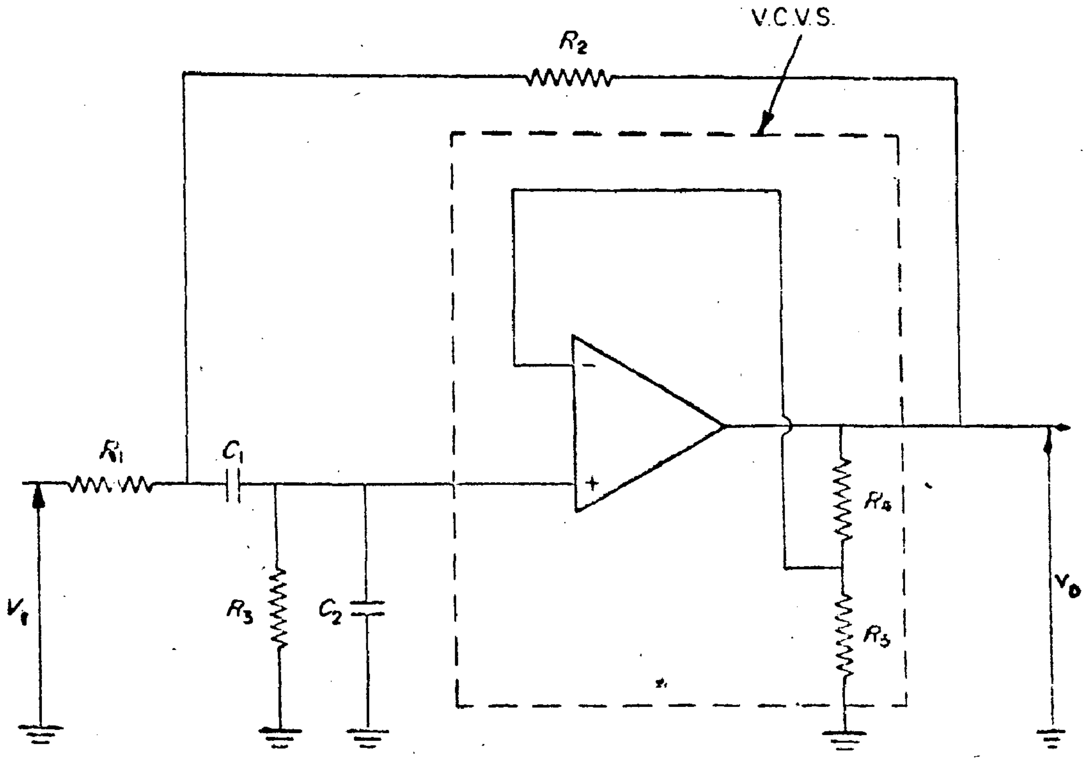


Fig. 7. 13 VCVS band pass filter

The relationship which gives the transfer functions parameter in terms of circuit parameters are

$$A_o = \frac{K}{1 + \frac{R_1}{R_2} + \frac{C_2}{C_1}\left(1 + \frac{R_1}{R_2}\right) + (1-K)\frac{R_1}{R_2}}$$

$$\omega_o = \left[\frac{1}{R_3}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\frac{1}{C_1 C_2}\right]^{1/2}$$

$$\text{and} \quad b = \frac{1}{Q} : \left(\frac{R_3}{\frac{1}{R_1} + \frac{1}{R_2}}\right)^{1/2}\left[\sqrt{\frac{C_1}{C_2}}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1-K}{R_2}\right) + \sqrt{\frac{C_2}{C_1}}\left(\frac{1}{R_1} + \frac{1}{R_2}\right.\right.$$

The above equations can be simplified considerably if we select C1 = C2 = C and R1 = R2 =R3= R, keeping AO as free parameter and the design filter for a specific value of WO and b as under

$$R = \frac{\sqrt{2}}{\omega_o C}$$

$$K = 5 - \frac{\sqrt{2}}{Q}$$

Taking ω_o = 475 KHz $Q = \frac{\omega_o}{\omega_2 - \omega_1} = \frac{f_o}{f_1 - f_o} = \frac{\text{Centre frequency}}{\text{Frequency band}}$

and b = 100 KHz.

or Q = 4.75 and K = 4.7023 from eqn (ii),

We choose the ratio of R4/R5 for this value of K. So if R5 = 10 KΩ, R4 = 47 KΩ. Also taking C1 = C2 = 47 pf and from equation (i)

R = 10.081 KΩ = R1 = R2 = R3 and

7.3.5 Antenna

Since the distance between the transmitter and receiver is not much the wire or loop antennas can easily be used for transmission.

7.4 Receiving end details

The signal transmitted from the motor, can be picked up by an antenna in the shape of loop or wire at the receiving end. The voltage level of the received signal will depend on the distance of receiving antenna from the transmitting antenna.

7.4.1 Amplification

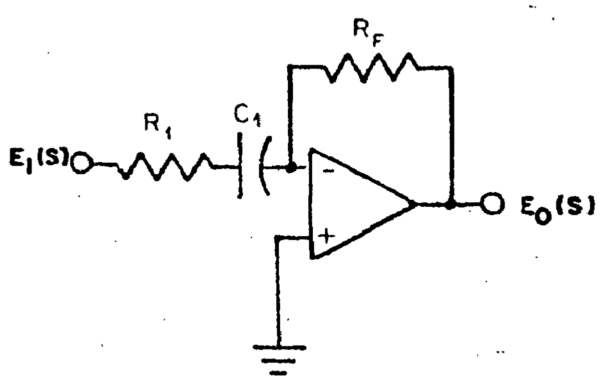
The signal received will be in the order of millivolts and will require amplification before being processed for temperature detection. The device used for this purpose is inverting type AC amplifier. Although the operational amplifier is designed to amplify dc signals , it has rather broad frequency response and is consequently quite useful for strictly a c signals . The feedback network can be tailored for exactly the desired pass band. A simple a.c. amplifier circuit is shown in figure 7.14(22), where the close loop gain is given by

$$\frac{E_o(s)}{E_1} = \frac{-R_f}{R_1} \frac{s}{s + \left(\frac{1}{R_1 C_1}\right)}$$

The dc gain is zero, and the high frequency gain approaches - Rf/R1 . The lower cut off frequency is

$$f_c = \frac{1}{2\pi R_1 C_1}$$

The amplifier circuit has been designed here for again of approximately 50. The IC used is 709 which can operate in high frequency range with proper frequency compensation components. As indicated in figure 7.15., the frequency compensations for different values of gain is as



INVERTING CIRCUIT

Fig. 7.14. Ac-coupled feedback amplifier .

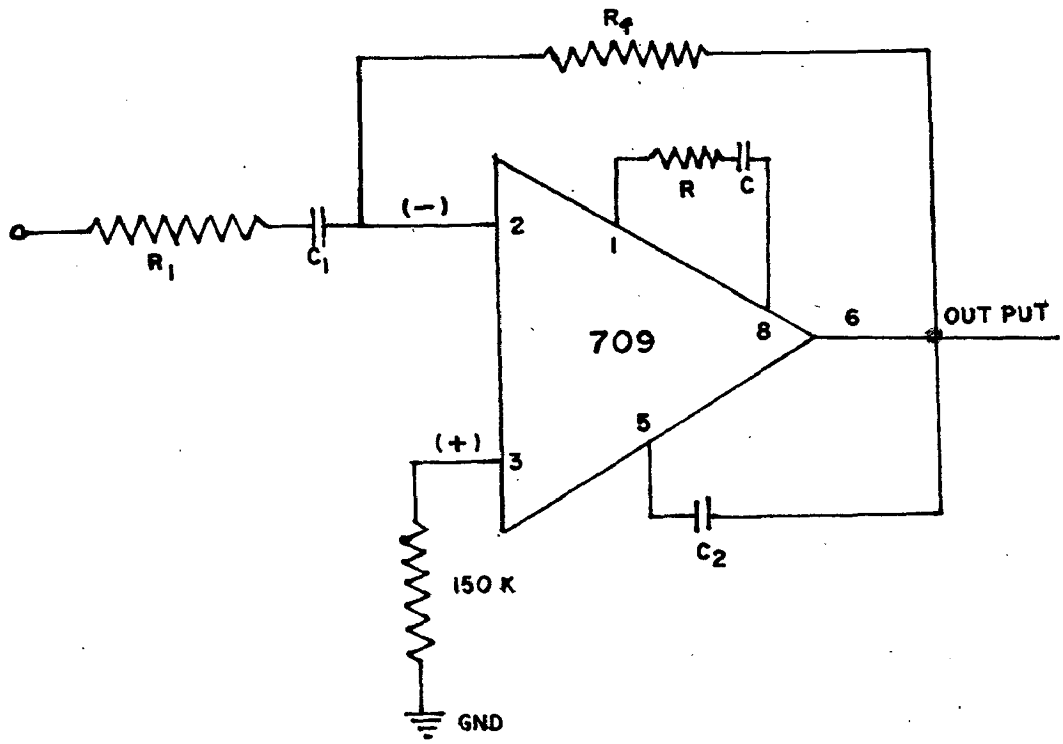


FIG.NO.7.15 AMPLIFIER CIRCUIT USED

follows :

For 20 db gain R = 1.5 KΩ, C = 500 pf, C2 = 20 pf

40 db gain R = 1.5 KΩ C = 500 pf C2 = 33 pf

Taking frequency compensation for 40 db gain that is, R = 1.5 KΩ C= 100pf and C2 = 3.3 pf, the gain of 50 can be achieve by following values. .

