HALL EFFECT AND ITS APPLICATIONS

A DISSERTATION

submitted in partial fulfilment of
the requirements for the award of the Degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(Measurement & Instrumentation)

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1977

CERTIFICATE

CERTIFIED THAT the dissertation, "HALL EFFECT AND ITS APPLICATIONS", which is being submitted by Shri B. VASU, in partial fulfilment for the award of the Degree of Master of Engineering in Electrical Engineering (Measurements and Instrumentation) of the University of Roorkee, Roorkee is a record of bonafide work carried out by him under my supervision and guidance. The matter presented in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further certified that he has worked for 5½ months from January 1977 to July 1977 for preparing this dissertation at this University.

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A C K N O W L E D G E M E N T

The author wishes to express his profound gratitude to Shri H. K. Verma, Reader in Electrical Engineering, for his unfailing patience and guidance throughout the preparation of this work. He is thankful to Dr. Rao, Head of the Department of Electrical Engineering for extending all the facilities of the Department during the course of this work.

The author is also thankful to those who have helped him directly and indirectly for the completion of this work.

ABSTRACT

A detailed review of the Hall effect phenomena and their application is carried out. With basic mathematical relations the Hall effect phenomena and their applications in measurement of Electrical, Magnetic and Electronic quantities are explained. A critical analysis is made with respect to the important Hall effect application.

Some useful instruments have been developed in the laboratory using Hall effect and they are tested under laboratory conditions. These include True RMS meters for the measurement of current and voltage of nonsinusoidal waveforms exploiting the product forming capability of the Hall crystal. Since the available Hall multiplier packs had a large inductance some compensation technique had to be incorporated. It is found that the frequency dependence of the output of the multiplier can be reduced considerably using these compensation techniques. From calibration tests the performance of the meters is found to be satisfactory.

Electric and magnetic wave analyser is another instrument developed here making use of the Hall effect. Wave to be analysed is compared with a sinewave of known and constant amplitude and adjustable frequency, and different harmonics of the wave are measured using Hall

crystal. A voltage controlled oscillator (VCO) for generating sinewave of variable frequency has been developed. This is an entirely new approach to get pure sinewave since the usual method is to use a non-sinusoidal VCO in combination with suitable filter. The new circuit developed is especially important because of the low range of frequencies (40-650 Hz) possible with it. Frequency is controlled by using a FET whose Gate-to-source voltage is varied according to the requirements of the associated circuit.

A phase locked loop system (PLL) has been worked out to minimise the phase angle and frequency error between the wave to be analysed and the reference. It is found that if the difference in frequency is adjusted manually within 10 Hz, the circuit can automatically, by virtue of the negative feedback incorporated, synchronise the two frequencies. The wave analyser was tested using a square wave whose Harmonic contents are analytically known. The results are very encouraging.

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1. INTRODUCTION

Hall effect occurs when a transverse magnetic field is applied to a current carrying conductor resulting in an electric field which is perpendicular to the direction of the magnetic field and current and is proportional to their product. The crystal which exhibits this phenomena is called Hall crystal. It was discovered in 1879 by Hall[1] who questioned Maxwell's earlier assertion that "... mechanical force which urges a conductor carrying a current across the lines of magnetic field, acts, not on the electric current but on the conductor which carries it". Hall, using a gold leaf mounted on a plate of gold, was able to show that an electromotive force exists in the direction perpendicular to the direction of current and of magnetic field.

Even though the Hall effect was discovered by 1879, the real work on the application started by Nineteen Fifties (1950s). Prof. H.E.W. Barlow was the first to make use of Hall effect for measurement of power at low and Audio frequencies. The greatest advantage of Hall crystal is their ability to form the vector product. The advances in thin film high mobility semiconductors are related to increased utilisation and development of Hall effect devices.

Measurement of the true RMS value of current and voltage of a non-sinusoidal waveform is a problem encountered in the laboratories. The Hall crystal can conveniently be used for measuring true RMS values. The errors that might occur in conventional meters can be eliminated. Except at a very low frequency and at very high frequencies the Hall crystal characteristics are linear. In most of the electrical, electronic and communication systems this property of the crystal with the product forming capability is made use of. The output impedance of the crystal is usually of the order of ohms and so their could not be any matching problem.

Magneto resistance and Hall effect devices can be the answer for Engineers who must worry about the effect of high temperature or radiation on either conventional semiconductors or integrated circuits.

An upto date review of the literature and development of few instruments based on Hall effect was carried out by the author and same is reported here. The information is classified in several chapters.

In Chapter II a simple but detailed account of the Hall phenomenon is given. As far as possible only simple mathematical treatment is used to explain Hall effect and related phenomena. It is found that these simple mathematical relations give sufficient information to understand the working of the Hall effect devices. A detailed account of the limitations and capabilities of Hall crystal when it is used for measuring electric quantities are also brought out.

The different applications of Hall crystals are given in Chapters III and IV. The basic principle, instrumentation scheme and brief description are included where it is necessary. Some applications of Hall crystal in very high frequency and microwave engineering is also included in this report. Chapter IV also gives an elaborate description of Hall multipliers.

The details of the instruments developed and tested in the laboratory are given in Chapters V and VI. The instruments developed are the true RMS Ammeter, true RMS voltmeter and electric/magnetic wave analyser.

In the chapter on conclusion the author enumerates the actual difficulties encounted in the fabrication of instruments and how the performance can be improved.

Tabulation of the test results are given in the appendices.

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2. HALL EFFECT AND HALL CRYSTALS

The Hall effect and Magnetoresistance in solids are discussed in terms of the Lorentz force on current carriers. A detailed analysis of the material used in Hall effect devices and their limitations are explained.

2.1 Hall effect

The Hall effect, discovered in 1879 by Hall, occurs when a transverse magnetic field is applied to a conductor carrying current. Under these conditions it is found that in addition to the longitudinal electric field normally present a transverse field is produced so that the current (which continues to flow longitudinally) and the electric field are no longer parallel. The effect thus produces a measurable transverse voltage across the specimen. The cause of this effect is that the magnetic field exerts force on the electrons and deflect them sideways[1].

An introductory pictorial description of the Hall effect in terms of the particle physics is given. For making explanation simpler, the random velocities of the particles are neglected.

It means that after each collision they are brought to rest so that all the motion they acquire is produced by the applied fields. (It can be shown that the random velocities cancel out on the average, as they do for the case of conductivity). Under these assumptions, the motion of positive and negative particles in combined electric and magnetic field will be as shown in Fig. 2.1. A positive particle starting at the origin will be accelerated by the electric field. As it gathers speed, it is subjected to a sideways thrust by the magnetic field. This deflects its along the curved path until it suffers a collision and start over. The existence of the electromotive force perpendicular to direction of current and of the magnetic field is demonstrated by Hall using a gold leaf mounted on a plate of gold.

The physical significance of the Hall effect becomes apparent when the current is considered to be a stream of electron moving in a magnetic field $\bar{B}$ with a velocity $\bar{V}$ experiences the Lorentz force

$$F = e(\bar{V} \times \bar{B}) \qquad \ldots \qquad (2.1)$$

where, e is the absolute value of electron charge

Since the current is constrained by the boundaries of the solid, electron will at first be deflected by the magnetic flux density $\bar{B}$; soon enough, however, there is a built up of charges towards one side of the solid. This will create an electric field which will counter balance the Lorentz force acting on the bulk of the current carriers and current will continue to flow in its original direction as if unaffected by the magnetic field.

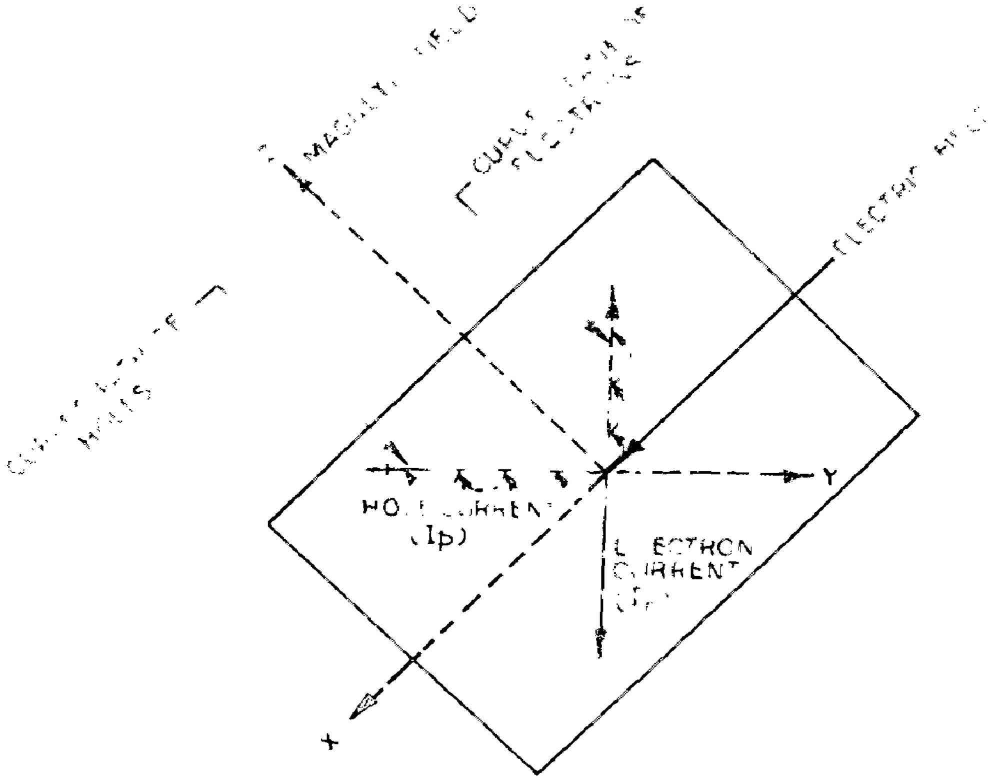

FIG 2.1 PICTORIAL DESCRIPTION OF HALL EFFECT

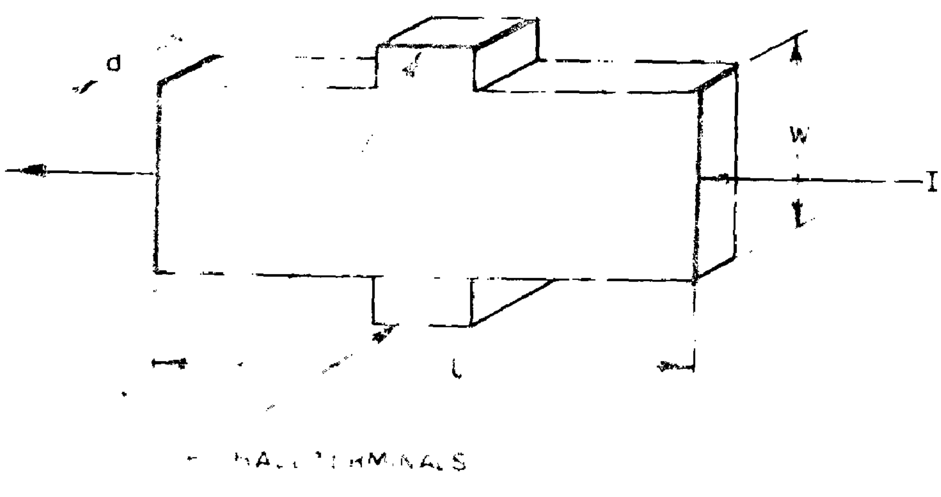

FIG 2.2 SCHEMATIC VIEW OF HALL ELEMENT

The time required to reach this equilibrium is of the order of 10^{-14} sec.

So the Lorentz force and electric field produced, known as Hall field, are same under equilibrium.

i.e. $\frac{E}{e} = \bar{V} \times \bar{H} = E_H$ ... (2.2)

The current density, $\bar{i} = ne\bar{V}$ ... (2.3)

where, n = density of the carriers

e = charge of the carriers

Rearranging

$$\bar{E}_H = \frac{1}{ne} iB \sin(\bar{i}, \bar{B}) \quad \ldots \quad (2.4)$$

(Current density i is characterised by a single electron velocity).

$$\text{i.e. } \bar{E}_H = R_H iB \sin(\bar{i}, \bar{B}) \quad \ldots \quad (2.5)$$

where, R_H is defined as the Hall Coefficient which is inversely proportional to the carrier density in the solid. Since the carrier density is always *less* in semiconductors than in metal this explains the fact that the Hall effect is more pronounced in semiconductors. In more complicated cases, when real solids are considered, the Hall coefficient becomes

$$R_H = K/ne \quad \ldots \quad (2.6)$$

The value of K depends upon the scattering mechanisms of the carrier in the solid, and its range is $1 < K > 2$. In most cases K, which varies also with the magnetic field, does not vary from unity by more than 30 per cent.

For more practical use it is necessary to express the equation (2.4) in terms of electric potential and the total current through the solid.

$$V_H = wE_H \qquad \text{(Refer Fig. 2.2)}$$
$$\text{and } I = ivd$$

By using relation (2.2) to (2.6)
Hall potential is given by

$$V_H = \frac{R_H}{d} \bar{I} \times \bar{B} \qquad \ldots \qquad (2.7)$$

(B and H are taken as linearly related).

In conjunction with Ohm's law $\sigma = ne\mu$ where σ and μ are the conductivity and mobility of the carriers respectively. The Hall effect can be used to measure mobilities and carrier densities. In semi-conductors in which electric conduction is obtained by a controlled and limited number of carriers, the Hall effect has played an important role as a measuring tool.

The equilibrium between the Lorentz force and the Hall effect field can be attained only for the case of current carriers with single velocity. In actual solids, and in particular in semiconductors, the carriers are characterised by a distribution of velocities. Hence, the Hall field balances out the Lorentz force for charge carriers having velocity nearer or average velocity. These charge carriers will, therefore, continue to move along the same path as in the absence of magnetic field. But the charge carriers having velocities considerably greater than the average velocity will be deflected either way. The deflected charges will now acquire smaller drift velocities between collision which will result in smaller mobilities and thus in increased resistivity. This change of resistivity is referred to as Magnetic resistance. A considerable larger change in resistance can be obtained if the Hall effect is eliminated.

2.2 Equivalent Circuit

Equivalent circuit is obtained by noting the basic phenomena that takes place. Describing those phenomena in mathematical form, and finally combining the individual parts by approximate matrix manipulation the equivalent circuit can be derived.[2] From equation (2.7)

$$V_H = \frac{R_H}{d} (\bar{I} \times \bar{B})$$

If I is constant

$$V_H \text{ is proportional to } \bar{B}$$

The closest conventional component is an ideal transformer having variable turns ratio. Output voltage is directly proportional to the magnetic field (Fig. 2.3).

Hall generator is a linear passive device and yet it has the additional property of not being bilateral. The device having this property is known as Gyrator. The representation of the Gyrator is shown in Fig. 2.4.

From Hall effect phenomena in a solid explained above is clearly an analog of the magnetic deflection in a cathode Ray Tube. Since this Hall effect is taking place in a solid the internal resistance should be taken into account. There are two internal resistances; the resistance to floor of the control current and the resistance to flow of the output current. Let us represent these two resistances by r_C and r_H respectively.

It is found that these resistances, are not constant but are varying with the applied magnetic field. The increase in resistance with the magnetic field is termed as the magnetoresistance effect and it is proportional to the square of the carrier mobility.

Approximately $r_C(B) = R_C(0) + 0.03\ B^{1.5}$

$$r_H(B) = R_H(0) + 0.03\ B^{1.5}$$

where, $r_C(B)$ = Control terminal internal resistance in ohms.

$r_H(B)$ = Hall terminal internal resistance in ohms

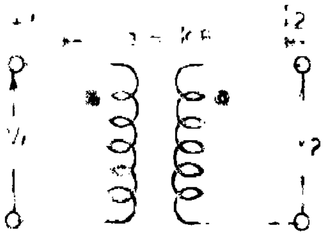

FIG. 2.3 IDEAL TRANSFORMER

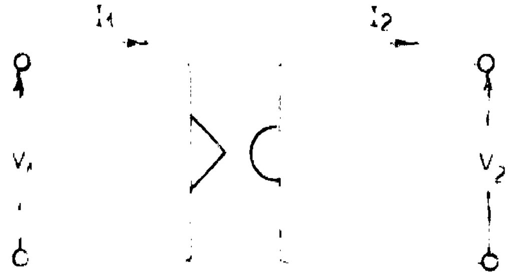

FIG. 2.4 GYRATOR

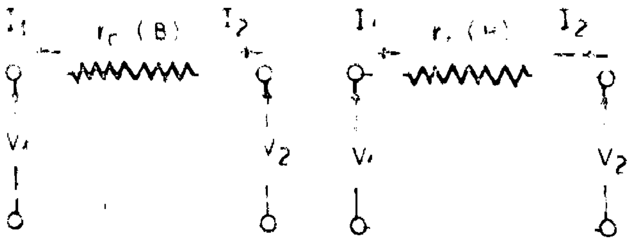

FIG. 2.5 INTERNAL RESISTANCE

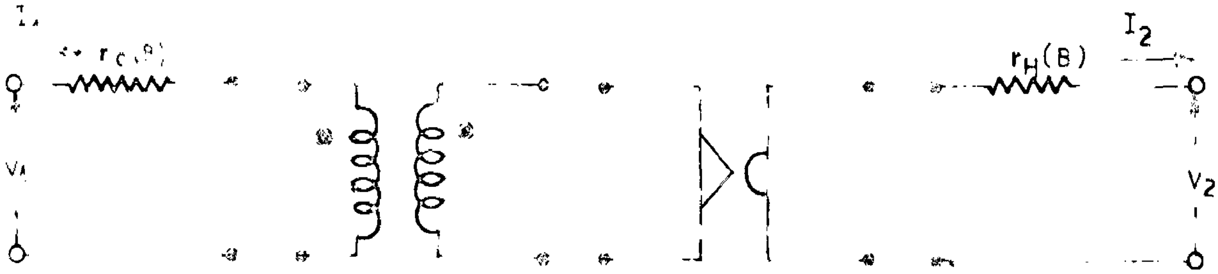

FIG. 2.6 CASCADED EQUIVALENT CIRCUIT

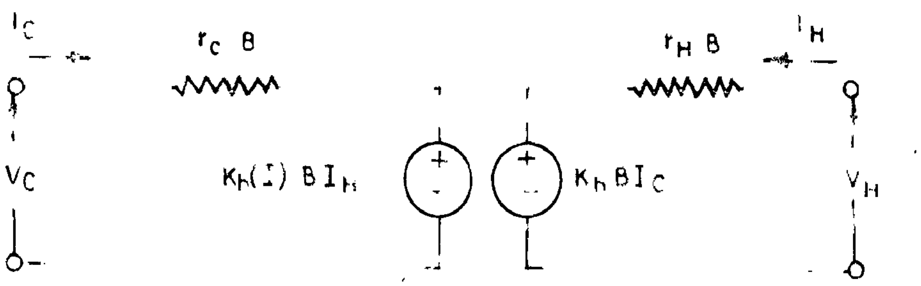

FIG 2.7 EQUIVALENT CIRCUIT

B = Magnetic flux density in kilogauss.