If C1 = 100 pf.

For cut off frequency of 450 KHz and from equation

$$R_1 = \frac{1}{2\pi C_1 f_c}$$

= 3.5 KΩ

and therefore if Rf =200 KΩthe gain will be about 57 .

7.4.2 Filter and Reamplification

The filter identical to that used in transmitter has been used here. It filters unwanted and undesired noise & interference of different frequencies. The centre frequency of the filter is 475 KHz with band of 100 KHz ie Q = 4.75.

The filter circuit is shown in Figure 7.13 . The values are R1 = R2 = R3 = 10.081K, C1=C2=47pf and R4 = 47KΩ and R5 = 10 KΩ

The filtered signal, which is free from noise & interference signals to a large extent, is again amplified . The gain of this amplifier is 5. Taking frequency for 20 db gain, that is, R2 = 1.5KΩ C = 500 pf and C2 = 20 pf gain can be achieved by following values

If C1 = 100 pf and R1 = 3.5 KΩ Rf will be 22 KΩ

7.4.3 Demodulation

The signal received after filtration and amplification has to be demodulated to obtain the orignal pulses, which is the measure of temperatures of different points in rotor windings . The device used for this purpose is a phase locked loop (PLL) which is used to synchronise the frequency of a controlled oscillator to that of an incoming signal.

In its simplest form, a PLL consists of three functional blocks - a phase detector, a low pass filter and a voltage controlled oscillator (VCO)(18) The basic loop may also have an amplifier and the units are connected together in a closed loop as shown in figure 7.16 .

7.4.4 PLL - Principle

The phase detector is assumed to exhibit a multiplier characteristic . Thus with no input signal applied to the system, the output from the phase detector is zero . The error voltage applied as the control signal to the VCO is also zero and VCO operates at its free running frequency,

$$f_0 \left(f_0 = \frac{\omega_0}{2\pi} \right)$$

, this frequency is denoted as the centre frequency. When an input signal of frequency fs is applied to PLL, the phase detector produces an output signal which contains two components fs + f0 and fs-f0. If fs is significantly different from f0, both components are attenuated by the low pass filter, the frequency of the VCO is not changed and the loop does not acquire a lock.

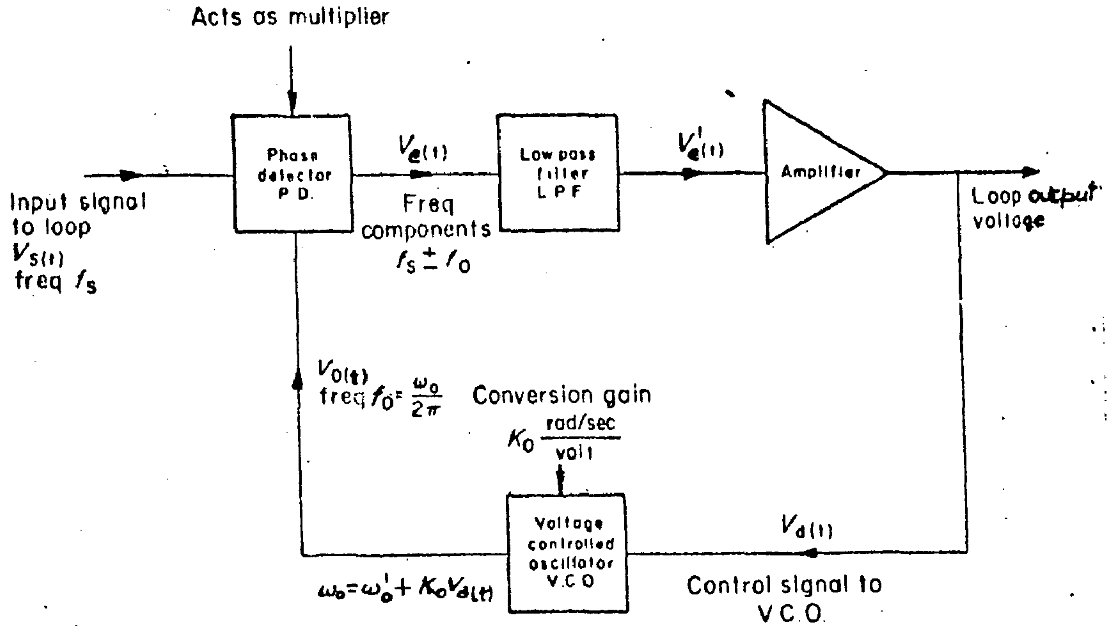


Fig. 7.16 Block diagram of basic PLL

In other case when the frequency component fs & fo lies within the pass band of the low pass filter, output is then amplified and applied as control signal to the VCO. This causes the VCO frequency to change in a direction which reduces the frequency difference between fs and fo. When fs is sufficently close to fo, the feed back action of the loop causes the VCO to synchronise or 'lock' with the incoming signal. When the lock has been acquired the VCO frequency is identical to that of the input signal. The PLL can 'track' any frequency changes of the input signal once lock has been acquired. The range of the frequency over which a PLL can maintain lock with an input signal is called the 'lock range' of the system.

The type of PLL used in this application is LM 565. This is general purpose PLL containing stable, highly linear voltage controlled oscillator for low distance FM demodulation and a double balanced phase detector with good carrier supression. The centre frequency of the PLL is determined by the free running frequency of the VCO which can be adjusted internally with a resistor or a capacitor and a tuning range of 10:1 can be obtained with the same capacitor. A block diagram showing the internal components in 565 PLL is shown in figure 7.17(20) . The free running frequency of the VCO with both inputs grounded is given by.

$f0 = 1.2/ 4\ RC1$ in Hz

The external resistance R should lie within the range 2 KΩ to 20 KΩ with an optimum value of the order of 4 KΩ.

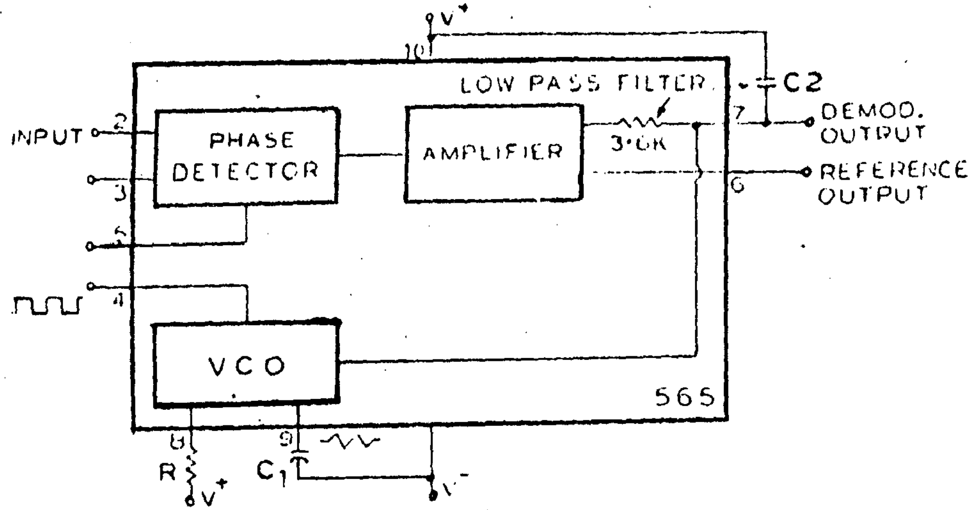


Fig. 7.17 Block Diagram of 565 PLL.

A short between pins 4 & 5 connects the VCO output to the phase selector . The free running frequency can also be controlled by applying an external voltage to pin 7. The input signal can be coupled directly if the d.c. resistance as seen from pins 2 & 3 are equal, and there is no d.c. voltage reference between the pins . Pin 6 provides a d.c. difference voltage that is close to the d.c. voltage of the demodulated output . This also facilitates connecting the output to an operational amplifier compensating for drifts etc.