$R_C(0)$ = Control terminal resistance with $B = 0$ in ohms

$R_H(0)$ = Hall terminal internal resistance with $B = 0$ in ohms.

So the equivalent circuit can be drawn as shown in Fig. 2.5.

The four basic parameters, control terminal resistance, multiplier effect, Gyrator and terminal resistances are cascaded to get the overall equivalent circuit of the Hall generator effect (Fig. 2.6).

The four sections of the equivalent circuits can be used to simulate the overall Hall generator effect. After writing Matrix equations and multiplying and transforming the equivalent circuit can be drawn as shown in Fig. 2.7.

In the final equivalent circuit,

V_C = The voltage across control terminal

I_C = Control current through the control terminal

V_H = Voltage across Hall terminal

I_H = Current through the Hall terminal

B = is the instantaneous magnetic field density component that intercepts the Hall generator perpendicular to the plane of its control current.

$r_C(B)$ & $r_C(H)$ are defined previously

k_h = Hall constant = R_H/d

$k_h(I)$ = Inverse Hall constant

2.3 Choice of Material[3,4]

In considering the choice of material for the Hall element, a distinction is made between the requirement for the maximum power transfer and for the maximum output voltage. The current in an Hall element is limited by two factors which are the heat dissipation and permissible temperature of the crystal. The output power on the other hand related to the maximum permissible power input.

Power output (P_{out}) and Power input (P_{in}) are related by the following expression

$$P_{out} \propto \mu^2 B^2 P_{in} \qquad \ldots \qquad (2.8)$$

The output power is independent of the thickness of the Hall element. For the case of maximum voltage output the equation can be written as

$$V_H \propto \left[\frac{w \mu R_H P_{in}}{d} \right]^{1/2} B \qquad \ldots \; (2.9)$$

If the Hall element is cooled and the current is limited by the maximum permissible rise in temperature in the centre of the element ΔT, the output voltage is proportional to

$$V_H \propto (\mu R_H \Delta T)^{1/2} \frac{l}{d} B \qquad \ldots \qquad (2.10)$$

Equation (2.9) indicate that to get the maximum power output the Hall element should be made of material with highest mobility (μ). Intermetallic compounds of III-V group, Indium Antimonide and Indium Arsenide, have highest mobilities. Indium Antimonide can be prepared with the impurities of the order of 10^{14} cm^{-3} which can have a mobility of the order of 75000 cm^2/V-sec. at room temperature and as high as 500,000 cm^2/V-sec. at the temperature of liquid nitrogen. On the other hand the Germanium and Silicon, which can be prepared with even greater purities, exhibit very high Hall coefficients and can be shown to have the quantity $\sqrt{\mu R_H}$ somewhat higher than III - V compounds I_nS_b and I_nA_s. But the very high level of current noise will prevent Si and Ge from using them as Hall crystals. From equations (2.9) and (2.10) it is clear that for getting maximum output voltage the specimen should be made as thin as possible. There are other advantages also for thin elements. They are :

(1) Air gap of the magnet circuit can be made minimum.

(2) Due to the low resistivity of the inter-metallic compounds, in particular I_nS_b, thick specimen have very low resistance and often requires bulky transformers to utilise their low noise capability when used in conjunction with conventional amplifiers.

(3) At very high frequency operation thin element reduce the eddy current.

The fabrication of thin Hall element from bulk I_nS_b and I_nA_s, which is most desirable as far as material characteristic are concerned, is very costly. By mechanical method it is impossible to make specimen thinner than 10 μm. For getting very thin specimen several technique of vacuum deposition of I_nS_b and I_nA_s were utilised. The most successful depositions were obtained by utilising the 3 temperature method, wherein the components I_n and S_b of the compound are evaporated in separate sources and the substract maintained at still another temperature. A modified technique of flash evaporation was also reported to be quite successful in obtaining I_nS_b films of comparable quality. Here the only drawback is that the mobility is reduced by one third.

Recent work on recrystallisation of evaporation I_nS_b films indicate that still higher mobilities can be obtained. Other technique of anneling of evaporated I_nS_b rendered very thin films (about 1 um) with useful mobilities. A scheme to obtain thin films by squeshing molten bulk I_nS_b was suggested but, so far, appears to be inferior to the latest method of recrystallisation. The recrystallisation techniques are capable of providing thin film of I_nS_b with mobilities in the range of 30000 - 40000 cm^2/V-sec and thickness of 1 - 3 um. The Hall coefficient of such film at room temperature is about one half its value for bulk I_nS_b, approximately 10.5×10^{-4} m^3/C. However, the combined effect of thickness of the evaporated Hall element and its material parameters in recrystallized film does not provide the best fabrication technique for most Hall effect devices.

When sensitivity is not a compelling factor in the choice of material but other considerations, such as temperature stability, prevails mixed compounds of the III-V group have been employed. Also, in very special applications, other high mobility compounds of the II - VI group e.g. H_gS_e and H_gT_e are considered.

In the Hall effect multiplier a magnet core is also provided in addition to the Hall crystal. Hall crystal is placed in the air gap of the core. The core is made up of Ferrite material.

2.4 Limitations of Hall effect Devices

As in other types of electronic devices the Hall effect device also exhibits current noise. This noise is known as generation recombination noise or 1/f noise. The current noise which appears at the output terminals of the Hall element is due to the following two mechanisms :

(1) Hall effect noise is produced similar to the Hall potential, due to the product of the current and the magnetic flux density.

(2) Hall terminal noise which is present at the output terminal of the Hall element in the absence of magnetic

field and is due to the current flow only. It should be noted that this noise is present even in the case of perfect balance of the Hall terminals ie when the current flow in the Hall element does not otherwise produce a potential difference at the output terminals. The magnitude of the noise depends also on the shape of the Hall element, and, for typical specimen with high length to width ratio of 2 to 4, the noise levels are of the same order of magnitude as those measured across the entire length of the element in the direction of current flow.

The subject of noise in the Hall element plays a very important role in the choice of material. The intermetallic semi conductors, and in particular I_nS_b are characterized by an unusually low level of current noise which is in sharp contrast to the high level of noise in Ge and Si. On the other hand, very thin Hall element with large effective surface-to-volume ratios are known to exhibit current noise otherwise not present in bulk specimens. In case of evaporated film of I_nS_b and I_nA_s surface conditions and grain boundaries in the material contribute to 1/f noise.

It is of interest to note that the limitations in the sensitivity imposed in the Hall effect device due to low frequency current noise remain even in the case of alternating control current in the Hall element, e.g. in the case of an amplitude modulation, where the current in the Hall element represents the modulating signal and the magnetic field represent the carrier, the low frequency noise will still appear within the band width of the desired output signal. Only in a few cases, such as a superhetrodyne Convertor or mixer, where the output signal is in the IF band and is therefore far removed in frequency from both the incoming RF signal and the local oscillator, can low frequency effect be eliminated.

In addition to the current noise, a list of some other limiting factors in the performance of a Hall effect devices follows :

2.4.1 Ohmic Residual Voltage

This voltage due to, primarily, the misalignment of the output terminals. Nonuniformity in the Hall element also contribute to this effect. Later is due to the nonuniform power dissipation in the device which is very difficult to correct. A mathematical analysis of the voltage due to the misalignment is given somewhere[5].

2.4.2 Induced Voltage

Magnetically induced voltage is another source of disturbance. The inductive null voltage (Induced Voltage in the output circuit of the Hall element by the varying magnetic field) induced control voltage (Induced potential in the control current circuit by varying magnetic field) and mutual inductive coupling between input and output circuit of the Hall element are more obvious.

2.4.3 Magneto Resistance

The Hall element internal resistance may vary due to the magnetic field. This variation in resistance produce some undesirable noise.

2.4.4 Thermo electric and thermomagnetic effects

These effects are due to longitudinal thermal gradients in the Hall element and transverse magnetic field[5]. Since temperature variations are relatively slow, these effects can be neglected in other than static or very low frequency applications, of Hall effect devices. An analysis of this is given somewhere[5].

By enclosing the Hall generator in an epoxy resin considerably reduces the thermo electric effects. In an a.c. system it also possible to eliminate the thermo-electric effect by proper coupling networks.

2.4.5 Sensitivity and Linearity

Even with linear matching the relationship between Hall voltage and control field is not ideal[6]. Sensitivity is also varies with different type of elements.

The linearity error due to non-linearity of Hall voltage as function of the field current together with temperature error and the zero output field voltage constitute the main part of the total error of the multiplier

2.5 Capabilities of Hall Effect Devices[7]

The capabilities of the Hall effect devices are

(i) By this device the magnetic induction can be directly measured, not the rate of change of same.

(ii) The Vector product properties provide a convenient angle resolver technique.

(iii) A high linearity, four quadrant multiplication are also possible.

(iv) A Hall device exhibits non-reciprocal transfer characteristics and is useful in Gyrator, Isolator etc.

(v) The output is electrically isolated from one input with an absence of coupling from output back into the input circuit.

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3. APPLICATIONS OF HALL CRYSTAL

The advances in thin film high mobility (of the order of 10,000 cm^2 V-Sec.) semiconductors are related to the increased utilization and development of Hall effect devices. Several applications of the Hall effect devices to measurement, communication and control are discussed in the present and next chapters. The limitation of these devices are also brought out where relevant.

The applications are classified into the following five categories:-

1. Measurement : Applying crystal alone
2. Application of Hall probes with associated magnets
3. Application of Hall probes with flux concentrators
4. Application of Hall effect multipliers
5. Specialized applications

The applications with the first three categories are taken in this chapter°

3.1 Measurement : Applying Crystal Alone

3.1.1 Measurement of Magnetic field :

Hall crystal is placed in the magnetic field whose amplitude is to be determined. A constant current (control current) is passed through one pair of the terminal of the

°The applications of Hall multipliers and specialised applications are the subject matters of the next chapter.

Hall crystal. The voltage available at the output terminal is

$$V_H = K\ i\ B\ \cos\theta \quad \ldots \quad (3.1)$$

where, V_H = Hall output voltage

K = Proportionality constant

B = Flux density

θ = Angle between control current and flux

By applying known flux the instrument can be calibrated.

Magnetometers have been built and a number of commercially available units offer measurement ranges from a fraction of Gauss to many kilo gauss[7]. Since the detecting probes are available in miniature size (1.0×10^{-2} cm) they are particularly applicable for measuring air gap flux of motors, generators, relays, speaker magnets etc. They are also used for the study of magnetic property of materials.

3.1.2 Sensors for magnetic control

A magnetic field can be maintained constant by using the Hall voltage supplied by the Hall effect devices located in the magnetic field. The output of the Hall device is compared with a reference signal and using the error signal to actuate a control device which adjusts the current supplied to the magnet. Manufacturers claim that field regulation better than 5 parts in 10^7 can be secured with Indium Arsenide Phosphide probes. It should be recognised that instead of a reference signal a programmed input be used, to result in a prescribed time dependent magnetic field. The system arrangement is as shown in Fig. 3.1.

3.1.3 Sensors for microwave power

Power in wave guides and coaxial transmission lines can be measured by using Hall probes. The power associated with transmitted wave is proportional to the product of the E-field and H-field[3]. The E-field causes a current to flow in the device which is influenced by the H-field . Dielectric matching and elimination of thermal effect are the major problem in this measurement.

In a coaxial line the Hall element is mounted between the central and outer conductors with the plane of the element perpendicular to the field generated by the current in the central conductor. The device current is then, is related to the voltage difference between conductor while the field is related to the flow of current, therefore the output is proportional to the time dependent product of the current and voltage.

In practice millivolt outputs are secured with power in the order of few hundred milliwatts at X-band, 10,000 megacycles.

3.2 Application of Hall probe with associated magnets

In this section we are considering the applications

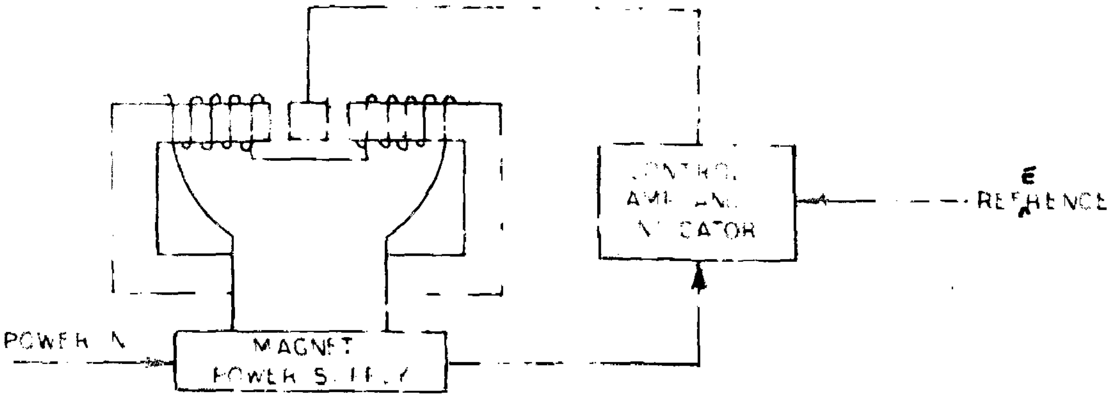

FIG 3.1 MAGNETIC CONTROL

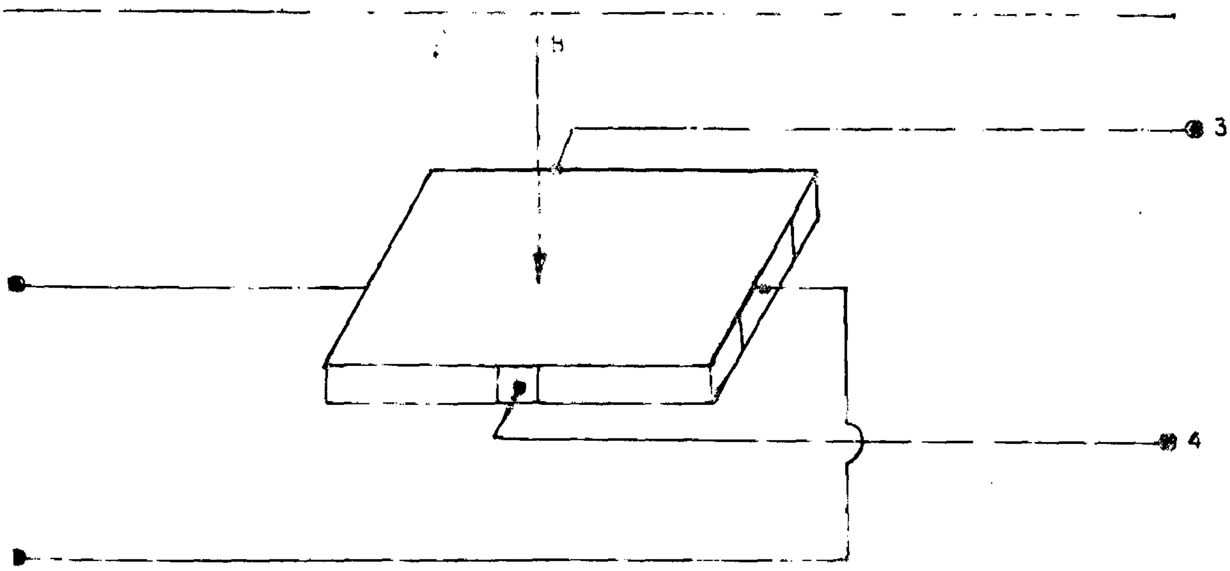

FIG. 3.2 GYRATOR

with constant magnetic field. This constant magnetic field is obtained by permanent magnet or by electromagnet with constant excitation.

3.2.1 Gyrator

A Gyrator is an antireciprocal 4 pole device. A simple Gyrator is shown in fig. 3.2. When a voltage V_1 is applied between 1 and 2, the output is KV_1 across 3 and 4, while V_1 is applied between 3 and 4 the output across 1 and is $-KV_1$. To get a Gyrator action from a Hall crystal the applied field must maintain constant.

3.2.2 Isolator

An Isolator is described as a non-reciprocal four pole device in which one of the two transfer impedances is zero. It can transmit signals in only one direction.

The Gyrator can be converted into isolator by the use of proper external shunting resistance. With carefully adjusted resistance a forward loss of 7.5 db and a reverse loss of "the order of 100 db" has been obtained for Indium antimonide.

3.2.3 Displacement Transducer

The Hall effect displacement transducers devices of all types utilises the dependence of the Hall voltage on flux density of magnetic field acting perpendicular to the Hall plate. The flux density variations are realised by changes of position of the Hall generator with respect to the field. Good sensitivity has been reported for separation as much as 5 cms between the line joining the pole faces and the probe line of movement.

The non-conducting nature of such transducers has generated interest in elevator applications and various production process. Different types of arrangements are tested[9].

3.2.4 Function Generator

Sine and cosine functions can easily be generated by using a Hall crystal. From the basic expression (3.1) it is clear that the output voltage is proportional to the cosine of the angle between I and B provided they are kept constant.

For getting cosine function the Hall crystal is placed perpendicular to the field for reference. Then the crystal is rotated and the output voltage gives the cosine function.

If the Hall probe is rotated by 90° at the reference then the output voltage will be proportional to the sine of the angle of rotation from this point.

It is necessary that the control current be maintained constant and the magnetic field be uniform throughout the volume occupied by the Hall probe during its rotation.

3.2.5 Resolvers

Two function generators are used as shown in Fig. 3.3 to make a resolver which can be used to measure angular position in terms of electrical output. One of the function generators are rotated 90° with respect to the other at the reference position. Both are coupled to the same shaft which is rotating at an angular velocity ω°/sec.

Angular rotation in the order of a minute has been measured.

3.3 Application of Hall probes with flux concentrators

Mainly Ferromagnetic materials are used as the flux concentrators. This concentrators will pick up the flux with the combination of Hall crystal it is possible to enhance it or to integrate it in order to determine the exciting current.

3.3.1 Ammeters[5,6,7]

Hall effect magnetic sensors can be used to measure D.C. currents in the conductor without interrupting the current carrying conduit. The Hall crystal is mounted in a slot of a permeable ring surrounding the wire, the current flowing through which is to be determined. The magnetic material effectively integrates the magentic induction around the closed circuit and the Hall probe can be calibrated to indicate the d.c. current by its d.c. output.

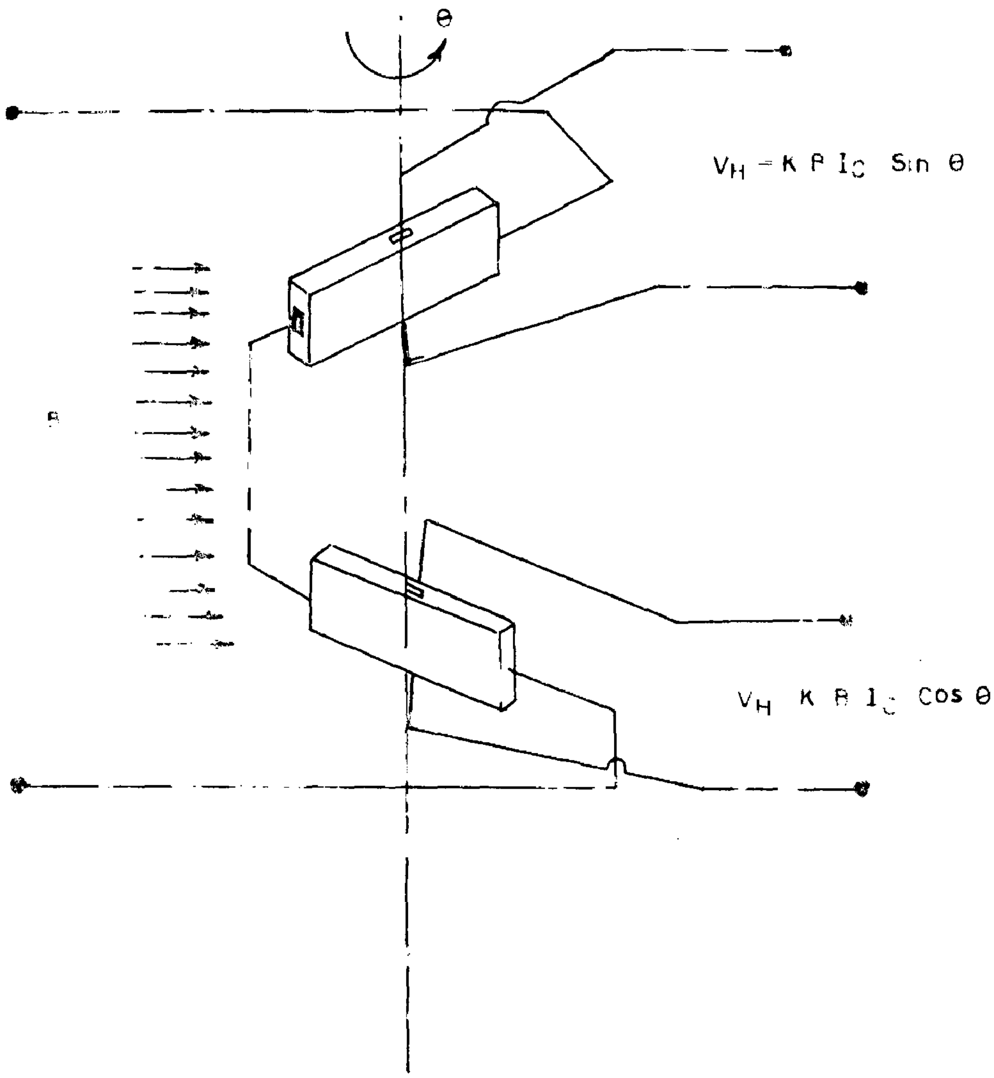

FIG 3 3 RESOLVERS

Current transducers capable of measuring current from a few milliampere to several hundred kiloamperes have been constructed. An overall accuracy and linearity better than 2% is already reported. In certain cases accuracy in the order of 0.1 percent is possible. The general arrangement is shown in Fig. 3.4.

3.3.2 Magnetic compass

A Hall effect device together with linear magnetic concentrators may be used as a magentic compass as in the arrangement shown in Fig. 3.5. The output is proportional to the cosine of the angle between the axis of the concentrators and the applied magnetic field induction in a field region which is assumed to be uniform.

The role of the concentrators is to effectively amplify the magnetic field to a level which provides significant Hall output. Concentrators have been shown to be useful in securing field enhancements in excess of 100.

In order to ensure maximum directional sensitivity it may be desirable to use the Hall compass at a null point with a high gain system.

3.3.3 Magnetometer

This is similar to the magnetic compass explained in section 3.3.2. The only difference is that the amplitude of flux is measured in the place of angle. This is especially

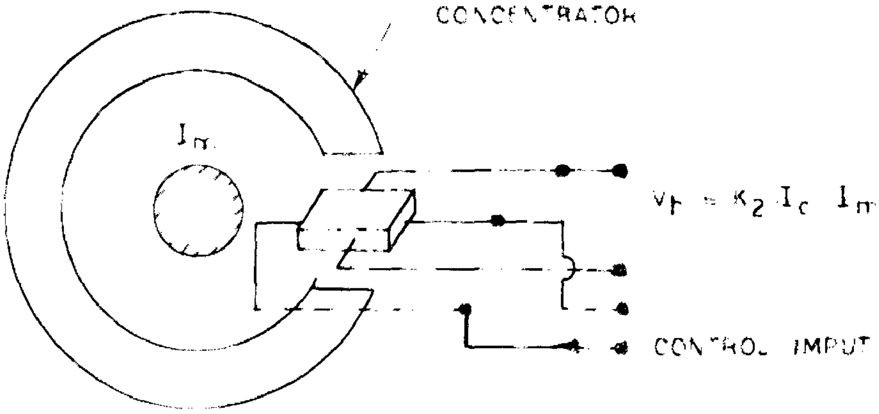

FIG. 3 4 HALL EFFECT AMMETER

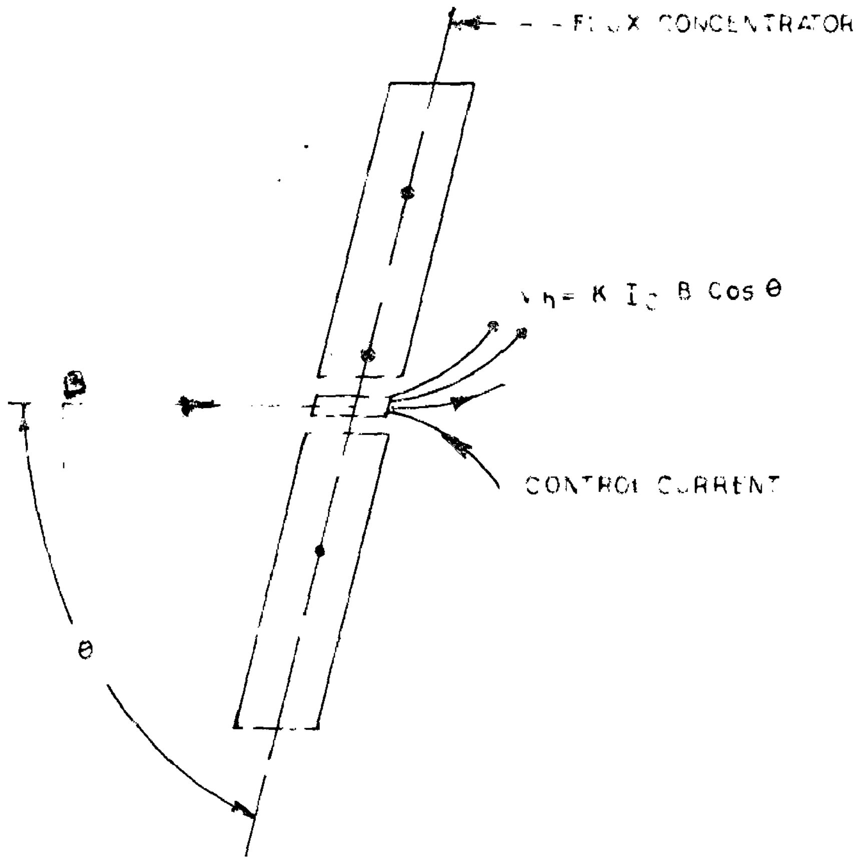

FIG 3 5 MAGNETIC COMPASS

useful to detect low level magnetic fields. The basic arrangement is shown in fig. 3.6. At liquid nitrogen temperature, − 196° C, magnetometers have been built which provides an output of 1 V/G.

3.3.4 Impedance Relay[10]

The circuit diagram of the relay is given in Fig. 3.7. The Hall e.m.f. V_H appears across the resistor R_H, whose value is large compared with the terminal resistance of the crystal. (The output voltage of Hall crystal consists of a d.c. component and an a.c. component twice the supply frequency. V_H represent only the d.c. components). V_H is normally balanced against the corresponding time average, V_B, of the output from the square law rectifier across R_3. In this circumstance, the voltmeter V shows no deflection, since we have established exactly the same condition as in the induction type of the relay.

In the event of a fault, the line current rises and the impedance at the point at which the relay is connected falls. Thus, $\bar{V}_H$ becomes larger than $\bar{V}_B$ and an out of balance voltage, V, appears which can be used to operate an ordinary electromagnetic relay. The inertia of the relay makes it incapable of responding to the a.c. component of V, and alternating current in this part is suppressed by inductance of the relay.

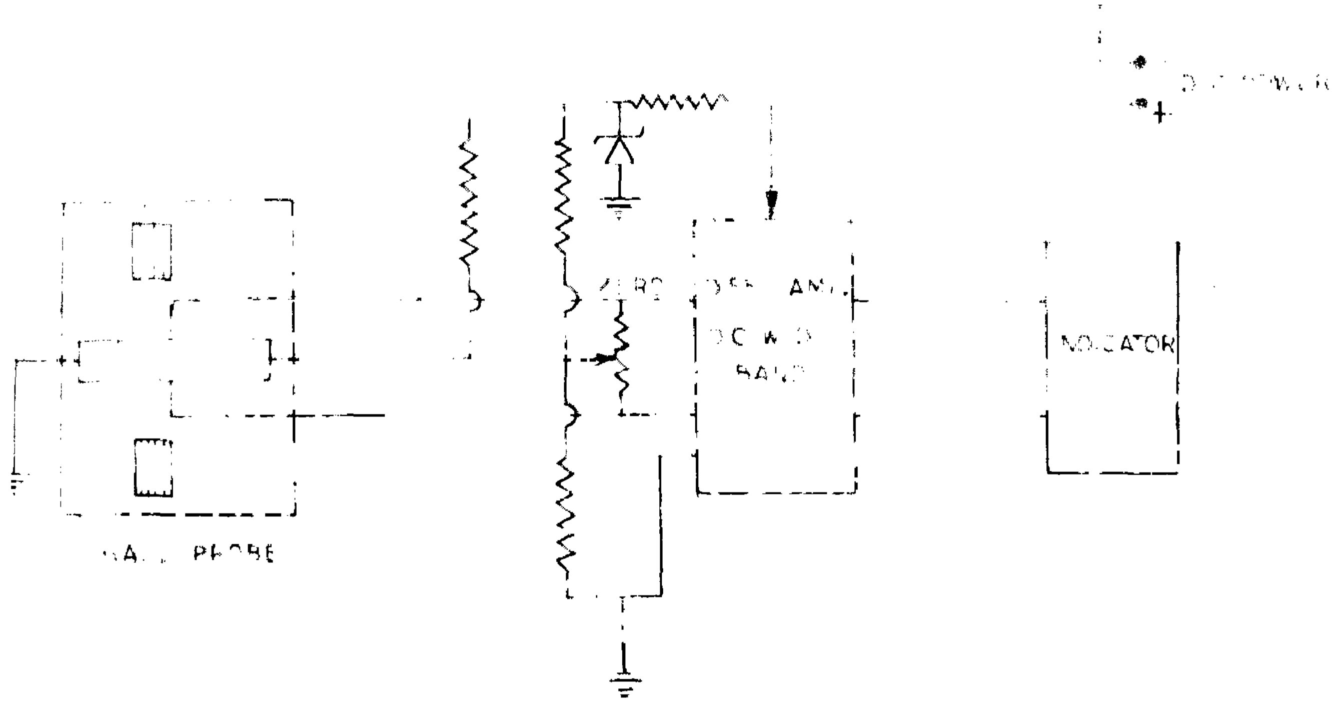

FIG 3 6 MAGNETOMETER

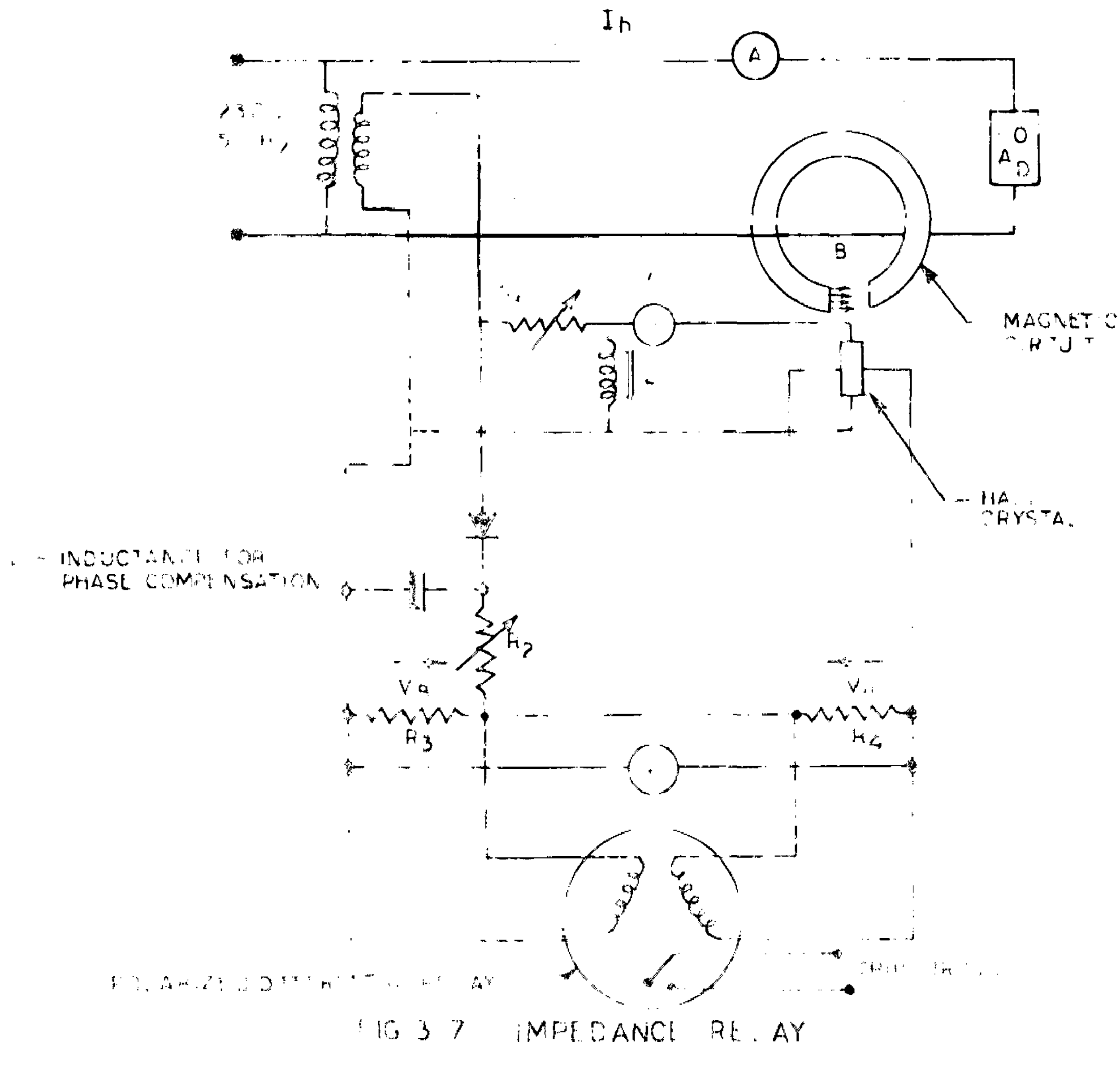

FIG 3 7 IMPEDANCE RELAY

In practice, it is convenient to use a polarised relay having two windings connected in opposition and excited respectively by $\bar{V}_B$ and $\bar{V}_H$. When the unbalanced m.m.f's are sufficient the relay operates and closes the trip circuit of a circuit breaker.

3.3.5 Magnetic tape read out[3,7]

In combination with a suitable magnetic concentrator unit the Hall probe provides a device which is sensitive to the magnetic field produced by tape rather than the usual rate-of-change of flux. This indicates that the same amplitude information is obtained whether the tape is stationary or in motion.

Because the magnetic fields are quite small and the structure introduces appreciable reluctance, the signals secured are relatively small.

—

4. APPLICATION OF HALL EFFECT MULTIPLIERS

Hall multiplier is a unit which combines the Hall probe with an electromagnet in such a fashion that the magnetic field can be produced by an exciting current applied to a winding on the magnetic structure. In this way the circuit designer has a packaged multiplier unit in which the inputs are electric currents.

The outstanding characteristics of the Hall effect multiplier is its ability to form products of two signals over a large range of amplitudes without the generation of a spurious signals. Hence unlike all other electronic amplifiers which utilises the nonlinear transfer character-istics of the device, the Hall effect multiplier is the only true or ideal product forming device. On the other hand, practical Hall effect multipliers suffers from a number of limitations, such as (1) Relatively small output signal which requires amplification, (2) The need to provide one of the inputs signals in the form of a magnetic field results in an inefficient use of power, in particular, when a wide range of frequencies of such signals is designed, (3) Induced potentials at the output of the device due to rate of change of magnetic field, (4) Potential difference at the output terminals due to their misalignment, or due to nonuniformity of the specimen.

4.1 Analog Multiplier

Analog multipliers using Hall generator are based on

$$V_H = K_1 K_2 \, I_c I_m \quad \ldots \quad \ldots \quad (4.1)$$

where, V_H - Hall Voltage

K_1 - Proportionality Constant

K_2 - The transfer function of magnetic circuit to relate I_m, the coil current, to B, the flux density.

I_c - Crystal (Control) current.

The Hall voltage is directly proportional to the product of the magnetising current and the Hall current. The accuracy is better than 1% .