The diagram used in this application for frequency shift keying demodulation is shown in figure 7.18(20).The transmitted data with the carrier has been shifted between two frequencies (450 KHz and 500 KHz) with the help of a VCO during with the '0' and '1' signal at the transmitting end.

The arrangement shown in the figure receives frequency shift keying (FSK) signals of 450 Khz and 500 KHz. As the signal appears at the input, the PLL locks to the input frequencies and tracks it between the two frequencies with a corresponding d.c. shift at the output. A three stage filter connecting to pin 7 removes the carrier components. A capacitor (in pfs) connected to pin 6 removes noise signal at the reference voltage. The output signal is made logic compatible by a voltage comparator. The IC used in this application for this purpose is LM 311.

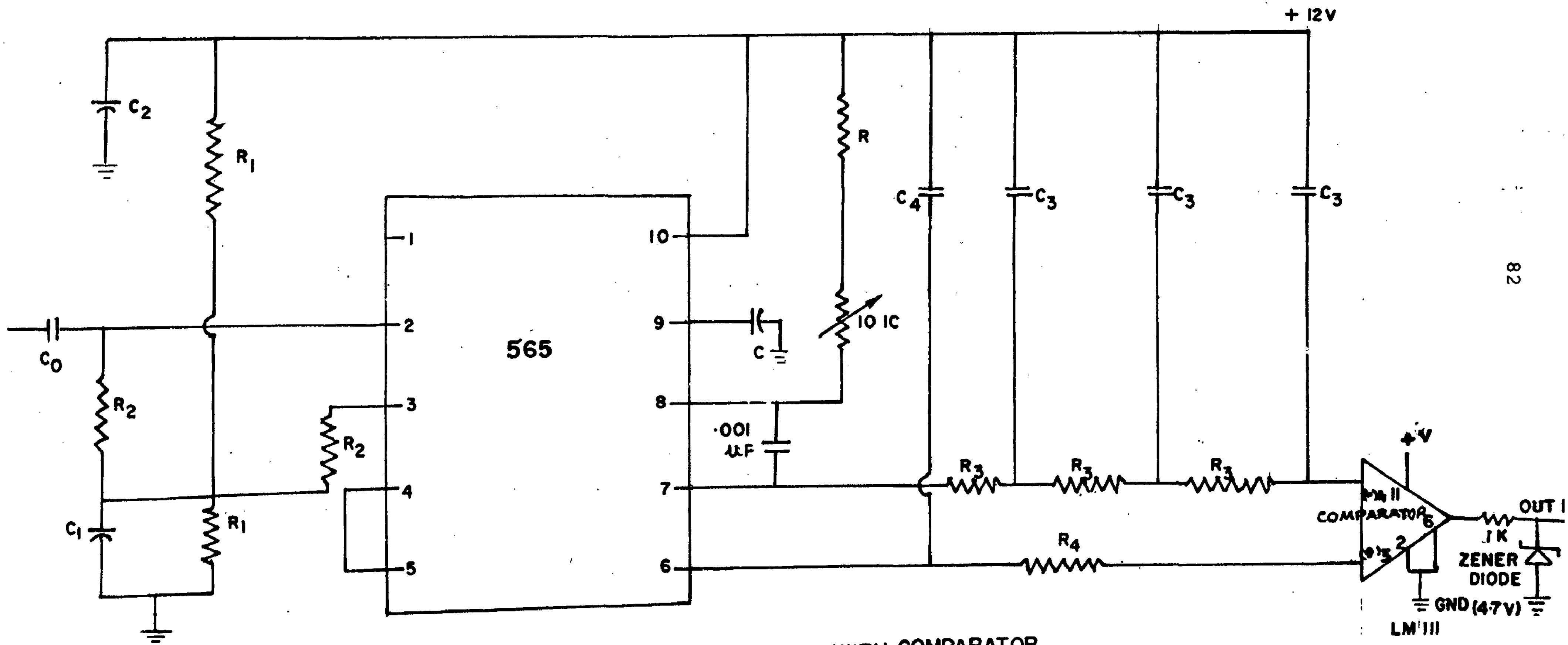


FIG. NO. 7.18 FSK DEMODULATOR WITH COMPARATOR

Design

Considering the circuit used for frequency shift keying (Figure 7.18) The values used are

R1 = 10 KΩ R2 = 4.7 KΩ R3 = 10 KΩ and R4 = 3.3 KΩ

also C1 = 5μf, Co = 2000pf, C2 = 10 μF, C3 = 330 pf

C4 = 470 pf

The values of R & C can be calculated by the equation

$f0 = 1.2 / 4 RC$

If f0 = 475 KHz and C = 100 pf, then R = 6.2 KΩ

The output of the comparator in this case varies between 0 and 12 volts. To make it TTL compatible, the circuit used is as in figure 7.18. The value of resistance is 3.3 K and two zener diodes of value 2.7V have been used in series to give output from 0 to 5 V.

CHAPTER-8

DIGITAL SIGNAL PROCESSING FOR TEMPERATURE SCANNING

In this chapter the digital signal processing part of the proposed scheme will be discussed. The output of the receiver is in the form of pulses and has 8-channels . The hardware and software, which will be discussed later in this chapter , have been developed to demultiplex these 8-channels and count the time period of 50 pulses in each channel. The software will also convert the time periods of 50 pulses in each channel into temperatures using the lookup table. And also non-linearity of the temperature - resistance characteristic of the thermistor also gets eleminated.

8.1 System Description

The output of the receiver after being demodulated has eight channels. One out of these light channels will have the have the sync pulse of distinctly low frequency (10 Hz in this case) while the other channels will have frequencies in the range 1.53 KHz to 10.75 KHz which are measure of temperatures at seven different points in the rotor winding and bearings. This signal is fed to a microprocessor system for basically three operations as follows :

a) Demultiplexing of all the eight channels after detecting the sync pulse.

b) Measurement of the time periods of the pulses in seven channels.

c) Conversion of time periods into temperatures using lookup table which will also remove the nonlinearity element of the thermistors.

Each channel in one frame is having duration of 100 ms and each channel will, therefore, be repeated after every 800 ms (frame period). An approximate illustration is shown in figure 8.1. The microprocessor will first sense the sync pulse by virtue of its large time period and then demuliplex the eight channels. It also will count time period of 50 pulses in each channel. Lastly it will match this time period with the time corresponding to temperature of rotor from the lookup table. The temperatures can be read from the prefixed memory locations of the microprocessor.

8.2 Hardware Description

An eight bit microprocessor alongwith a "divide by 4" counter have been utilized for realising the functions described in para 8.1. A hardware schematic of the system is shown in the figure 8.2.

The system has got 8085A as the central processing unit (24). The CPU 8085 A communicates with other element of the system through 8 bit data bus and 16 bit address bus. The lower 8 address lines and 8 bit data lines are multiplexed. The clock frequency of the system is 3 MHz.

A 2 K byte CMOS RAM (6116 chip) has been included for storing data and for stack operation. The total on board memory can be expended upto 64 K byte. The various chips

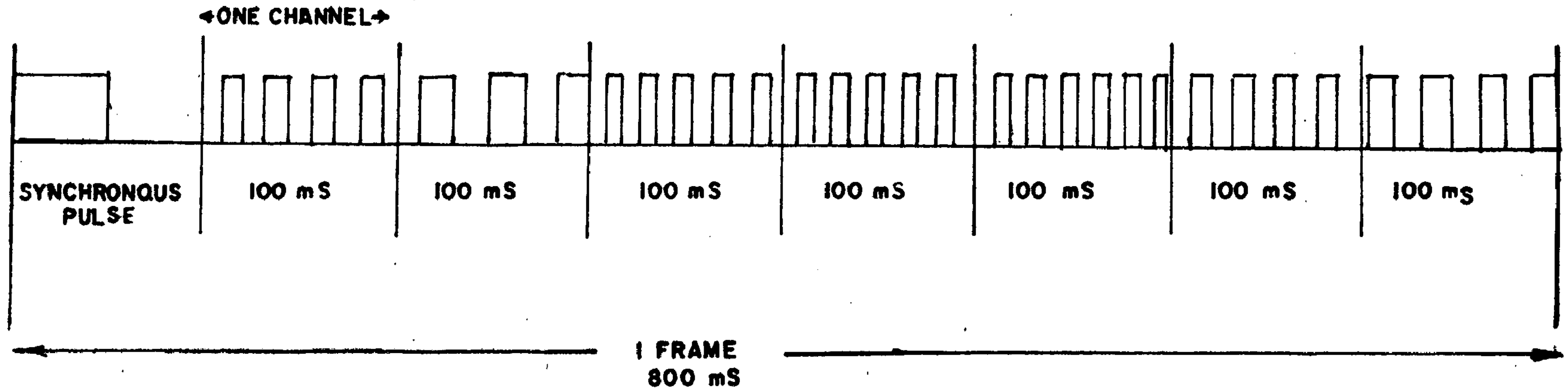


FIG. 8·1 APPROXIMATE INPUT TO THE MICROPROCESSOR (OUTPUT OF RECEIVER)

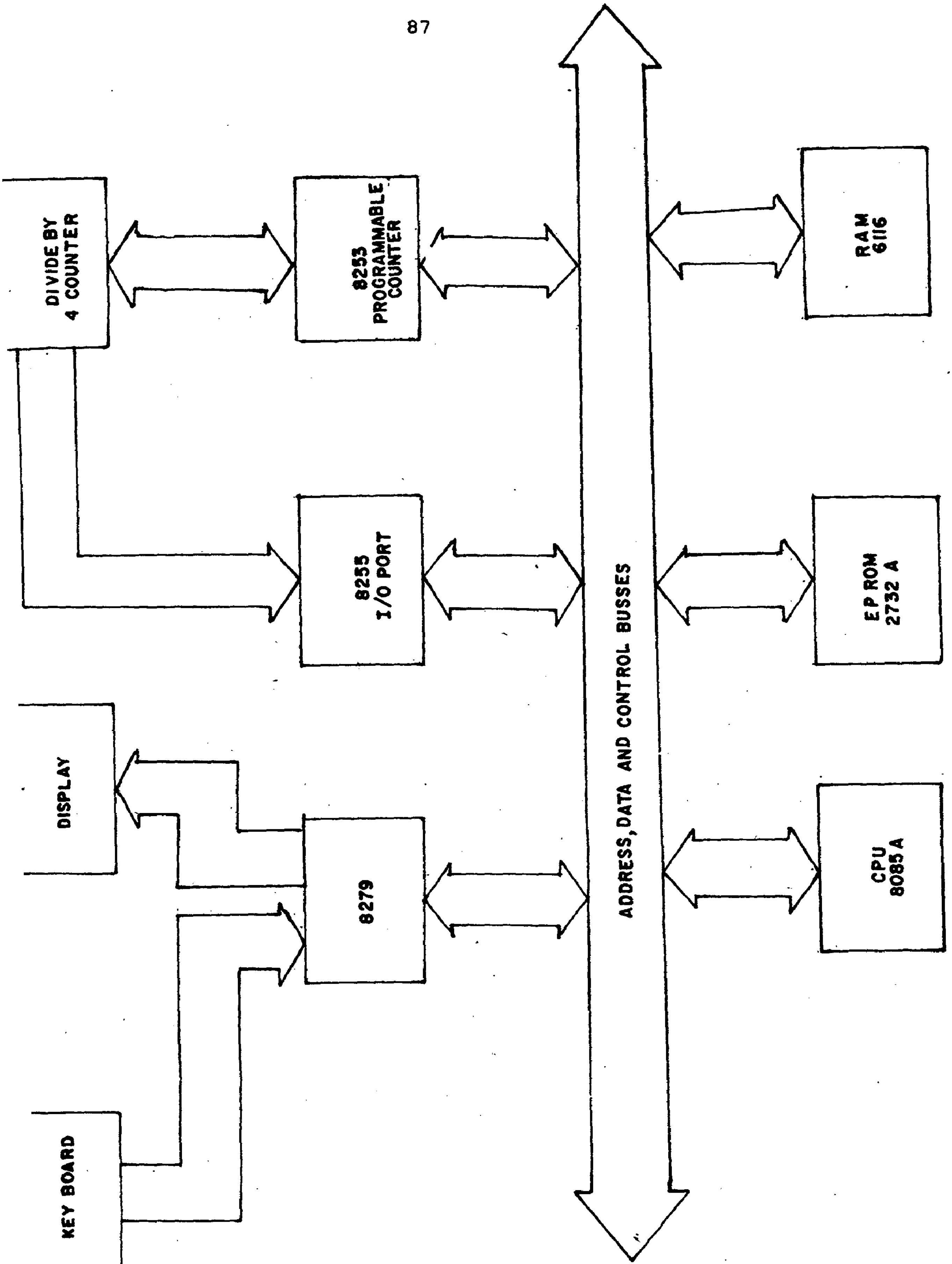


FIG. 8·2 HARDWARE SCHEMATIC

which can be used are 2716, 2732, 2761 , 27128 and 6116. An EPROM (2732A chip) has been used for storing the program of this temperature scanner.

8279 is a general purpose programmable keybord and display I/O interface designed for use with 8085 microprocessor. It has got 16 x 8 display RAM which can be loaded or interrograted by the CPU. When a key is pressed, its corresponding code is entered in FIFO queue of 8279 and can subsequently be read by microprocessor. 8279 also refreshes the display RAM automatically.

A programmable peripheral interface (PPI) 8255 has been used to communicate between microprocessor and the scanner. It has got three ports which can be used as I/O ports in three different modes, which are mode 0, mode 1 and mode 2. Selection of the modes depends on a control word to be written in the control word register. In this present system, 8255 has been used to communicate with the receiver of the scanner whose output is a set of pulse trains. To meet this requirement port C lower has been used as inport and the port C upper has been used as outport. 8255 has been used in a basic Input/Output mode, that is, mode 0.

8253 is a programmable interval timer / counter and can be used for the generation of accurate time delays under software control. Various other functions that can be implemeted with this chip are programmable rate generation event counter, binary rate multiplier, real time clock etc. This chip has got 3 independent 16 bit counters, each having a count rate of up to 2 MHz. For the single step operation CLK 0 signal of counter 0 is getting a clock of 1.535 MHz. The counter 1 and 2 are being used in this applications for measuring the time period of channels and to interrupt the processor after every 100 ms. To meet the requirement of interrupt generation, has been used a continuous square wave generator with count length of 9602 H.

There is a control word register in 8253 to select the modes of three counters. So for selecting the modes of the counters, control word has to be written in the command register. The information stored in this register controls the operational mode of each counter, selection of binary or BCD counting and loading of each counter . The register can only be written into and no reading facility of its contents is available. The 8253 can be programmed into 5 different modes, that is, from mode 0 to mode 5. In this application counter 1 has been used in Mode 0, that is , Interrupt on terminal count. The counter has been loaded with count length of 9602 H and is connected to RST 6.5 for interrupt after 100 ms. The gate of timer has been connected to PC4 of the 8255 PPI. The counter 2 has been used in 'Mode 4' that is, software triggered strobe. This counter has been latched after detecting 50 pulses in each channel excepting the sync pulse channel and the time period will be read on fly at this point. The gate of this counter has been kept permanently high. The input of both the counters in this scheme has been clock of 1.535 MHz after being "divided by 4."

The " divide by 4" operation has been performed by a dual flip-flop 7474. The circuit imployed for this purpose is shown in figure 8.3 . The 7474 has got two flip-flops or "divide by two" circuits and has been used as in figure. The input signal to this circuit has been applied from the counter '0' of the 8253 which has a clock of 1.535 MHz . This circuit will divided the frequency by four so, the counters '1' and '2' which are connected to this circuit can be used upto 160 ms time period. A circuit diagram interfacing the 7474 and 8253 has been shown in figure 8.4.

8.3 Software Description

The software of the temperature scanner will have to perform the following tasks :

a) To sense the sync pulse with the help of its larger time period.

b) To demultiplex all channels after sensing the sync pulse.

c) To measure the timeperiod of fifty pulses in each channel of the frame.

d) To findout the temperature corresponding to the measured value of the time period from the lookup table, thereby eleminating the non-linearity generated by the thermister and resistance to frequency conversion circuit.

8.4 Flow Charts

The flow charts for the sytem software which accomplish above tasks are :

a) Main program.

b) Interrupt service subroutine.