Hall effect generators may also be used for performing other analog computer functions such as division, summation and subtraction. For performing division, a proper feedback arrangement is provided.

For multiplication the quantities to be multiplied are given to control terminal and magnetic field terminal, as shown in Fig. 4.1. Since either positive or negative signal may be accepted the unit is a 4 quadrant multiplier. For summation and subtraction control current is kept constant and the quantities to be summed are given to the magnetising windings provided.

A simple arrangement for performing analog division

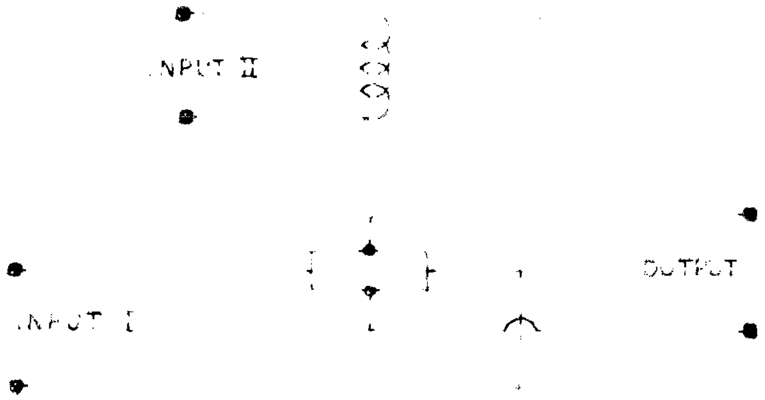

FIG 4.1 ANALOG MULTIPLIER

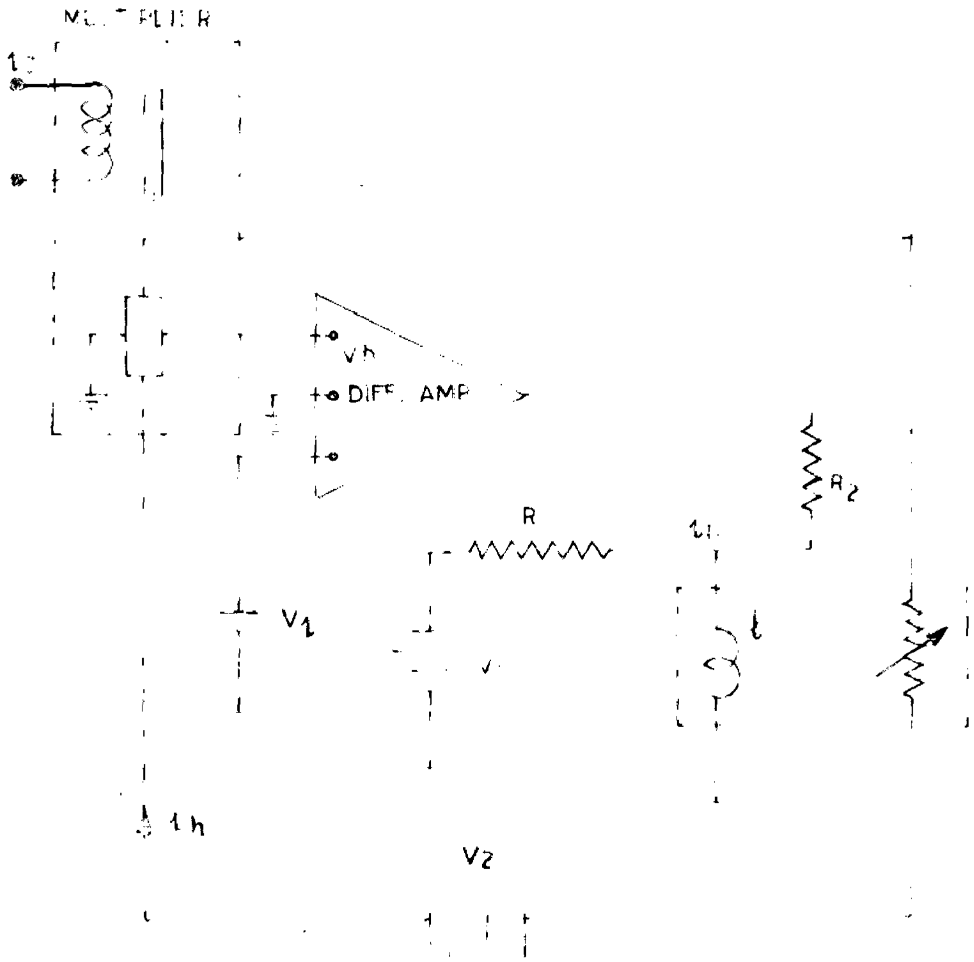

FIG. 4 2 ANALOG DIVIDER

is shown in Fig. 4.2

A differential amplifier is used to produce an output signal proportional to the difference between an arbitrary input signal V_i and the Hall voltage V_H. The amplifier output is applied to the resistance R_2 in series with the lamp l. The light intensity of the lamp controls the magnitude of the photo resistor r which is in series with the voltage source V_2 and consequently controls the Hall current i_h. The electrooptic device, completes the feedback loop around the amplifier and also isolates the input from the output circuit of the Hall plate. The bias made up of V_1 and R_1 is used for setting the lamp in l at a maximum closed loop power gain and minimum control power requirement.

Let $i_c = 0$ then $V_h = 0$, therefore, $V_i = \propto i_{ho}$

where $\propto$ is a constant and i_{ho} is the initial Hall current. Let magnetic field be developed by a current i_c applied to the solenoid. A Hall voltage V_H will develop across the Hall plate and the high gain negative feedback loop will be in balance when

$$\propto i_{ho} = Ki_h i_c \qquad \ldots \qquad (4.2)$$

Consequently, in quiescent state, the Hall current is proportional to the ratio of the input voltage to the magnetising current

$$i_h = V_i/Ki_c \qquad \ldots \qquad (4.3)$$

This I_H can be measured by using a low resistance precision galvanometer.

Some modifications of the above circuit to obtain reciprocal of a quantity and quotient of two currents are discussed somewhere[11].

If one input to the multiplier is sinusoidal with a constant amplitude and other input is a low level d.c. signal the output is sinusoidal but has an amplitude which is proportional to the d.c. applied. A convenient chopper to convert low level d.c. signal into a.c. signal results. The approximate equation is

$$V_H = K_1 K_2 I_c I_m \sin \omega t. \qquad \ldots (4.4)$$

4.2 Phase Detector

Hall multiplier can be used as a phase detector. If a sinusoidal signal is applied to the control input and another sinusoidal signal of the same frequency but with an arbitrary phase shift is applied to the coil input an output is secured with a d.c. component proportional to the cosine of the phase difference between the input signals.

$$\text{If } I_c = I_1 \sin \omega t \qquad \ldots (4.5)$$

$$I_m = I_2 \sin (\omega t - \phi) \qquad \ldots (4.6)$$

$$\text{then } V_H = K_1 K_2 \frac{I_1 I_2}{2} \left[\cos \phi - \cos (2 \omega t + \phi)\right] \ldots (4.7)$$

It should be noted that both d.c. term and an a.c.

signal of twice the input frequency occur. It is a simple matter to filter out the a.c. term and secure a d.c. term which indicates the phase relationship.

4.3 Wattmeter[12, 13]

Hall multiplier have been utilised in the design of wattmeter for signals over a very wide range of frequencies. In the case of low frequencies the field producing and control current represent the current and voltage respectively, of the measured signal. The average value of the output voltage of the Hall effect device is proportional to the average of the measured power. Suitable precautions must be taken to avoid the phase angle error.

At high frequencies, several GH_z, the Hall element can be used to measure the power of the electromagnetic field, or, more specifically, the Poynting Vector, which is the vector product of the electric and magnetic fields. In this case the control current is obtained directly from the electric field component of the electromagnetic field when the Hall element is placed in a resonant cavity, however, the device is then a narrow band instrument, requiring accurate tuning of the cavity.

In a low frequency device if a 90° phase shift is introduced into the voltage input by appropriate circuitary, reactive power or KVA can be measured.

4.4 Frequency deviation meter

A frequency deviation meter can be formed by arranging the magnetic circuit input so that the relative phase shift is a function of frequency when driven by a common source. A dc term will then be measured which is a function of frequency. The output can conveniently be made a linear function of frequency deviation.

4.5 Modulator[7,14]

Subject to the limitations discussed earlier, the Hall device still remains the only ideal electronic multiplier. The approximate expressions for the inputs are

$$I_c = I_1 \sin w_1 t$$

$$I_m = I_2 \sin w_2 t$$

The output becomes

$$V_H = \frac{K_1 K_2}{2} I_1 I_2 \left[\cos (w_1 - w_2)t - \cos(w_1 + w_2)t \right]$$

i.e. the output contain sum and difference of the input frequency component, but either input signal components are missing. This is a double side band suppressed carrier modulator output. In practice over 70 db carrier suppression has been obtained. Two specialized applications are possible

By using two Hall effect balanced modulators in quadrature can yield an effective generator for single side band suppressed carrier signal. The output of one modulator contains a double side band suppressed carrier signal while the other modulation provides an output of identical frequencies and amplitude except that the phase of each component is shifted by 90°.

The output of the two modulators are

$$V_1 = \frac{K_1 K_2}{2} I_1 I_2 \left[\cos(w_1 - w_2)t - \cos(w_1 + w_2)t\right] \quad \ldots \quad (4.8)$$

$$V_2 = \frac{K_1 K_2}{2} I_1 I_2 \left[\cos(w_1 - w_2)t + \cos(w_1 + w_2)t\right] \quad \ldots \quad (4.9)$$

$$\therefore \quad V_1 + V_2 = K_1 K_2 I_1 I_2 \cos(w_1 - w_2)t \quad \ldots\ldots \quad (4.10)$$

which is the lower side band of the modulator signal.

The success of the above method of single side band suppressed carrier modulator depends primarily on the capability of generating modulated signal without any component due to intermodulation. Hence, the product forming characteristics of the Hall effect multiplier can be applied here to great advantage. The block diagram is shown in Fig. 4.3. The generator has been found capable of providing single side band modulation of audio signals from 300 to 3000 hz with the suppression of unwanted side band as high as 30 db below the desired signal.

Another case of special application is the phase modulation. Her the carrier is provided in the magnetic field and the modulating signal constitute the control current.

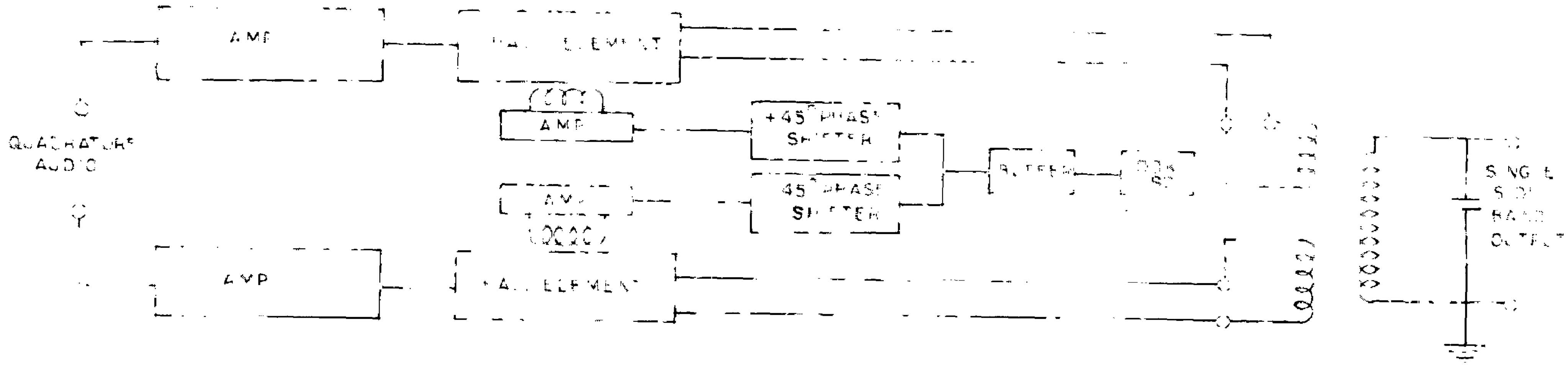

FIG 4 3 SINGLE SIDE LAND MODULATOR

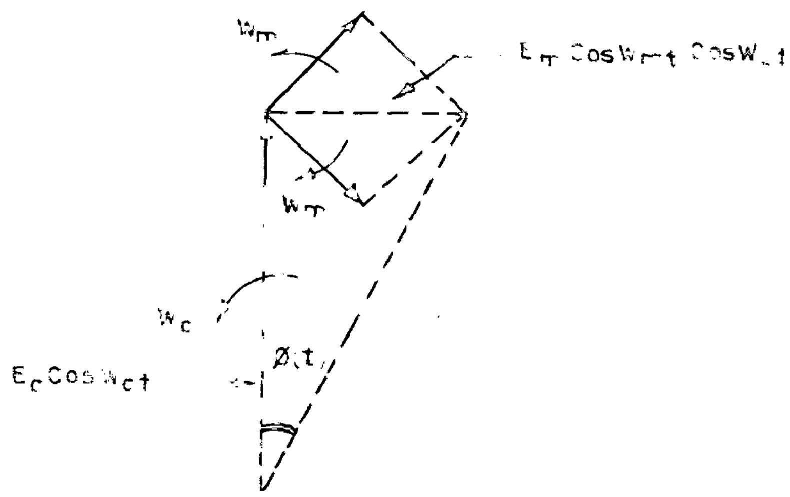

FIG 4 4 (a) PHASOR DIAGRAM

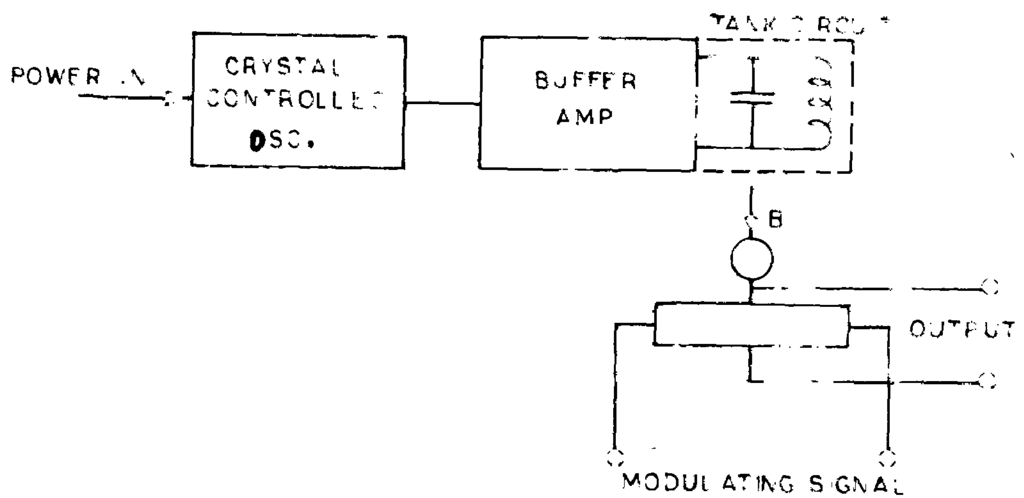

FIG. 4.4(b) SCHEMATIC DIAGRAM OF PHASE MODULATOR

The output of the Hall element, which represents the product of two signals, is added to the quadrature of the carrier. The latter can be obtained very conveniently by letting the output leads form a loop around the Hall element, and, thereby inducing a potential which is proportional to the rate of change of the magnetic flux density. Its major advantage is carrier frequency stability which can be obtained from a crystal controlled oscillator. The phase modulator represents an interesting application of the Hall effect device where in the usually deleterious induced voltage is utilised for advantages.

4.6 Demodulator

In this the incoming signal is applied to both the inputs. The Hall effect demodulator follows the square law. From the basic equation (2.2) it can be seen that

$$V_H = \frac{K_1 K_2 I_1^2}{2} - \frac{K_1 K_2 I_1^2}{2} \cos 2\omega t \quad \ldots \quad (4.11)$$

The Hall output signal, when filtered remove the a.c. component, is proportional to the square of the amplitude of the input signal.

If a linear detection is desired it may be obtained by applying the signal to be detected to one input and a signal of the same frequency, but constant amplitude to the other input. A d.c. output proportional to the input signal amplitude will be measured after filtering.

4.7 Phase Modulator

Phase modulation of sinusoidal signal, for small maximum phase deviation, can be obtained by the following method; the sinusoidal carrier is combined with the modulating signal in a balanced modulator and the output is added to a quadrature component of the original carrier. If the added quadrature signal is at least twice as large as the balanced modulated signal, the phase of the combined signal will be linearly related to the modulating signal. (Thus, the linearity can be achieved for phase deviation upto the order of 28^{o}). Fig. 4.4(a) shows a phasor diagram of p-m wave. The amplitude modulation of the resultant wave for a modulation index $m \leq .5$, does not exceed 6 per cent, and is periodic at twice the modulating frequency.

This method of phase modulation is already tested. Fig. 4.4(b) shows the schematic diagram of phase modulator.

4.8 True RMS measurement

When the field producing coil and the Hall element are connected in series such that the field producing and control current are the same, the output of the Hall element represents a square of the input signal. Such an instrument is very useful in the measurement of mean square values of signals of various (non-sinusoidal) waveforms.

Measurement of signals over a frequency range from zero to 250 k Hz are possible. The dynamic range of measured signal is limited on the low end by the noise at the output terminals of Hall effect multiplier and on the high end by the heating of the Hall element and nonlinear behaviour of the magnetic structure of the multiplier. Details of the fabricated meters are given in the next chapter.

4.9 Magnetic field spectrum analyser[3,15]

This spectrum analyser is intended for the study of low frequency electromagnetic field environment, such as produced by electrical machines, power lines, and transformers. In addition to this application, the analyser can be used in the measurement of the frequency spectrum of currents in conduit and electron beam.

In this application the field sensing and product forming capabilities of the Hall effect device are utilised at one and the same time. The Hall element is placed between two ferrite magnetic flux collectors to increase its sensitivity to the measured magnetic fields. The control current in the element is obtained from a voltage controlled oscillator by a saw tooth sweep generator. The latter linearly modulates the frequency of the control current, in 5 sec. period, and also provide a horizontal sweep signal for a CRT display. The output of the Hall element, which is the product of the sweep frequency current and the measured magnetic field, is then fed, through a narrow band filter and an amplifier to the vertical deflection plate of the CRT.