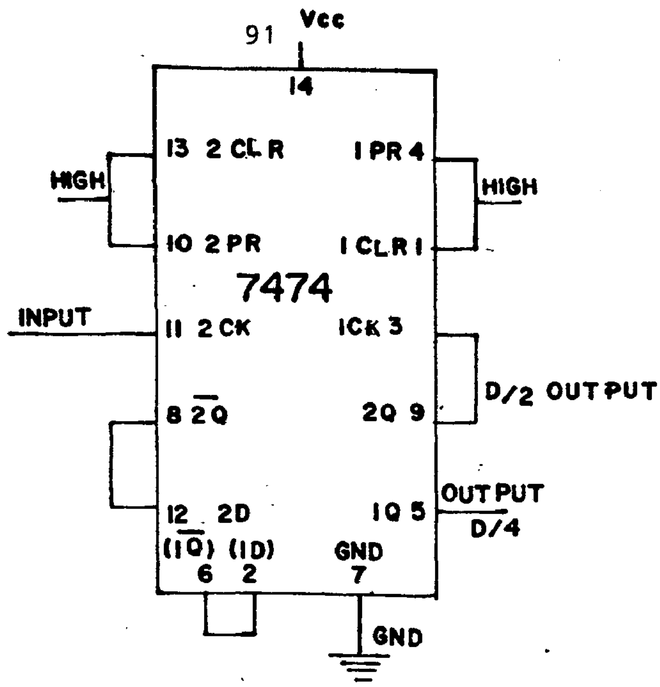


FIG. 8.3 DIVIDE BY FOUR COUNTER

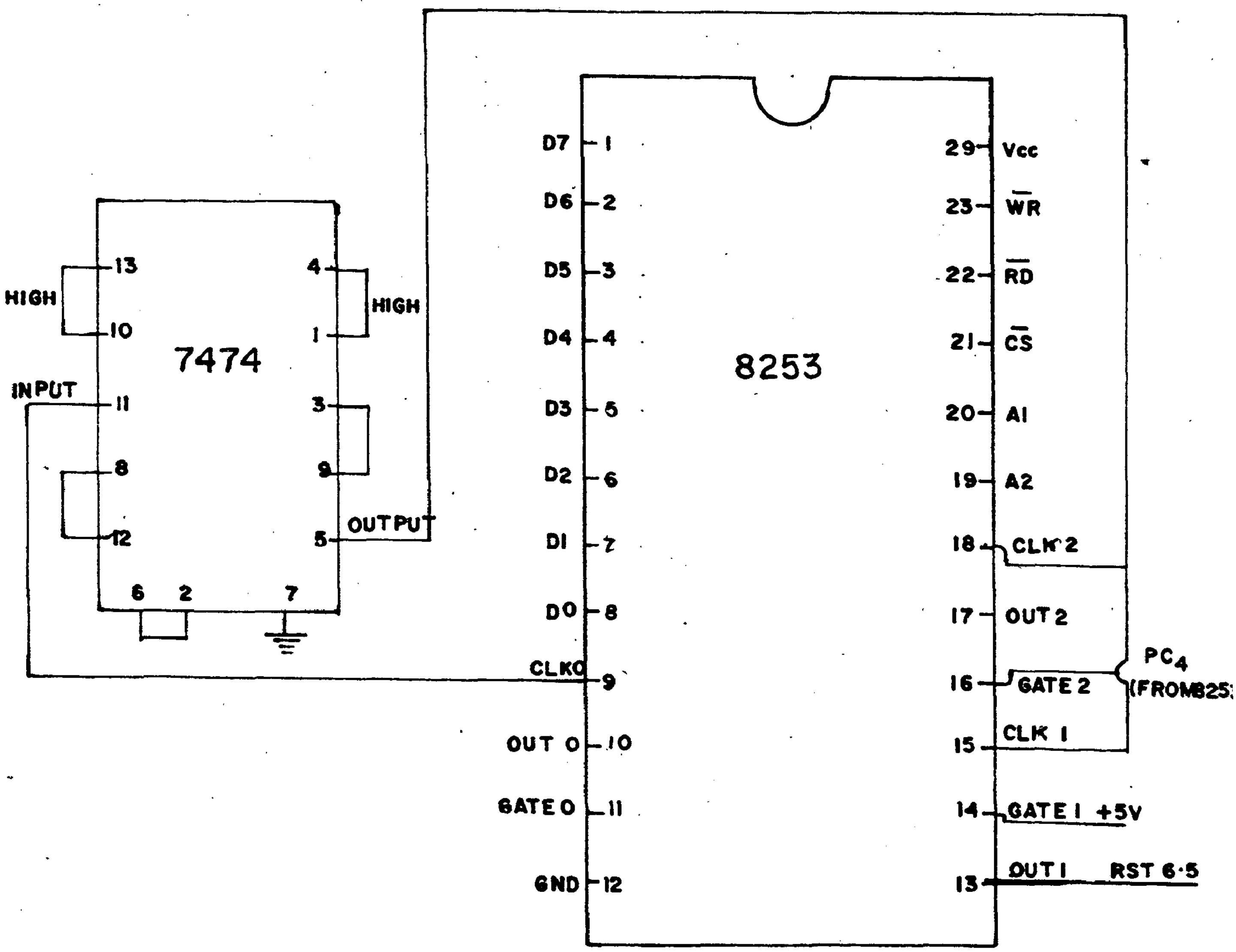


FIG. 8.4 INTERFACING 7474 WITH 8253

c) Lookup table subroutine.

The above flow charts have been shown in figures 8.5 to 8.7 and are briefly described below.

(a). **Main Program**

In the main program, the stack pointer has been initialised to save the contents of program counter, before calling any subroutine. Now various counters like two hardware counters, interrupt counter (counter1) and, time period counter (counter 2) , and also the software counters like channel counter is initialised to zero . The counter which store address form where the value of the time period of all the seven channel starts is initialized. When input pulse frame is connected, the progam will first check the pulse frame for the synchronous pulse. The time period of this pulse is approximately 50 ms., Which is very large compared to that of the other pulses. The low and high states of pulses are checked and if the duration between two subsequent low states of a pulse is more than 34 ms, then this pulse is the synchronous pulse. Now counter 1 is loaded for interrupt at RST 6.5 after a very short period. Since only RST 6.5 has been used other interrupts terminal are masked and interrupt system is enabled . The system waits for interrupt now and the program goes to the interrupt subroutine which will be discussed in details lateron. The main program continuous after the interrupt subroutine where the channel of the frame is decided or in otherwords demultiplexing is performed.

Now the time period of the fifty pulses for each channel is counted with the help of counter '2' which is