The instrument is capable of measuring magnetic field intensities of 0.5 μ G to 1 G, with dynamic range over 40 db at each setting of the scale. Its resolution is 10 Hz in a frequency range of 0 to 1000 Hz. Details of the circuitary is given in Fig. 4.5.

4.10 Frequency Spectrum Analyser

A Hall effect multiplier can be used to make a highly selectable frequency specturm analyser. The unknown signal is applied to one input and the other input is connected to a variable known frequency. A dc component will be measured when the input signal has a component at the same frequency and phase as the variable input. The exact phasing is a problem, and that can be overcome by some special technique.

The details of construction and operation of a frequency spectrum analyser is explained in the next chapter.

4.11 The Hall Effect Correlator

The basic principle of cross combolation is used in this correlator. The cross correlation of two random noise signal is equal to zero. This technique can be used to measure the desired signal from a large percentage of noise. The output of the two independent amplifiers are cross-correlated, the output signal is ideally zero, even in the presents of appreciable internal amplifier noise.

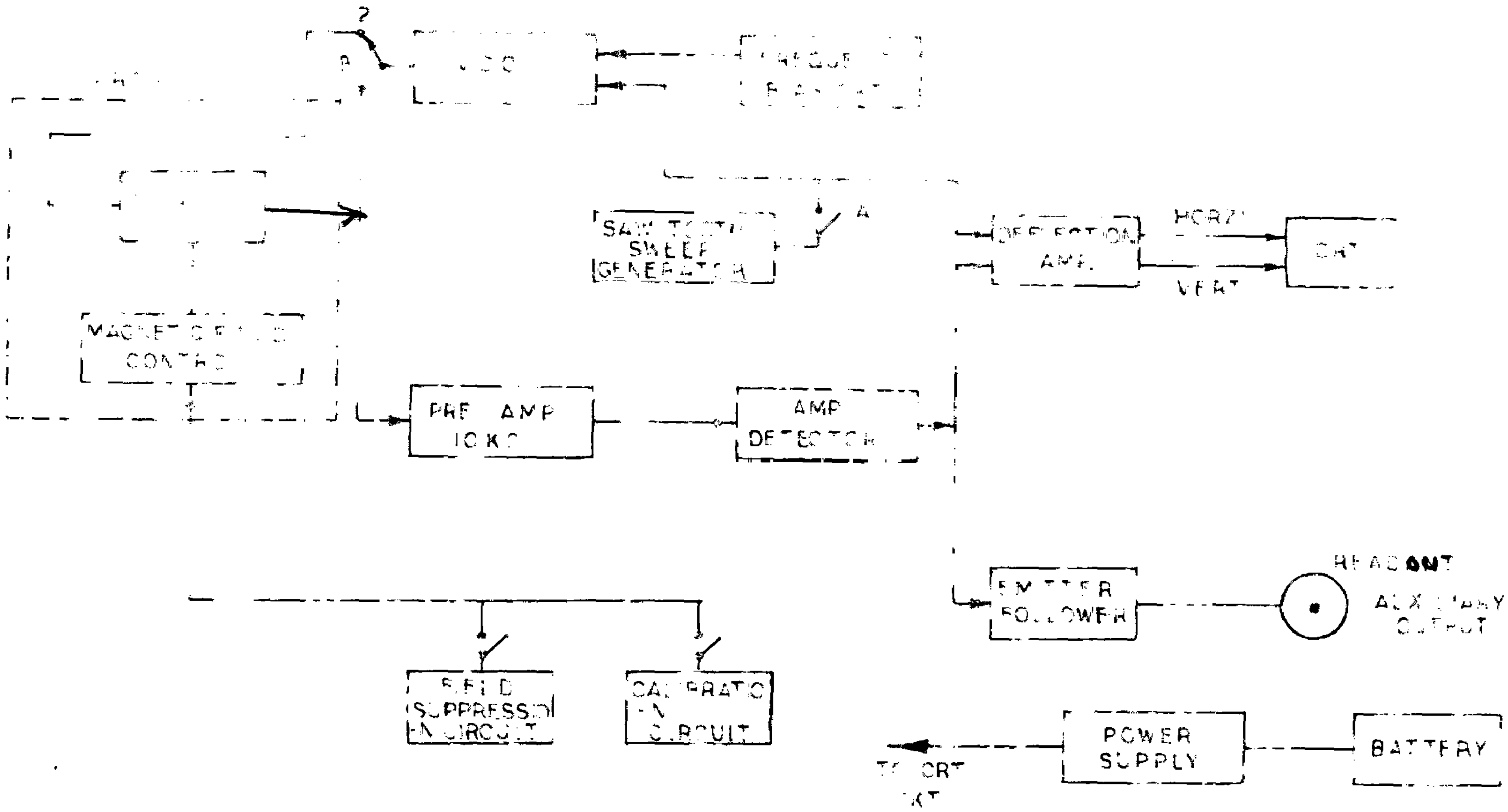

FIG 4.5 MAGNETIC FIELD SPECTRUM ANALYSER

Any signal presented to both amplifiers produces an output. So it is possible to detect signals levels which are much below the internal noise of the input amplifier.

This approach is particularly useful at low frequencies where 1/f noise in transistor seriously reduce the sensitivity of the practical amplifier.

The schematic arrangement shown in Fig. 4.6 is used to measure noise power spectrum in low noise/low impedance device. The output of one channel is applied to the field producing coil in the Hall effect multiplier, while the output of the other supplies the current to the Hall element. The output of the multiplier is then applied to d.c. voltmeter through a low pass filter.

The two major limiting characteristics of Hall effect multiplier, namely extraneous output signal due to electrode misalignment and inductive pick up, are of no consequence in the application. Since the signal at the output of the Hall element caused by misalignment of terminals is from one channel only, it is not contributing any output. The same applies to the inductive pickup which is caused by the signal in the field producing coil.

Let N_1 and N_2 are noise signal generated in each channel and n is the desired noise signal in the device, then the output of the correlator is given by

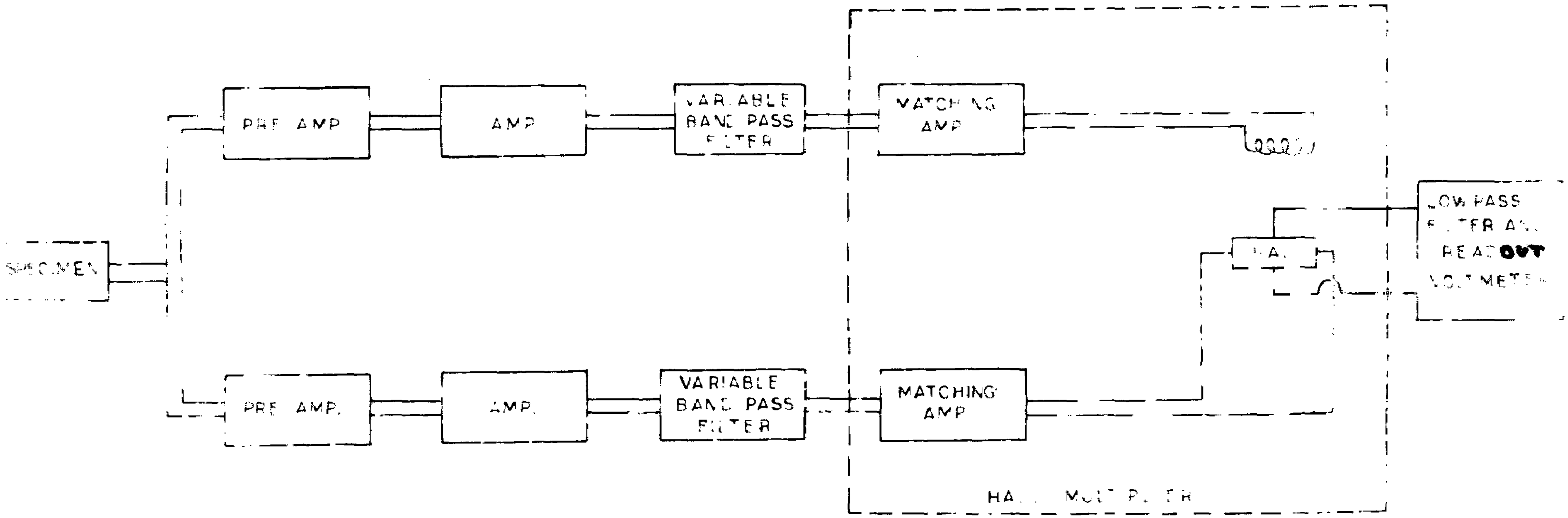

FIG 4.6 NOISE CORRELATOR

$$(N_1 + n)(N_2 + n) = (N_1 N_2) + (N_1 n) + (N_2 n) + (n^2)$$
$$= (n^2) \quad \ldots \quad (4.12)$$

Since N_1, N_2 and n are mutually uncorrelated and average of this product is zero, thus, the output of the correlator is equal to the mean square value of the measured noise signal.

It is of interest to note that the above technique of measuring noise power spectrum does not require that the two channels of the amplification and filtering be identical. Any phase shift or difference in gain which may occur in the two amplifiers and/or band pass filter can be accounted for by the calibration procedure usually employed in noise measurement.

Noise power spectrum in the range 10 Hz to 10 K Hz is analysed by this type of correlator. It is found to be capable of detecting input noise levels from 5 x 10^{-15} to $10^{-1.9}$ V^2/Hz which were two to three orders of magnitude smaller than the noise level of individual dual amplifier.

4.1[illegible] <u>Digital to Analog Convertor</u>

The arrangement of a Digital to Analog Convertor is shown in Fig. 4.7. The Hall crystal is supplied with a constant d.c. current. The digital inputs are given in the magnetic field input, the number of turns on the windings

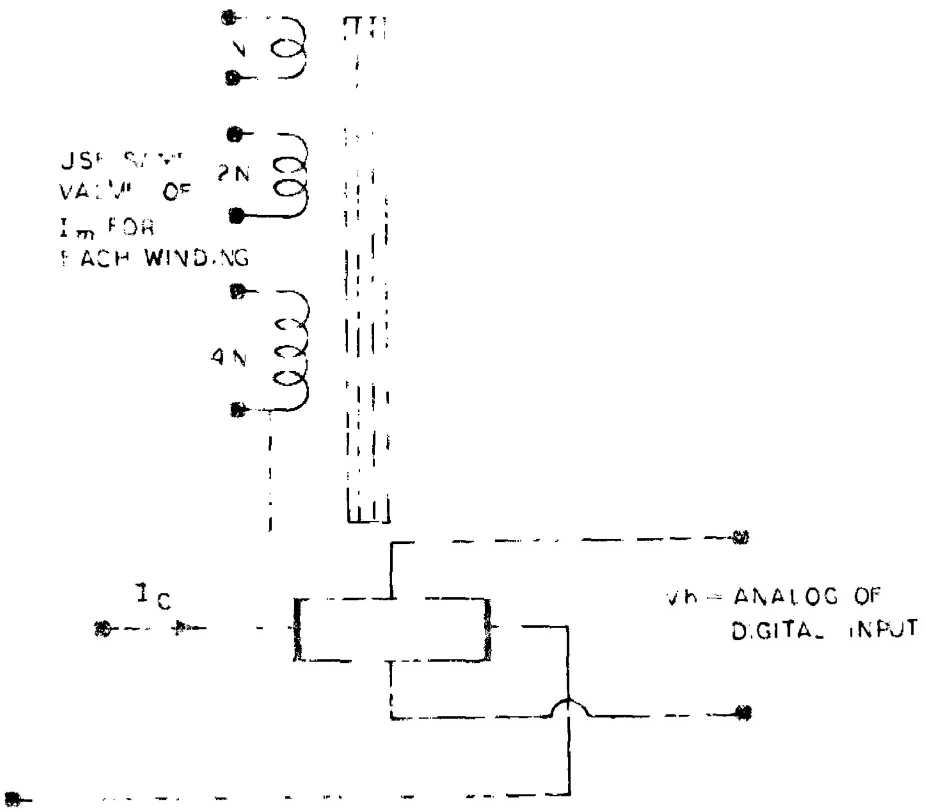

FIG. 4.7 D/A CONVERTER

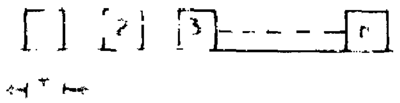

FIG 4.8(a) PULSES

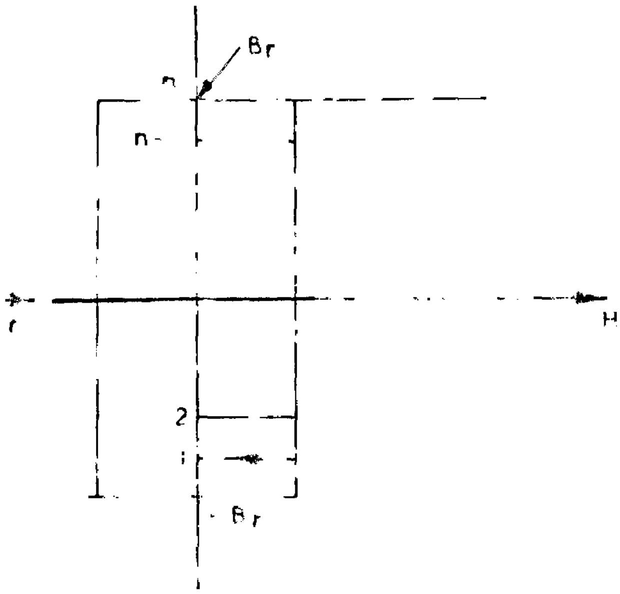

FIG. 4.8(b) MULTIPLE MEMORY ELEMENT

are arranged in the ratio of N, 2N, 4N, 8N etc. Each winding to be excited by the same magnitude of current. Hall output is the analog of the digital input to the magnetising winding.

The isolation of the various windings from one another and the output provides a significant advantage while the time of response of magnetic circuit limits the speed at which such a circuit can operate.

4.13 Multi level Memory Element[16]

The combined properties of Hall element and a square loop Ferromagnetic material is made use of. The magnitude of the output voltage is an indication of both the present state and the past history. The memory of the past will be provided by the remanent flux in the ferromagnetic material.

The Hall element is inserted in an airgap of the square loop magnetic material torroidal core.

The operation is based on the fact that the value of remanence Br in a square loop core is a function of the volt-time integral of the input pulses.

Let the core be at negative saturation ($-B_r$) as shown in Fig. 4.8(b).

Assume that the winding resistance can be neglected, the rectangular pulses of sufficiently small amplitude will be related to induced voltage by

$$E = \frac{N d\phi}{dt} \qquad \ldots \quad (4.13)$$

Thus the change of the flux level will be equal to the Volt-time integral of the input pulse

$$\Delta \phi = \frac{1}{N}\int_0^T E.dt \qquad \ldots \quad (4.14)$$

If the input pulses are applied in sequence, the core flux level (and hence the remanence) will increase until the positive saturation ($+ B_r$) will be reached.

If the pulse duration is T and the number of steps required to go from the negative to positive saturation is n, then,

$$nET = 2N\phi_s \qquad \ldots \quad (4.15)$$

$$n = \frac{2.N.\phi_s}{E.T} \qquad \ldots \quad (4.16)$$

With the proper selection of parameters, it is possible to achieve 'n' of the order of a few hundred. A direct electrical read out is provided in the Hall output.

Only problem with this arrangement is that it is difficult to obtain an ideal rectangular hysteresis loop.

4.14 Contactless Commutator

Signal voltage to be commutated are used to produce the magnetic field inputs to Hall generators[17]. Other input is switching current. Sampling rate is in excess of 30 K Hz is possible.

Fig. 4.9 shows two Hall generators connected for commutation of two dc signals. The d.c. input signals are converted to magnetic field strength. The second input is the control current and unless it is present the input signal does not appear at the output.

In Fig. two compensatory connections are also shown. The potentiometer R_2 applies a small amount of control current voltage to the output leads. These potentiometers are adjusted to produce zero output voltage from the Hall generator while the control current is flowing and the magnetic field is zero. This will compensate any inherent electrical unbalance (it is difficult to place the output leads exactly at null point). Potentiometer R_1 in combination with C_1 compensate for the spikes caused by induction. (Hall crystal is placed in within the air gap of split C-Core. Air gap minimises inductive effect of signal changes and reduces hysterisis effects). Special circuitary are used for sequential switching.

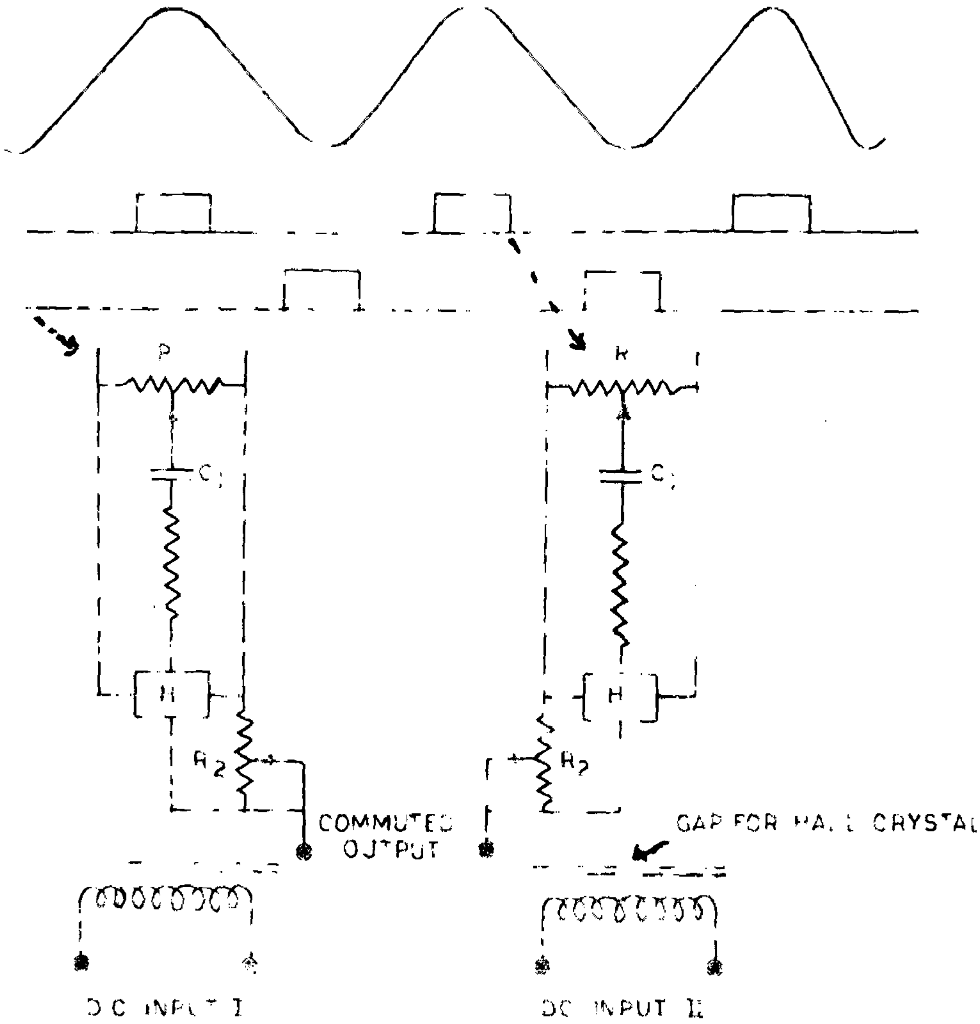

FIG 49 CONTACT LESS COMMUTATOR

4.15. Specialized Applications[6,16,19]

There are a number of specialized applications with Hall crystals. These include Hall effect Synchros, contactless signal transmission, Hall oscillators, etc. Elimination of winding, lamination, brushes and slip rings are advantages of Hall effect synchros.

Contactless signal transmissions are used for the repetition of motion steps in machine tools and a small brushless d.c. motor can be considered to be related to position information[11]. The Hall oscillation is produced by feeding back Hall voltage to the excitation of the magnetic field.

5. R.M.S. METER DEVELOPED USING HALL GENERATOR

5.1 True R.M.S. M. Meters for non-sinusoidal wave-form

The measurement of true RMS value of voltage and current of non-sinusoidal waveforms is a problem encountered in the laboratory very frequently. In the conventional meters, Moving iron and Electrodynamometer types, which are employed for the measurement of RMS value have got so many drawbacks. (Thermo electric meters are not considered here because of the very slow response, cramped scale, error due to differences in temperature of the working wire and the base of the instrument, inability to withstand overload, fragility and high power consumption). The drawbacks of the conventional meters are summarised as follows. The discussions hold good for Ammeters and Voltmeters.

In Moving iron meters the movement of the indicating mechanism is produced by attraction or repulsion, produced by the flux produced by the current[20]. The expression for torque produced is

$$T_d = 1/2\ I^2\ dL/d\theta \qquad \ldots \qquad (5.1)$$

where, I is the current through the coil

L is the inductance of the coil.

If there is no saturation, the change of inductance with the angle of deflection is uniform i.e. $dL/d\theta$ = a constant For such an instrument, the scale can be easily laid as the measured quantity is proportional to the square root of deflection. In actual instruments $dL/d\theta$ is not constant and is usually a function of angular position of the moving iron and thus scale is distorted from the square law in a manner depend upon the way in which inductance varies with angle. For the dynamometer type instrument also the same error exists. The torque produced in a electro dynamometer type meter is

$$T_d = I_1 I_2 \frac{dM}{d\theta} \quad \ldots \quad (5.2)$$

where, M is the mutual inductance between the fixed and the moving coils and $I_1 I_2$ are the current in the fixed and moving coil respectively. So $dM/d\theta$ factor will vary according to angle of deflection of the moving system and so the meter will not read the true RMS value. The variation of $dL/d\theta$ or $dM/d\theta$ became more unpredictable when a non-sinusoidal signal is given.

The error due to stray magnetic field (field other than the operating magnetic field) may be appreciable with weak operating magnetic field and hence the operating field get distorted. An external shield is required to reduce this stray magnetic field effect. This error is present in both moving iron and electrodynamo meter type meters.

Another error that usually occurs in the Moving Iron instrument is the frequency error. This frequency error consists of two components (a) Reactance of the instrument coil vary as the frequency, (b) Eddy current loss. The change of reactance of the instrument coil is important in case of voltmeter where an additional resistance R_s is used in series with the instrument coil. Let the resistance and inductance of the instrument coil be R and L. Then the current I in the instrument coil for a given voltage 'V' is given by

$$I = \frac{V}{\sqrt{(R + R_s)^2 + (\omega L)^2}} \quad \ldots (5.3)$$

So according to the change in the frequency the current flowing through the coil changes and hence introducing some error. At higher frequencies the deflection is less and at low frequencies the deflection is more for the same applied voltage. Therefore, when such a meter is used with non-sinusoidal waveforms, the presence of various harmonics would distort its response. The same calibration would, in other words, not hold good for different waveforms.

The eddy currents induced in the iron part of the instruments introduce some error in the conventional meters. The induced voltage E_e (= ωMI) due to current I. in the instrument coil lags the current by 90°. As a result of this induced voltage an eddy current I_e flows and its magnitude is

$$I_e = \frac{\omega MI}{\sqrt{R_e^2 + L_e^2 \omega^2}} \quad \ldots (5.4)$$

where, R_o and L_o are the resistance and inductance of the eddy current path. I_o lags E_o by an angle

$$\theta_o = \tan^{-1} \frac{wL_o}{R_o} \qquad \ldots \quad (5.5)$$

A component of this current $I_e' = I_e \cos (90 - \theta_o)$

$$= I_e \sin \theta$$

opposes the instrument current I and sets up an opposing field thus reducing the torque on the moving system.

At low frequencies the eddy current error increases with the square of the frequency while at a higher frequencies the error is practically constant. Thus it leads to an erroneous measurement on non-sinusoidal waveforms.

Low torque/weight ratio is the another cause of error in the Electrodynamometer type instrument. The magnetic field produced by air cored coils is essentially small and, therefore, the flux linkage per ampere in the moving coil are few (perhaps 3 to 4 per cent of the flux linkage per ampere in the permanent magnet moving coil instrument). Therefore the deflecting torque is low. Thus to produce a reasonable deflecting torque the m.m.f. of the deflecting coil must increase which can be done by increasing either the current through the coil or increase the number of turns. The current through the moving coil can not be increased beyond 200 mA as otherwise the spring would be heated too much. On the other hand, if the number of turns is increased its weight also increases and which results in low torque/weight ratio. A low torque/weight ratio indicates a heavy moving system and, therefore, the friction losses in electro dynamometer type of instrument are larger than in other types. Friction errors thus tend to be high.

Even though all the limitations cited above could not be eliminated in the true RMS meter developed in the laboratory using Hall crystals, further modification on this will definitely lead to a meter with higher order of accuracy on all waveforms. A comparison of the developed meter with the conventional meters are made in section 5.4.

5.2 True RMS Ammeter

The details of the true RMS meter developed in the laboratory are given in the following pages :

5.2.1 Principle

A Hall multiplier pack is the heart of the meter developed. This pack consists of a hall crystal and a magnetising winding as shown in fig. 5.1. The characteristics of the Hall multipliers HM 3030 (manufactured by BELL) used is given in Appendix 'A'.

When the field producing coil and Hall input circuit are connected in series, the output of the Hall

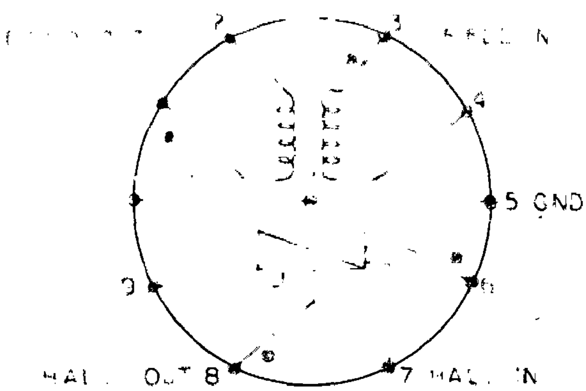

FIG. 5.1 HALL MULTIPLIER

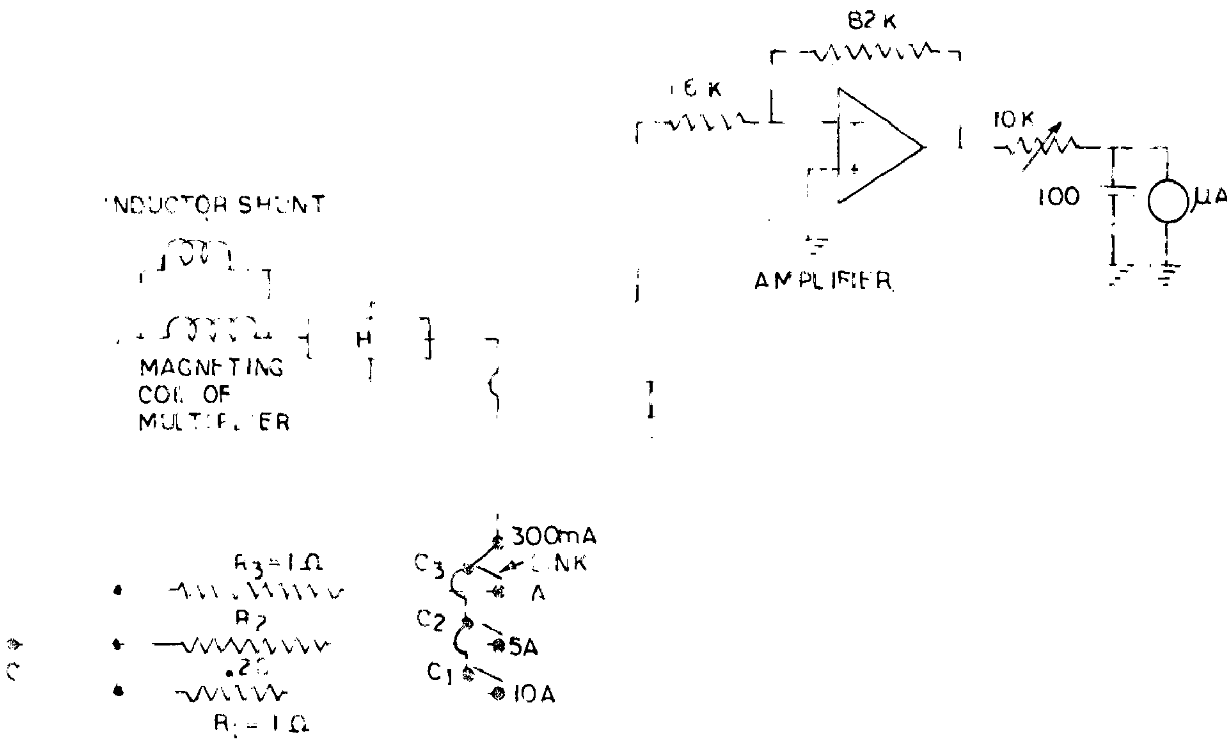

FIG. 5.2 COMPLETE CIRCUIT DIAGRAM OF RMS AMMETER

element represents the square of the applied signal[3].
From basic equation 2.7

$$V_H = \frac{R_H}{d} (I \times B)$$

$$\text{i.e.} \quad = K \, i_c \times i_m \cos \theta,$$

where, K is the proportionality constant

i_c is the instantaneous control current

i_m is the instantaneous magnetising current which produces the flux.

θ is the angle between i_m and i_c

Since $i_m = i_c$

$$V_H \propto i_c^2$$

i.e. the Hall output is proportional to the square of the input. The output voltage is measured by using a moving coil microammeter, the reading of which is proportional to the mean of the square value of the incoming signal. The scale of the meter is calibrated in terms of RMS values.

The Hall output, except for d.c. input, consists of a d.c. component and an a.c. component having double the frequency of the incoming signal. The average value of the a.c. component is zero and so the meter reading is proportional to the d.c. component which is related with the RMS value. As an illustration consider a pure sinewave

$$i_c = I_c \sin \omega t$$

$$V_H \quad I_c^2 \sin^2 \omega t$$

i.e.

$$V_H \propto \left(I_c / \sqrt{2} \right)^2 \left[1 - \cos 2 \omega t \right] \quad \ldots \quad 5.6$$

But for a pure sin wave $I_c/\sqrt{2}$ is the RMS value i.e. the d.c. component is proportional to the mean of the square value of the signal. Similarly, for all types of waves it can be proved that the d.c. value is proportional to the mean of the square value of the signal. If the micro ampere is not damped properly the a.c. ripples can be eliminated by using a simple capacitance filter.

True RMS voltmeter is also working under the same principle.

5.2.2. Circuit Diagram of Ammeter

The complete assembly of the developed meter is shown in Fig. 5.2. Since the maximum current rating of the multiplier pack is used is limited 300 mA, non inductive resistances shunts R_1, R_2 and R_3 are used to limit the current through the multiplier within safe limits. The values of the resistance shunt are .1 ohm, .22 ohm and 1 ohm and the corresponding full scale deflection values are 10 A, 5A and 1A. A range of 0 - 300 mA is obtained by not including any shunt.

The characteristic of the Hall multiplier clearly shows that its field coil has a very large inductance. If the compensation is not provided this will introduce frequency error. Hence the compensation is provided by using an inductor shunt which is connected across the magnetising winding of the multiplier. The inductance of the shunt is about 50 times less than the inductance of the magnetising coil. The R/L ratio of the shunt is kept equal to that of the field coil. By this arrangement, a major part of the current will flow through the shunt, so the voltage drop across the instrument is reduced considerably. The measured value of the voltage drop across the meter is about 1 V, at full scale deflection.

The output of the Hall crystal is amplified by using an inverting amplifier, having a gain of about 60. The amplifier output is filtered and then given to the moving coil microammeter. The ammeter scale is calibrated in terms the RMS value.

In addition to a common terminal, different terminals are provided for the various ranges of the instrument. The connection diagram is shown in Fig. 5.3. A link has to be placed between the terminal marked with the desired range and the corresponding C_1, C_2 etc.

No RMS responding meter was available in the laboratory, so it was decided to check it only on sinusoidal

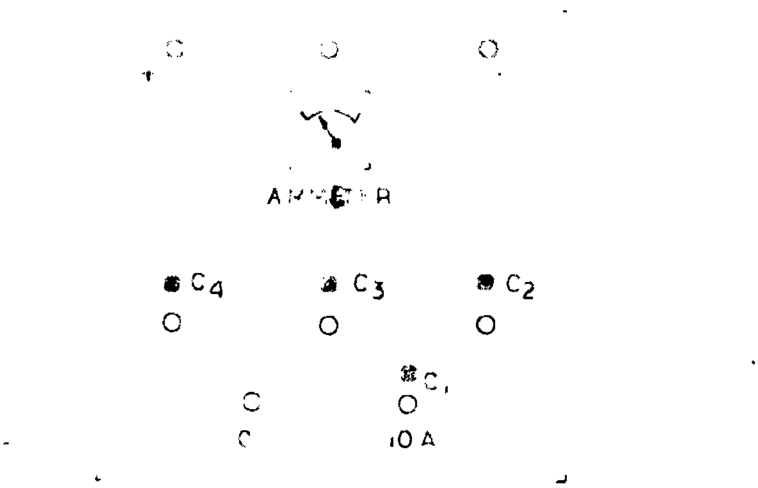

FIG. 5.3 a   TOP VIEW OF RMS AMMETER

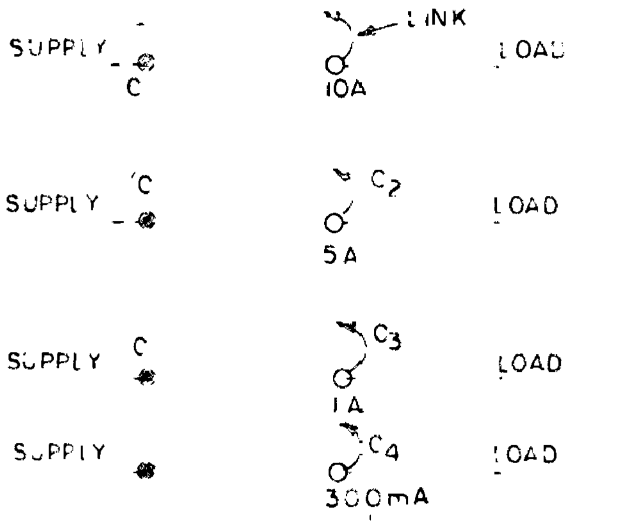

FIG. 5.3 b   CONNECTION FOR DIFFERENT RANGES

waveform at 50 Hz to ensure as the meter follows a square law. Accordingly, it was tested by using a substandard induction type meter.

5.2.3 Test Results

The test results are tabulated in the Appendix 'B'. Calibration curve drawn with micro ammeter reading versus square of the substandard meter reading having a straight line relation.

5.3 True RMS Voltmeter

The voltmeter assembled using Hall crystal it works on the same principle as the ammeter. HM 3050 Hall multiplier is used characteristics of which are given in Appendix 'A'.

5.3.1 Circuit Diagram

Complete circuit diagram is given in Fig. 5.4. Voltmeter has got 3 ranges, 220 V/110 V/75 V. The input impedance is increased considerably by connecting very large resistances in series with the input terminal of the multiplier. To eliminate frequency error the value of ωL must be very very small comparing to the resistance in the circuit. For different ranges different terminals, which introduce different resistances, are provided.

5.3.2 Test Results

The meter is calibrated by using a substandard electrodynamometer type voltmeter. The results are tabulated in the Appendix 'C' and a calibration curve is drawn as in the case of ammeter. The locus is found to be straight line which establishes the square law followed by the Hall multiplier used in the meter.

5.4 <u>Merits and Demerits</u>

From the discussion given in Section 5.1, it is clear that the conventional meters have so many limitations. Of course, all these drawbacks could not be eliminated in the meter developed. The error due to dL/dθ or dM/dθ is not present in the meter. Eddy current loss is minimum because there is no iron part in the magnetic field. Stray fields are eliminated by a shield provided in the multiplier. The low torque/weight ratio problem is not present in the meter.

Eventhough frequency error compensation is made the frequency range of the meter is limited because of the variation of reactance with frequency. Sensitivity depends upon the sensitivity of the microammeter and the gain of the amplifier. Use of the amplifier in the meter makes the latter bulky because of the power supply to be incorporated. It is a costly instrument because of the high cost of the Hall crystal.