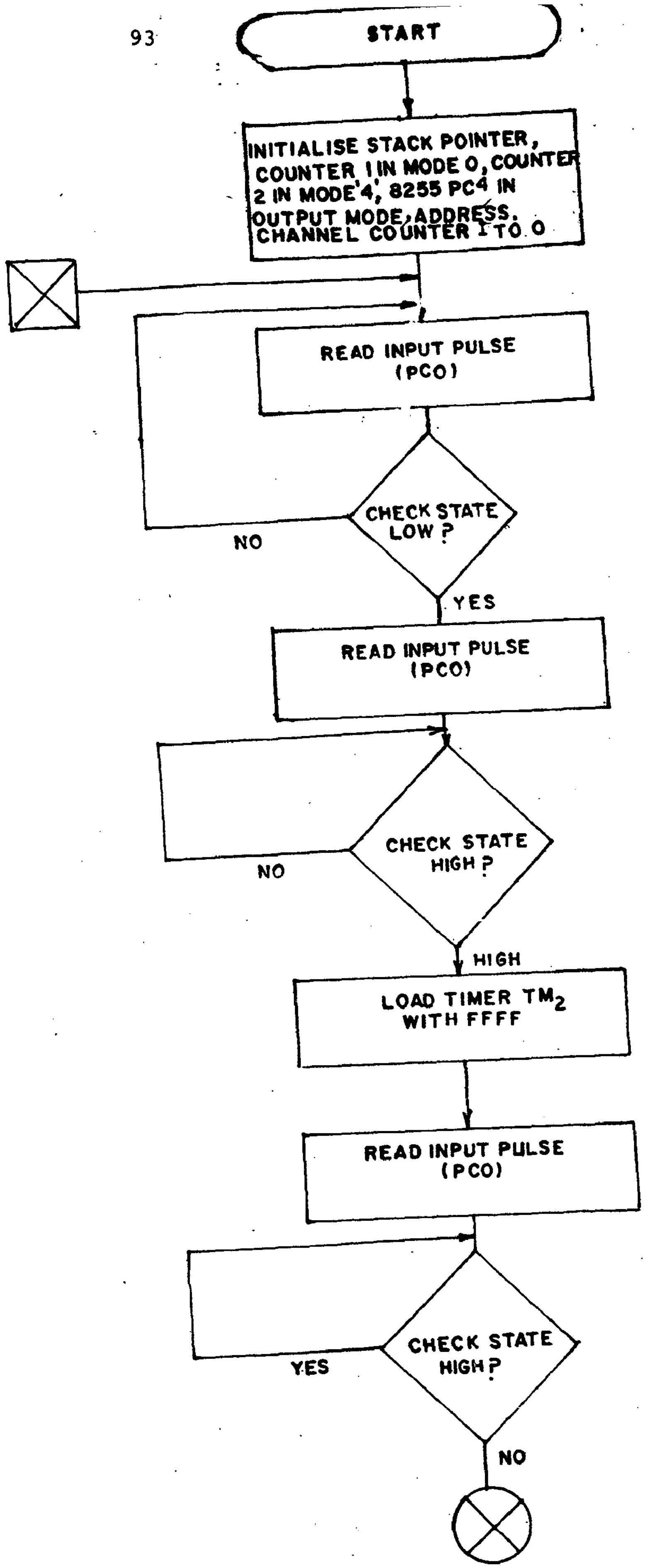
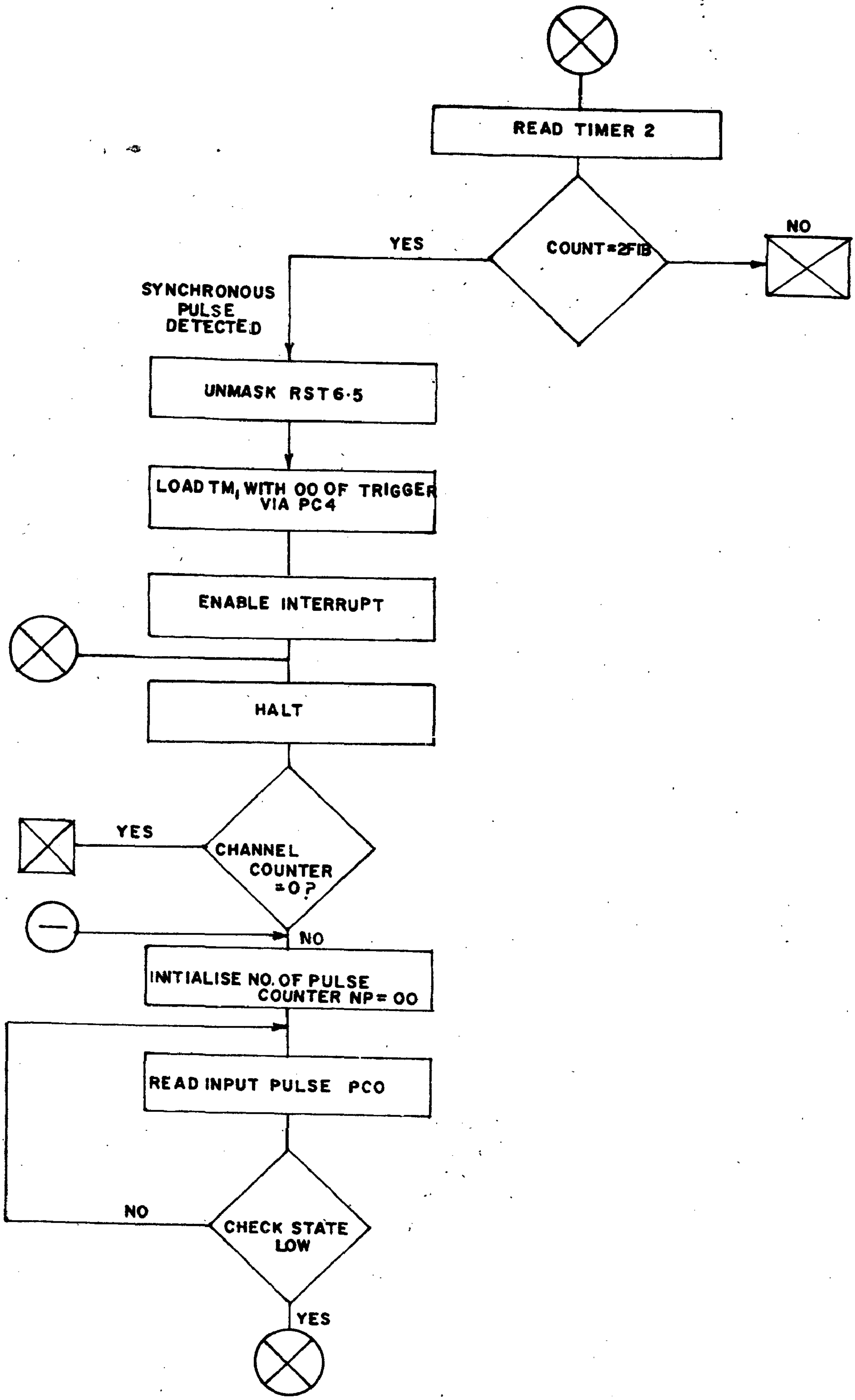
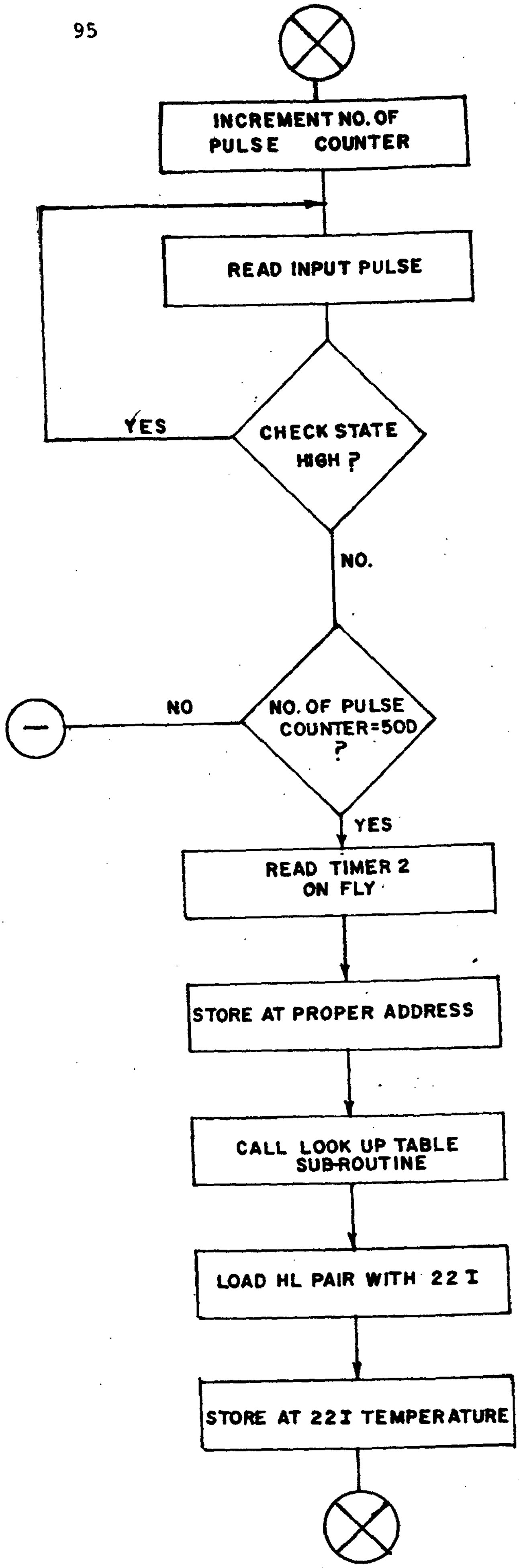


FIG.8·5 MAIN PROGRAM (CONTD.)



MAIN PROGRM (CONTD.)



MAIN PROGRAM (CONTD.)

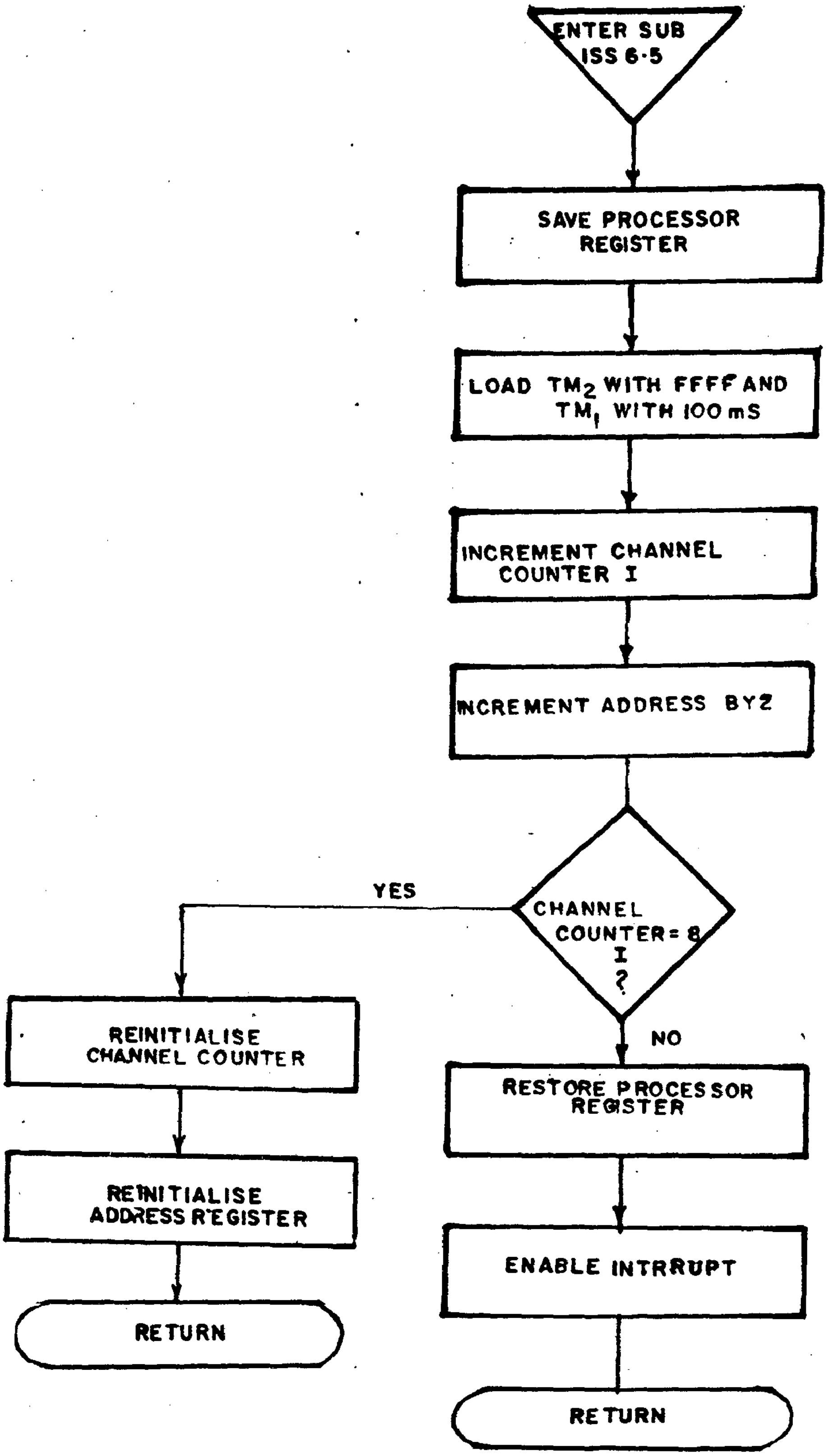


FIG.8·6INTERRUPT SERVICE SUBROUTINE

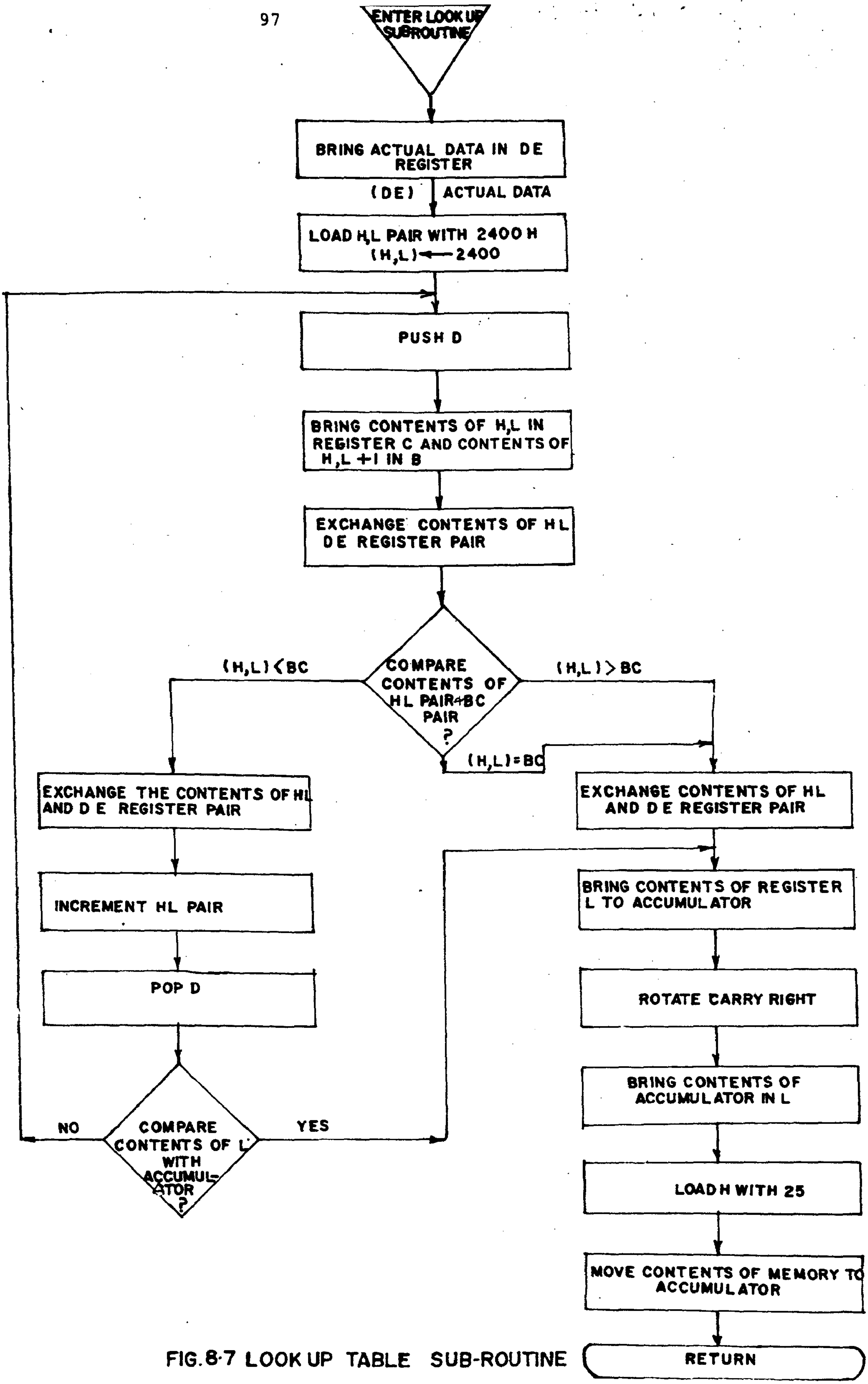


FIG. 8·7 LOOK UP TABLE SUB-ROUTINE

latched for 50 pulses and is being read on fly. This count value is stored at proper address and lookup subroutine is called to see the corresponding value of temperature and value of temperature is stored at 22 I memory location where I is no of channel from 01 to 07 . When interrupt comes , the processor starts executing interrupt service subroutine .

(b). Interrupt Service Subroutine

First of all, the processor saves contents of all registers. The first interrupt will come immediately after the loading of counter "1" is done and the duration for for other interrupts is set in this subroutine for 100 ms that is, the demultiplexing is done with the help of interrupts. The time for each channel is controlled by interrupts for 100 ms. This value of 100 ms is obtained by loading counter "1" with 100 ms data , that is, 38402) D or 9602 H. When the measurement of the time period in all the seven channels has been completed, that is , I = 08, this subroutine will then reinitialise the channel counter to zero and memory location where address has been stored to orignal value.The counter 2 which measure the time period of 50 pulses is also loaded in this subroutine. Before returning from interrupt subroutine, processor restores all registers and enables the interrupt system to entertain next request.

(c). **Lookup Subroutine,**

The measured time period count for the 50 pulse is compared with the prestored count in the lookup table. The measured count is compared first with the highest count in the lookup table and if it is lower than this value it will compare with next lower value and if the value lies between these two values, it will give temperature corresponding to first value. If the measured count is still lower, it will repeat this process further untill the measured value, finds its comparable value. The temperature corresponding to this value will be displayed.

CHAPTER-9

CONCLUSIONS

A microprocessor based seven point temperature scanner has been developed and tested in this work. The different temperatures at the seven channels of the scanner were simulated with connecting resistances of different values as sensors. In one channel 4.7 K thermistor was used as sensor. Temperatures, after being converted into pulses of different frequencies were transmitted with Frequency Shift Keying Modulation. All the seven channels were demodulated and were scanned with the help of microprocessor which demultiplexes the seven channels and counts the time duration of fifty pulses in each channel. After comparing the measured value with the time periods available in lookup table, the temperatures are stored in different memory locations. The values of temperature stored in the locations got automatically modified with the changes in the temperatures or presisely the resistance of thermistor without changing any hardware in the transmitting end . The system may also give alarms or actuate relays for any preselected values of temperatures by slightly modifying the software and hardware at the receiving end .