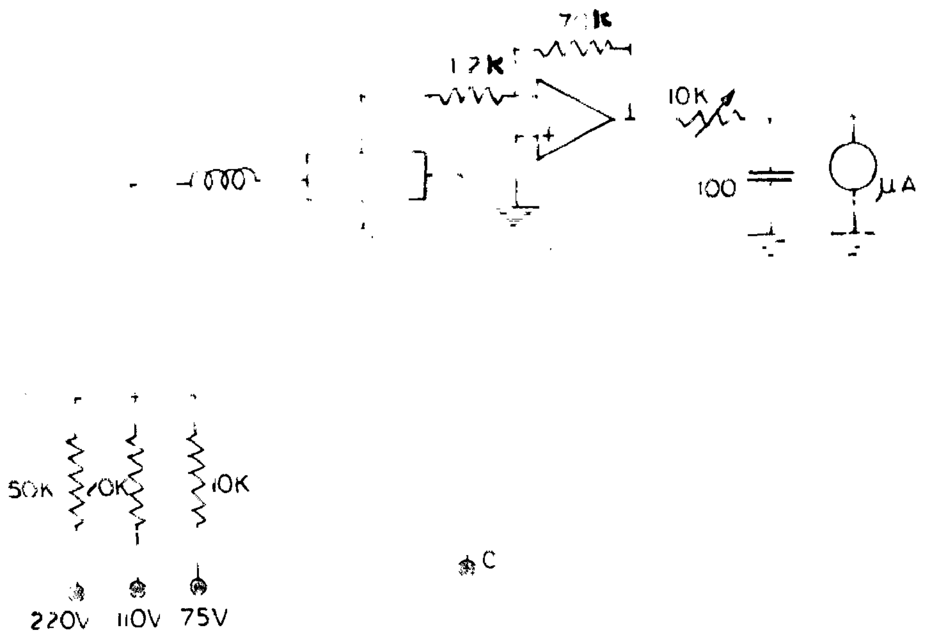

FIG 5.4 TRUE RMS VOLTMETER CIRCUIT

6. ELECTRIC AND MAGNETIC WAVE ANALYSER

The linear Hall effect demodulator may be used to make highly selective wave analyser . Basically, the electric and magnetic wave analysers are the same and so the circutary developed is applicable to both of them.

6.1 Principle of Operation

If the unknown signal is applied to one input of the Hall multiplier and the other input is connected to an available variable frequency source a d.c component will be measured when the input signal has a component at the same frequency and phase as the variable input. This can be shown by using the basic equation of the Hall multiplier.

If $I_1 \sin w_1 t$ and $I_2 \sin w_2 t$ are the instantaneous values of current in magnetic winding and the crystal respectively, then

$$V_H = K_1 \; i_m \; i_c \; \cos \theta \qquad \ldots (6.1)$$

$$\text{i.e. } V_H = K_1 I_1 I_2 (\sin w_1 t \sin w_2 t) \cos \theta \qquad \ldots (6.2)$$

where, K_1 is the proportionality constant and I_1 and I_2 are the peak values of the signal, and θ is the phase angle between I_1 and I_2.

Equation (6.2) can be rearranged as

$$V_H = \frac{K_1 \; I_1 I_2}{2} \left[\cos\,(w_1 - w_2)t - \cos(w_1 + w_2)t \right] \cos\,\theta \qquad \ldots \quad (6.3)$$

From the above equation it is clear that the output of Hall device has got a d.c. component only when w_1 is equal to w_2.

Under this condition, equation (6.3) reduces to

$$V_H = \frac{K_1 \; I_1 I_2}{2} \left[1 - \cos\,2\,w_1 t \right] \;\; \cos\,\theta \qquad \ldots \qquad (6.4)$$

If the value of I_2 is kept constant, which is possible by using proper control circuit, the d.c. component of the output is proportional to the maximum value of the signal applied to the magnetic field. Since the signals are taken from different sources the value of θ is continuously changing. It is necessary to keep the value of θ constant and preferably near to zero, which can be achieved by using a Phase locked loop circuit.[20,21] The Phase locked loop circuit (PLL) consists essentially of a phase detector, low pass filter, voltage controlled oscillator and a frequency divider.

A moving coil micrometer can be used to measure the d.c. output voltage and the reading on the meter can be calibrated in terms of different Harmonic content.

For electric wave analyser the Hall multiplier can be used directly. For the magnetic field wave analyser the field sensing and product forming capabilities of the Hall effect devices are utilised at one and the same time. The Hall element is placed between two Ferrite magnetic flux collectors to increase its sensitivity to the magnetic field.

6.2 Block Schematic

Block schematic of the Electric wave analyser developed by the author is shown in Fig. 6.1. The wave to be analysed is given to the magnetic winding of the Hall crystal. The same signal is applied to a zero crossing detector (ZCD) and the resulting output is differentiated and rectified so that positive pulses will come to one of the two inputs (point 1 in the block diagram) of the phase detector. The duration of the output pulse of the phase detector is equal to the phase difference between the incoming signal and the reference signal (Reference signal is given to point 2 in the diagram). As long as the frequencies of the two signals are not same and phase difference between them is not zero the output of the phase detector does not become zero. This output is given to an averaging circuit and the varying d.c. voltage thus available is fed back to correct the frequency of V.C.O. Because of this negative feedback the frequency of the V.C.O. is automatically adjusted in such a manner as to reduce the error signal to a minimum. The error is minimum when the two input pulses of the phase detector appear almost at the same instant.

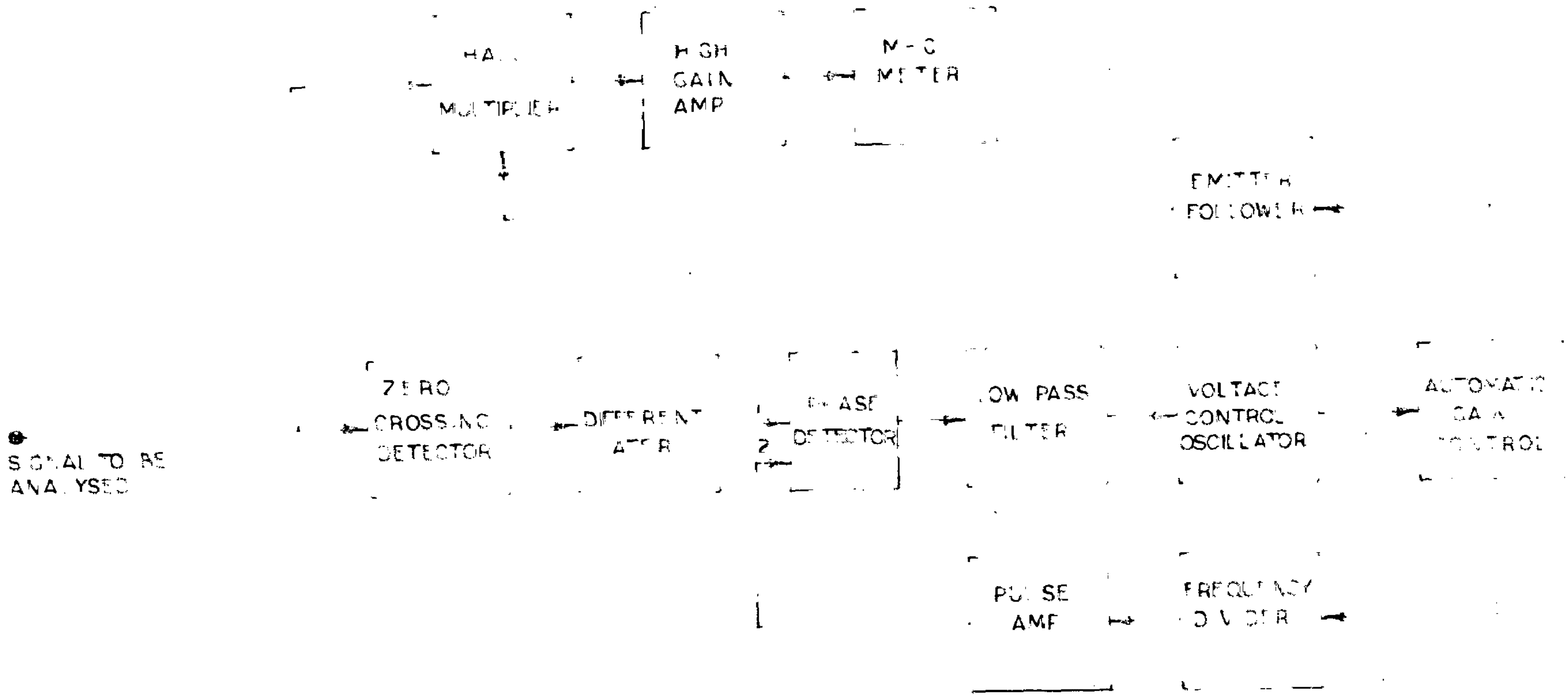

FIG 6.1 BLOCK DIAGRAM OF WAVE ANALYSER

The VCO used in the circuit has a special feature that its output is sinusoidal in waveform. However, it has a drawback that there is a reduction in the magnitude of the output when the frequency is increased. This reduction in magnitude of the reference signal will cause serious error in the measurement. So in order to keep the magnitude of the signal almost constant an Automatic Gain Control (AGC) is used. The power level of the output signal from AGC is not sufficient to send the required current through the Hall crystal, hence two stages of the emitter followers have been used.

The output of the VCO can be compared directly with the wave to be analysed only when the two frequencies are required to be equal. For 2nd and higher order Harmonics in the incoming signal of the reference frequency which is required to be equal to the Harmonic frequency, should be brought down to the fundamental frequency of the incoming signal. This is realised by a frequency divider (Storage counter) connected in the path of the reference frequency pulses being fed to the phase detector. Since the strength of the pulse coming from the divider is not sufficient to derive the phase detector a pulse amplifier is also included. The pulse is given to the point 2 of the phase dtector.

The output available from the Hall crystal is amplified, then filtered (if necessary) and then given to a moving coil meter.

6.3 Circuit

Different functional blocks of the wave analyser are explained in the section 6.2. Out of these different functional blocks circuits of only important few are explained below. Other functional blocks are well known so these are not explained.

6.3.1 Voltage Controlled Oscillator (VCO)

A multiloop active filter circuit by Kerwin is shown to yield a VCO whose oscillation frequency is conveniently controlled with one variable resistor[22,23]. A FET is used to obtain this voltage controlled resistor. VCO is the most critical element in the PLL.

One of the two Kerwin's feedback circuit, using a minimum number of capacitors, are shown in Fig. 6.2 . This is a basically Band Pass filter circuit[24]. The transfer function of this

$$T_{BP}(P) = \frac{V_o}{V_i} =$$

$$= \frac{PK_1K_2 / \left[Rc(1 - K_1K_2)\right]}{P^2 + P\,\frac{1}{Rc(1 - K_1K_2)}\left[\frac{1}{a_3a_4} + \frac{1}{a_4} + 1 + \frac{1}{a_2}(1 - K_1) + \left(\frac{1}{Rc}\right)^2 \times \frac{a_2 + 1}{a_3a_4(1 - K_1K_2)}\right]} \qquad \ldots (6.5)$$

It is seen that by suitable choice of K_1 independent of K_2, the denominator coefficient of P can be made to be zero.

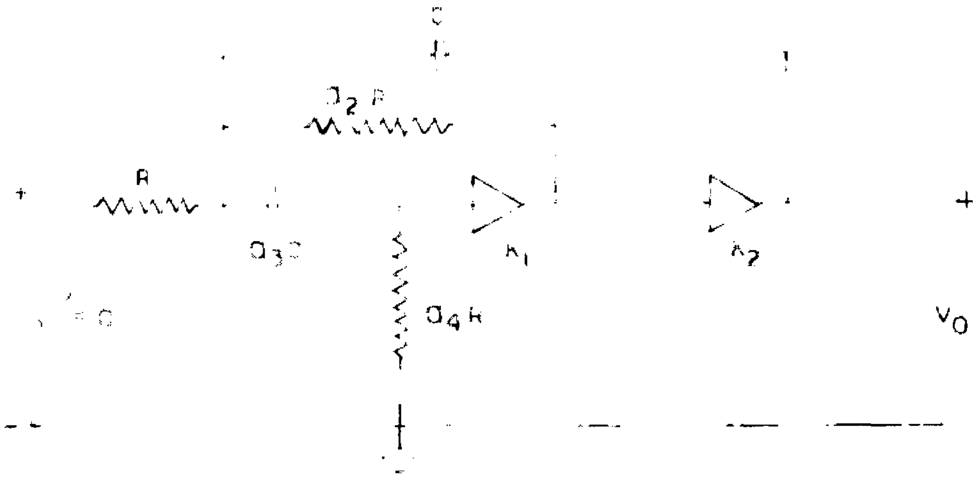

FIG 6.2 BAND PASS FILTER

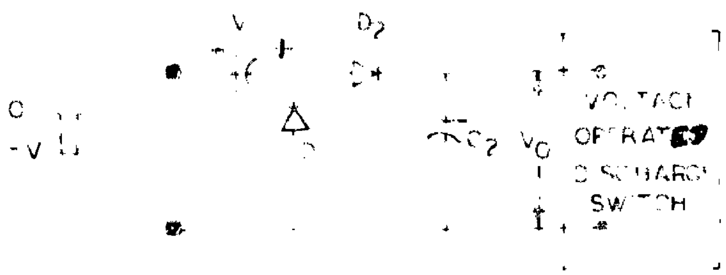

FIG 6.4 PRINCIPLE OF STORAGE TYPE FREQUENCY DIVIDER

Consequently, with these values of K_1, natural frequency of the circuit may be obtained on the $j(w)$ axis. As this is short circuit natural frequency, they will be physically realised by connecting the input resistor to the ground. This natural frequencies, w_0, being the square root of the denominator constant terms, are independently controlled through K_2 which in Kerwin's case was taken negative.

The conditions for oscillator and oscillation frequencies are then seen to be

$$K_1 = 1 + a_2 \left[1 + \frac{1}{a_4} + \frac{1}{a_3 a_4} \right] \quad \ldots (6.6)$$

$$f_0 = \frac{w_0}{2\pi} = \frac{1}{2\pi Rc} \left[\frac{1 + a_2}{a_3 a_4 (1 - K_1 K_2)} \right] \quad \ldots (6.7)$$

As K_2 can be realized to depend only upon a single variable resistor, the oscillation frequency can be varied by the single resistor. And since the single resistor can be realised by a FET working in the range below pinch off[25], the circuit of the Fig. 6.2 is seen to be conveniently yield VCO's . According to the requirement the different values of a_2, a_3, a_4 are selected as shown in Fig. 6.3.

For the circuit shown the dependence of K_2 upon FET drain to source resistance R_{DS} is given by

$$K_2 = -1/R_3 \left[\frac{R_2 R_4 - R_3 R_{DS}}{R_2 + R_{DS}} \right] \quad \ldots (6.8)$$

In turn, the drain to source resistance, at zero drain to source voltage is given by

$$R_D = \frac{1}{\beta\left[V_{GS} + V_o\right]} \quad \ldots \quad (6.9)$$

where V_o is the pinch off voltage for depletion device and the negative threshold voltage for enhancement mode device. β is a constant depends on the property of the channel. Substituting (6.9) into (6.8) and then into (6.7) yields the dependence of the VCO oscillation frequency f_o upon the controlling voltage V_{GS}.

i.e. for the band pass filter

$$w_o RC = \sqrt{2}\left[1 + 4\,\frac{R_2R_4\,(V_{GS} + V_o) - R_3}{R_2R_3(V_{GS} + V_o) - R_3}\right]^{\frac{1}{2}} \quad \ldots \quad (6.10)$$

From this it is clear that a choice of R_4 large negate the voltage control and R_4 small can lead to imaginary frequencies.

By conducting test it is found that when the value of condenser C changing from 0.03 to 0.12 a frequency variation of 700 Hz to 40 Hz is obtained. Different ranges of frequency are selected by a frequency range selector switch, shown in Fig. 6.3(b). If the frequency band is large in each range, it is found that at higher frequencies, the waveform is getting distorted slightly. The stability and the amplitude of the sine wave generated is depend upon the ratio of R_1 and R_2. When the ratio is 3, the exact sinewave is obtained. It is found that the output of the VCO is having good stability.

One drawback of the circuit is that the amplitude of the sinewave changes when the frequency changes. The amplitude at ranges varies from 0.04 V (Peak to Peak) to 4 V (Peak to Peak) for a frequency change by a factor three.

Two frequency selectors are included in the arrangement. For getting different ranges each condenser from the two sets are simultaneously connected to the circuit. For different values of condenser the ranges are shown below.

0.03 uF	-	400 to 700 Hz.
0.06 uF	-	200 to 400 Hz.
0.09 uF	-	100 to 200 Hz.
0.12 uF	-	40 to 100 Hz.

In addition to the frequency range selector there is a fine control adjustment by which any frequency between 40 to 650 Hz can be obtained. The automatic frequency correcting element of the circuit is effective within 10 Hz. So if the reference frequency is brought within 10 Hz of the input signal, the circuit will automatically get synchronised.

6.3.2 Automatic Gain Control (AGC)

Since the amplitude of the VCO output is changing of R_1 and R_2. When the ratio is 3, the exact sinewave is obtained. It is found that the output of the VCO is having good stability.

One drawback of the circuit is that the amplitude of the sinewave changes when the frequency changes. The amplitude at ranges varies from 0.04 V (Peak to Peak) to 4 V (Peak to Peak) for a frequency change by a factor three.

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In addition to the frequency range selector there is a fine control adjustment by which any frequency between 40 to 650 Hz can be obtained. The automatic frequency correcting element of the circuit is effective within 10 Hz. So if the reference frequency is brought within 10 Hz of the input signal, the circuit will automatically get synchronised.

6.3.2 Automatic Gain Control (AGC)

Since the amplitude of the VCO output is changing with frequency an AGC is provided in the output of the VCO. A voltage control junction field effect transistor permits an automatic gain control circuit[26] to maintain a constant output voltage over two decade input voltage range. The circuit developed is given in fig. 6.3(a). The deflection mode JFET is located in gain control loop of the noninverting amplifier A_3. The gain of the amplifier can be represented by

$$A_V = 1 + R_F/R_I \qquad \ldots \qquad (6.11)$$

where, R_I is the series combination of the 1 kilo ohm resistor plus the FET's drain source resistance.

$$r_{ds} = r_{ds(on)}/(1 - V_{GS}/V_{GS(off)}) \quad \ldots \quad (6.12)$$

$r_{ds(on)}$ is the resistance of the channel when the gate voltage is zero. For the BFW10 the value of this resistance is experimentally found out. The value is about 100 ohm (maximum). The $V_{GS(off)}$ from the manufacturer's data is - 8 V (maximum). The channel resistance, therefore, stays linear for about half the ranges of $V_{GS(off)}$, but tends to become nonlinear at voltages above 1/2 $V_{GS(off)}$ because of the FET's departure from the square law behaviour at high gate-source voltage[25].

The amplifier gain can be written as

$$A_V = 1 + \frac{75}{1 + 0.1/(1 - \frac{V_{GS}}{8})} \qquad \ldots \qquad (6.12)$$

The voltage divider formed by R_3 and R_4 attenuate input signal (by 6 : 1) to prevent the distortion at the output. Since the inverting input of the amplifier tries to track its non inverting input, the positive input is the one that determines the FET's drain to source voltage[26]. This channel voltage must be kept small to force the FET to remain in the Triode Region of operation. A shift in the FET's operating region will introduce large amount of distortion. Gain of this non inverting amplifier is adjusted in such a way that when the maximum value of the input comes the gain is automatically adjusted to unity.

A_4 is an ordinary high gain inverting amplifier, having a gain of 80. This large gain is required ~~to respond~~ the output for a small change in the input, i.e. a small change in the input cause a large change in the output.

The negative voltage is required to control the FET channel resistance and is obtained by rectifying and filtering the output of A_4. The 50 μF capacitor prevent a.c. ripples from modulating the FET's gate voltage and producing distortion. Its value is chosen by trading off circuit response time against the amount of filtering. Only a small change in the input of A_4 causes the circuit to adjust itself, producing whatever AGC voltage is required to maintain an output of almost 0.7 V peak to peak.

When the input signal amplitude increases, the input voltage to the noninverting amplifier also increases, causing the output A_4 going more negative, and so the resistance of the channel increases. Increased channel resist resistance reduce the gain and will bring back the output to the desired value.

At an input more than 4 V peak to peak or higher cut off the FET, making the voltage gain of A_3 equal to unity. The amplifier then trace the input, attenuating by a factor of 6. The output distortion of the circuit is found very small. When the input voltage decreases the feedback negative voltage also decreases and there is a reduction in the resistance of the FET. This reduction will increase the gain of the amplifier A_3 so that the output is again brought to the required value.

6.3.3 Frequency Divider (Storage Counter)

A stair case generator is used as a frequency divider. Any division from 1:1 to 1:10 is possible with the designed circuit. The basic principle can be understood by referring the Fig. 6.4.

Assume initial zero charge on the capacitor C_1 or C_2. The first pulse will cause the capacitor C_1 to charge through the diode D_1. The time constant with which C_1 charges is the product of C_1 times the sum of diode and source resistance. If this time constant is very small in comparison with the durationof the pulse, then C_1 will charge fully to the value $V_1 = V$ with polarity indicated.

during the charing time of C_1, diode D_2 does not conduct and voltage across C_2 remains at zero. At the termination of the input pulse, the capacitor C_1 is left with voltage $v_1 = V$, which now appears across D_1 and across the series combination of D_2 and C_2. The polarity of this voltage is such that D_1 will not conduct. The capacitor C_1 will, however, discharge through D_2 into C_2 until the voltage across the two capacitors are equal. The time constant with which the transfer of charge takes place must be quite small in comparison with the interval between the pulses in order to allow equilibrium to be established between the capacitor voltages. The capacitor C_2 is ordinarily quite large in comparison with C_1. As a consequence the voltage across C_2 is small in comparison with the voltage $V_1 = V$ across C_1. The next input pulse restores the voltage on C_1 to V, and at the termination of the pulse C_1 discharges again to C_2. Since now, however, C_2 has some initial charge, the amount of charge transferred from C_1 to C_2 will be smaller than before.

In the actual circuit designed, the pulses are of positive polarity. C_1 is charged through D_4 and then discharged through D_5. To make the steps of staircase generator are equal the transistor T_4 has connected as an emitter follower. Transistor T_3 is used to make the magnitude of the stair case steps remains the same between the two pulses. The step at C_2 in this case, appear at the leading edge of the input pulse.

Unijunction Transistor (UJT) is used as a voltage operated discharge switch. The firing voltage of the UJT can be adjusted by applying variable voltage across B_1, B_2. This can be achieved by connecting a potentiometer as shown in Fig. 6.3.

It is possible to obtain any ratio from 1 to 10. The position of the potentiometer P_1 can be calibrated in terms of the frequency division ratio.

The output pulse taken from B_2 is negative and the magnitude of this pulse at low frequency division ratio is not sufficient to drive the phase detector. A pulse amplifier is incorporated which, in addition to amplifying the signal, provides the required phase shift also.

6.4 Test Results

The wave analyser is tested using a square wave so that content of various harmonics can be calculated. Quantitative results are listed in the appendix. Qualitatively, the performance is found to be very satisfactory.

7. CONCLUSION

Though the Hall effect was discovered in 1877, even now there are some fields of application where the Hall device is having definite advantages over other electronic devices which are in use. The properties like isolation of one input from the output, a high linearity, good frequency response, four quadrent multiplication, vector product forming capabilities and response to magnetic field (not to rate-of-change of magnetic field) will make the Hall crystal a very important link in the advancement of Electrical, Electronics and Communica systems. On the other hand, the device has got some serious limitations like unwanted power loss in magnetic winding, noise problem at low signal level and very low power handling capacity. Even with these limitations the Hall crystals have been successfully tried in many applications, including some industrial application.

The revolution in thin film semiconductor technology will definitely improve the crystal's electrical and magnetic properties which will eliminate some of the limitations cited above. Major contributions in this field are expected from the work now being carried out in different parts of the world, especially in Russia and Germany.

The product forming property of the Hall crystal has been successfully exploited by the author to develop true RMS meters (both for voltage and current) and wave analysers (for electric and magnetic signals). It has been found by conducting experiments that the Hall multiplier pack available in the laboratory exhibits good linearity over a wide range of frequency and magnetizing current, which conform to the specification given by the manufacturer.

The major drawback of Hall multiplier packs, used in all the three instruments here, are the very high inductance of the field coil.

As it is, no modification can be possible in the Hall multiplier pack because of the integrator nature of this unit, external compensation, therefore, becomes necessary to improve the performance, especially to make the performance of the unit independent of frequency. With compensationprovided, the instruments designed gave satisfactory performance when these were tested in the laboratory. It would be desirable to develop these instruments with bare crystal, which would allow considerable flexibility in designing the magnetic circuit according to the requirement and finally improve the performance of the meters drastically. In that case the designer would have control over the inductance of the magnetic circuit and it would be possible to increase the linearity by adjusting the air gap between the magnetising core and the crystal. In some applications a provision to change the number of turns of the magnetic field coil may be of great help.

The design of a probe using a bare crystal to pick up flux from the air gap of electric machines is another challenging work that can be undertaken in future. The author could not work in this direction because of the inability to get the required crystal. If a properly designed probe is used with the circuitary developed by the author a handy instrument can be developed which would be useful in analysing the air gap flux of electrical machines and stray magnetic field.

The circuitary developed for use with Hall probe/multiplier in wave analyser needs some further remarks. The most important part of the circuit is PLL which generate sinewave with automatically adjustable frequency and constant magnitude and is first of its kind. Though the circuit has been found to be satisfactory, its performance can be further improved by eliminating the drawbacks noted in it. These drawbacks are :

(a) A slight distortion at the upper values of frequencies at all ranges.

(b) Low synchronisation limit (+ 10 Hz maximum)

(c) A small change in the amplitude of the generated wave with frequency at the lower end of each range.

Out of these drawbacks the amplitude change with frequency can be eliminated by providing two cascaded stages of AGC instead of one. Synchronization limit can be improved to ± 10 Hz by replacing the deflection mode FET by enhancement mode type. Some improvement is also required in VCO, which is the most important part of the PLL, to get a larger synchronization frequency range.

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APPENDIX - A

HALL-PAK MULTIPLIERS SPECIFICATIONS

Type 0 - Completely compensated		HM-3030	HM-3050	Unit
Magnetic Field Input	(data for parallel connected field coils)			
Resistance, approx.	R_f	5	500	Ohms
Temperature influence on R_f		+ .39	+ .39	%/°C
Reactance, approx.	x_f	400	40000	Ohm/KHz
Current rating	I_{fmax}	300	30	mA
Practical freq. range at I_{fmax}	dc to	1	.25	KHz
Hall Input		All models		
Resistance, approx. at $I_f = 0$	R_{in}	2.5		Ohm
Temperature influence on R_{in}, approx.		+ .15		%/°C
Magneto resistance at I_{fmax}	$pB\ I_f^2$	+ 25		% of R_{in}
Current Rating	$I_{c\ max}$	330		mA
Practical frequency range	dc to	500		KHz
Hall Output				
Resistance approx.	R_{out}	10		Ohm
Load resistance	R_l	50		Ohm
Output at max. inputs	$V_H\ \ I_f \times I_c$	200		mV
Temperature influence on V_H,				
ambient 0° to + 50°C		± .5		%
ambient - 25°C to + 75°C		± 1		%

Notes 1) Data is at 25°C. ac values are r.m.s. KHz (kilohertz) = kc/s.

2) For series connected coils R_f = 4x and I_{fmax} = .5x values shown.

APPENDIX – B

(10 A Range)

S. No.	U. meter reading	Substandard meter reading	Square of substandard meter reading
1	3	2.1	4.41
2	6	2.9	8441
3	9	3.6	12.96
4	15	4.7	22.09
5	20	5.4	29.16
6	25	6.0	36.00
7	30	6.5	42.25
8	35	7.2	51.84
9	40	7.6	57.76
10	45	8-0	64.00
11	50	8.4	70.56

(5 A Range)

1	3	1.0	1.0
2	5	1.2	1.44
3.	10	1.7	2.89
4	15	2.1	4.41
5	20	2.4	5.76
6	25	2.7	7.29
7	30	2.95	8.41
8	35	3.2	10.22
9	40	3.45	11.90
10	45	3.65	13.32
11	50	3.8	14.44

APPENDIX - B (CONTD.)

(1 A Range)

S. No.	uA meter reading	Substandard meter reading	Square of substandard meter reading
1	3	0.2	0.04
2	5	0.24	0.05
3	10	0.35	0.12
4	15	0.42	0.17
5	20	0.49	0.24
6	25	0.55	0.30
7	30	0.6	0.36
8	35	0.65	0.42
9	40	0.7	0.49
10	45	0.74	0.54
11	50	0.78	0.60

(200 mA range)

1	5	0.06	0.0036
2	10	0.08	0.0064
3	15	0.1	0.01
4	20	0.115	0.013
5	25	0.130	0.016
6	35	0.155	0.020
7	40	0.165	0.027
8	45	0.175	0.03
9	50	0.185	0.034

APPENDIX - C

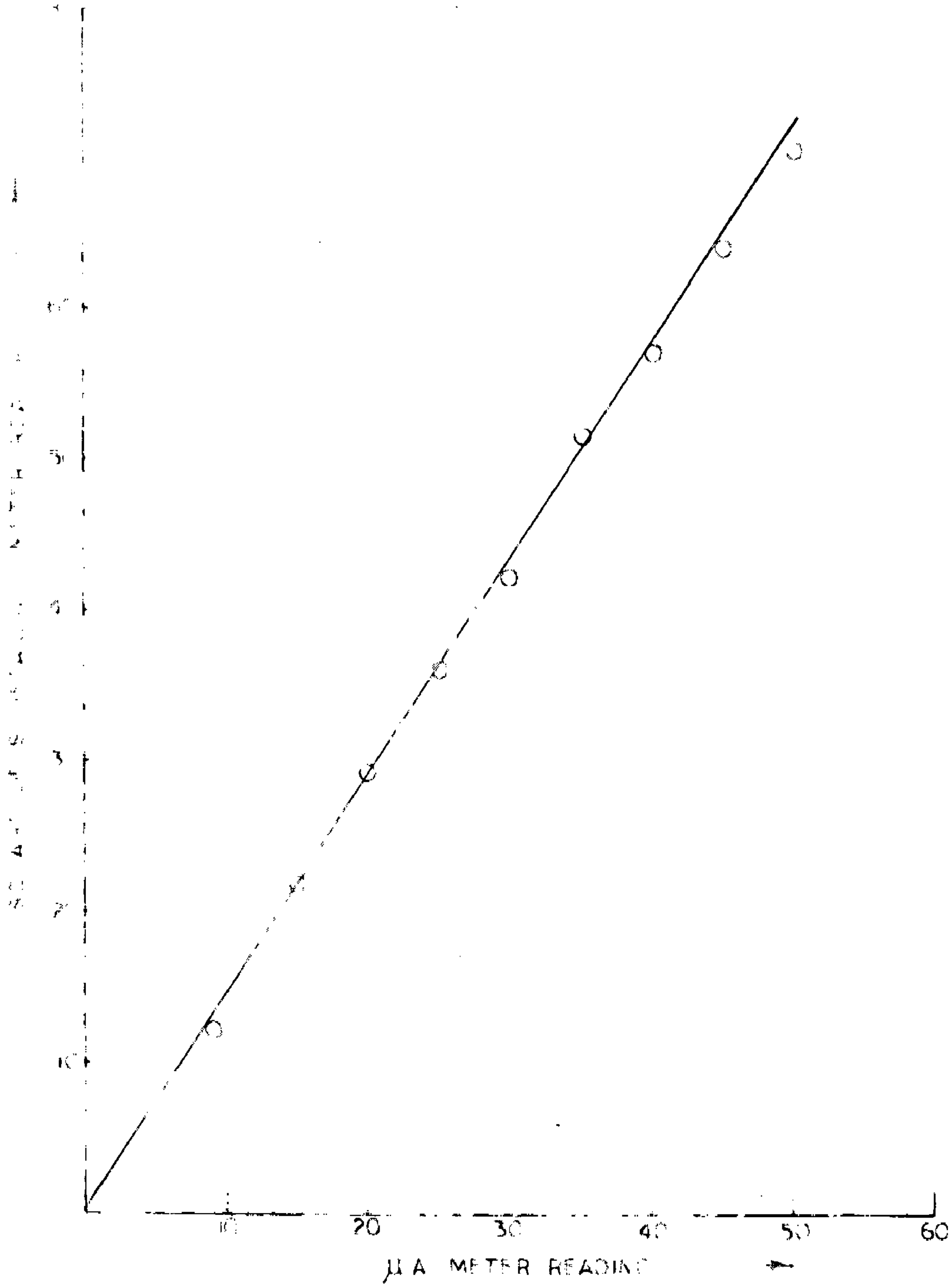
(Range 250 V)

S. No.	uA meter reading	Substandard meter reading	Square of substandard meter reading.
1	10	72	5184
2	20	102	10400
3	30	126	1588[illegible]
4	40	144	20740
5	50	162	26240
6	60	179	32040
7	70	194	37640
8	80	208	43260
9	90	220	48400
10	100	234	54760

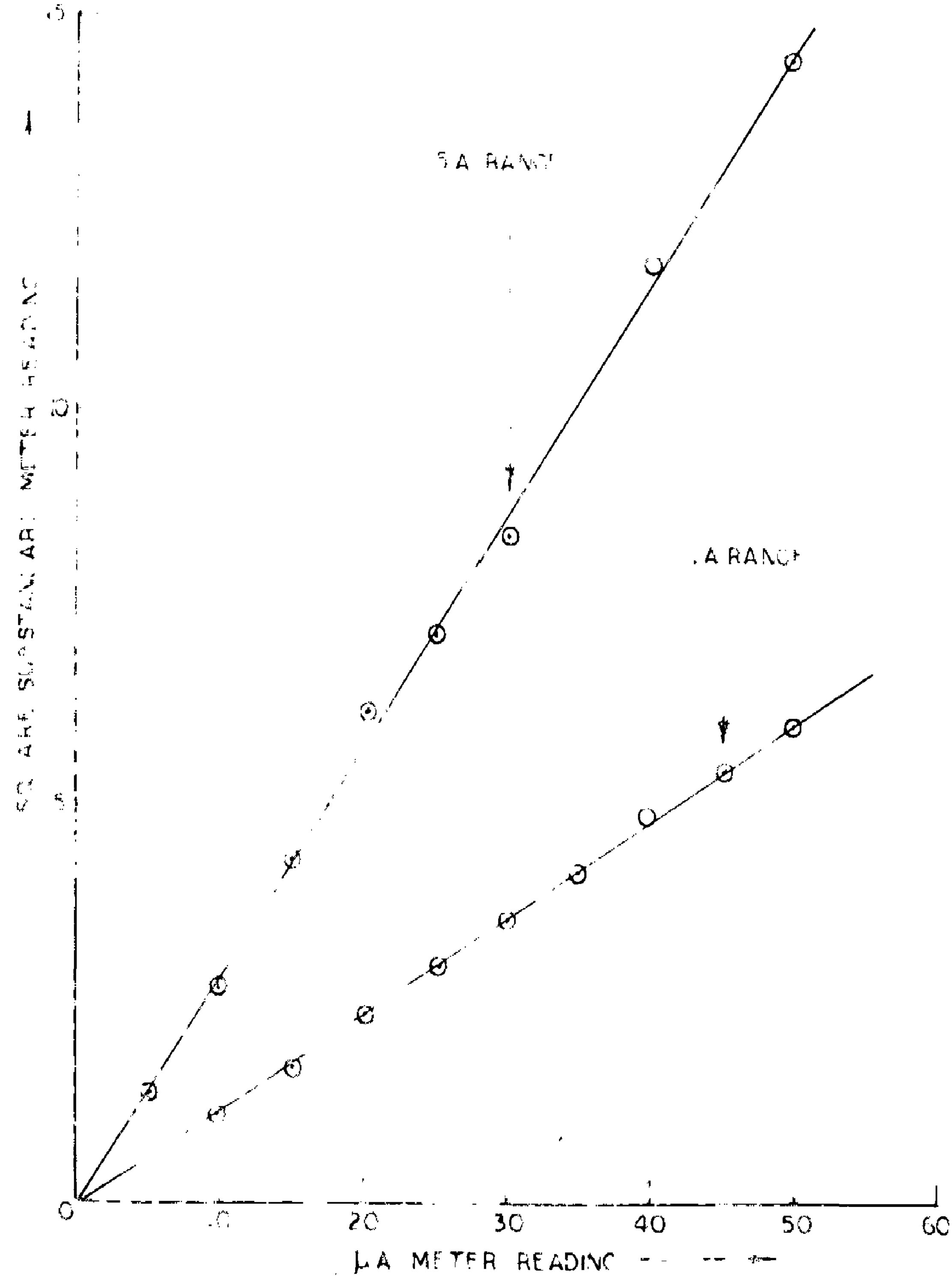
(175 V Range)

1	10	54	29[illegible]6
2	20	75	5625
3	30	94	8576
4	40	107	11450
6	50	120	14450
6	60	133	17690
7	70	144	20740
8	80	152	23100
9	90	164	26900
10	100	174	30280

CALIBRATION FOR 10A RANGE



CALIBRATION FOR 5A/1A RANGE



CALIBRATION FOR 250V RANGE