The sensors of the scanner can be mounted at the time of manufacturing the motor and can easily be retrofitted. Because of difficulty in mounting the sensors at a later stage, it was not possible for the author to actually mount the sensors (thermistor) on motor and scan the temperature of the motor while running. In actual application the transmitter circuit can be mounted near the over hang of winding where cooling is better. Also, the military grade components are recommended. Because of thier higher temperature ratings. The stablised power supply for the transmitter circuit can be provided by the storage cell which can be replaced during planned maintenance or/and overhauling of the motor. Further work can also be done for providing stabilised power supply for the transmitter circuit either by stepping down dc voltage available in the rotor of dc motor or converting ac voltage of the ac rotor into dc and stepping down in case of ac motors.This system can also be attached to a graphic plotter. By studying the day today plots , the condition monitoring of the motor for longer and trouble free life can be done. Also , the control signal from the microprocessor can be used for trouble shooting by connecting it to the alarm or the circuit breaker.

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APPENDIX

Temperature - Resistance , Time period, Frequency, Decimal count for 50 Pulse Chart

(FOR 4.7K THERMISTOR)

Temperature (Dg C)	Resistance (K	Time period	Frequency (KHz)	Decimal count for 50 pulse	Hexa equivalen
26	4.595	66640	1.504	51182.795	C7EF
27	4.51	63140	1.584	48494.623	BD1F
28	4.29	62370	1.6	47903.229	BB1F
29	4.16	60550	1.65	46505.376	B5AS
30	4.01	58450	1.711	44892.473	AF5C
31	3.87	56560	1.768	43440.86	A9B1
32	3.7	54410	1.848	41559.139	A257
33	3.56	52150	1.918	40053.763	9C76
34	3.415	50120	1.995	38494.623	965F
35	3.345	49140	2.035	37741.935	936E
36	3.225	47460	2.107	36451.612	8E64
37	3.09	45570	2.199	35000.000	88B8
38	3.035	44800	2.237	34408.602	8669
39	2.925	43260	2.311	33225.806	81CA
~~40~~	2.83	41930	2.385	31451.612	7DCC
41	2.76	40950	2.442	31451.612	7ADC
42	2.69	39970	2.502	30698.924	77DB
43	2.645	39340	2.542	30215.053	7607
44	2.56	38150	2.621	29301.075	7275
45	2.49	37170	2.69	28548.387	6F84
46	2.405	35980	2.779	27634.408	6BF2
47	2.325	34860	2.869	26774.193	6696
48	2.26	33950	2.946	26075.268	65D8
49	2.205	33180	3.014	25483.871	6386
50	2.125	32060	3.119	24623.655	6030
51	2.10	31710	3.154	24354.838	5F0F
52	2.045	30940	3.232	23763.440	5CD3
53	2.000	30310	3.299	23279.569	5AF0
54	1.910	29050	3.442	22311.828	572B
55	1.877	28595	3.497	21962.365	55BA
56	1.833	27972	3.575	21483.871	53EB
57	1.772	27125	3.687	20833.333	5161
58	1.7245	26453	3.78	20317.204	4F5D
59	1.673	25732	3.886	19763.44	4D33
60	1.625	25060	3.99	19247.311	4B2F

Temperature(Dg.C)	Resistance (K)	Time period	Frequency (KHz)	Decimalcount for 50 pulse	Hexa Equivalent
61	1.5705	24297	4.116	18661.29	482F
62	1.509	23436	4.267	18000.00	4650
63	1.4765	22981	4.357	17650.537	44F2
64	1.431	22344	4.475	17161.29	4309
65	1.399	21896	4.567	16817.204	41B1
66	1.364	21406	4.672	16440.86	4039
67	1.323	20832	4.800	16000.00	3E80
68	1.2945	20433	4.894	15693.548	3D4E
69	1.2605	19957	5.011	15327.957	3BD0
70	1.212	19278	5.187	14806.451	39D6
71	1.175	18760	5.330	14808.602	3849
72	1.1475	18375	5.442	14112.903	3721
73	1.121	18004	5.554	13827.957	3604
74	1.094	17626	5.673	13537.634	34E2
75	1.0685	17269	5.791	13263.44	33CF
76	1.0495	17003	5.881	13059.139	3303
77	1.018	16562	6.038	12720.43	31B0
78	0.986	16114	6.206	12376.344	3058
79	0.9565	15701	6.369	12059.139	2F1B
80	0.9305	15337	6.520	11779.564	2E04
81	0.9065	15001	6.666	11521.505	2D01
82	0.881	14644	6.829	11247.311	2BEF
83	0.8615	14371	6.958	11037.634	2B1F
84	0.8365	14021	7.132	10768.817	2A11
85	0.812	13678	7.311	10505.376	2909
86	0.7955	13447	7.437	10327.957	2844
87	0.779	13216	7.567	10150.537	2746
88	0.753	12852	7.781	9870.967	268F
89	0.736	12614	7.928	9688.172	25D8
90	0.718	12362	8.089	9494.6236	2517
91	0.703	12152	8.229	9333.333	2475
92	0.689	11956	8.364	9182.7657	23DF
93	0.6635	11599	8.621	8908.6021	22C3
94	0.632	11438	8.743	8784.9462	2251
95	0.634	11786	8.939	8591.3978	218F
96	0.6185	10969	9.117	8424.7311	20E9
97	0.605	10780	9.276	8279.5698	2058
98	0.589	10556	9.473	8102.9185	1FA7
99	0.5753	10367	9.646	7962.3655	1F1A
100	0.560	10150	9.852	7795.6989	1E74

Temperature – Resistance, Time period, Frequency chart

(For 10 K Thermistor)

Temperatu-re(Dg.C)	Resist-ance (K	Time period	Frequency (KHz)
26	9.54	135870	0.736
27	9.32	132790	0.753
28	9.14	130270	0.768
29	8.73	124530	0.803
30	8.36	119350	0.838
31	8.11	115850	0.863
32	7.83	111930	0.893
33	7.54	107870	0.927
34	7.27	104090	0.961
35	6.98	100030	0.999
36	6.70	96110	1.040
37	6.42	92190	1.085
38	6.17	88690	1.128
39	5.89	84770	1.180
40	5.67	81690	1.224
41	5.40	77910	1.284
42	5.19	74970	1.334
43	4.97	71890	1.391
44	4.80	69510	1.439
45	4.62	66990	1.493
46	4.45	64610	1.578
47	4.27	62090	1.611
48	4.08	59430	1.683
49	3.90	56910	1.757
50	3.78	53151	1.881
51	3.56	52150	1.918
52	3.46	50750	1.970
53	3.35	49210	2.032
54	3.23	47530	2.104
55	3.14	46270	2.161
56	3.02	44590	2.243
57	2.92	43190	2.315
58	2.86	42350	2.361
59	2.74	40670	2.459
60	2.66	39550	2.621

Temperatu-re(Dg.C)	Resist-ance (K	Time period	Frequency (KHz)
61	2.56	38150	2.621
62	2.49	37170	2.690
63	2.38	35630	2.807
64	2.32	34790	2.874
65	2.24	33670	2.970
66	2.18	32830	3.046
67	2.10	31710	3.154
68	1.94	39470	3.393
69	1.882	28658	3.489
70	1.863	28392	3.522
71	1.836	28014	3.569
72	1.798	27482	3.639
73	1.764	27006	3.703
74	1.730	26530	3.769
75	1.696	26054	3.838
76	1.662	25578	3.909
77	1.613	24892	4.0173
78	1.586	24514	4.0793
79	1.525	23660	4.227
80	1.506	23399	4.275
81	1.482	23058	4.339
82	1.464	22806	4.385
83	1.444	22526	4.439
84	1.428	22302	4.484
85	1.412	22078	4.529
86	1.392	21798	4.588
87	1.386	21714	4.605
88	1.376	21574	4.635
89	1.368	21462	4.659
90	1.354	21266	4.702
91	1.3235	20839	4.799
92	1.293	20412	4.899
93	1.275	20160	4.960
94	1.2575	19915	5.021
95	1.2345	19593	5.104
96	1.216	19339	5.172
97	1.193	19012	5.259
98	1.1665	18641	5.365
99	1.152	18438	5.424
100	1.1355	18207	5.4923