NULL DETECTORS AND POWER SUPPLIES FOR BRIDGES AND POTENTIOMETERS

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

By

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Sept. 1976

CERTIFICATE

Certified that the dissertation entitled "NULL DETECTORS AND POWER SUPPLIES FOR BRIDGES AND POTENTIOMETERS" which is being submitted by Sri MUKESH CHANDRA in partial fulfilment for the award of the Degree of Master of Engineering in Electrical Engineering (Measurement and Instrumentation) of the University of Roorkee, Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is to further certify that he has worked for *five* months from *Jan.*, 1976 to *June*, 1976 for preparing this dissertation at this University.

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ACKNOWLEDGEMENT

The author wishes to express his deep sense of gratitude to Shri H.K. Verma, Reader in Electrical Engineering Department and Shri A. Das, Lecturer in Electrical Engineering Department at University of Roorkee, Roorkee for their unfailing help and able guidance. The author also feels that he was lucky enough to have the great privilege of being associated with them in the preparation of this present dissertation and therefore greatly indebted to them.

The author is also thankful to Dr. P. Mukhopadhyay, Professor in Electrical Engineering Department at University of Roorkee, Roorkee for his cooperation, sincere advice and help in all fields from time to time.

He also takes this opportunity to express his sincere thanks to Shri S.C. Saxena, Shri Vinod Kumar, Shri D.S. Chitore and Shri Bharat Gupta, all lecturers in Electrical Engineering Department at University of Roorkee, Roorkee for rendering friendly encouragement and guidance during preparation of this work.

The author is highly thankful to Dr. T.S.M. Rao, Professor and Head, Electrical Engineering Department for providing the necessary facilities.

He also wishes to express his sincere thanks to Shri Pradeep Kumar, Assistant Executive Engineer, B.H.E.L., Hardwar for his cooperation and help during the preparation of this report.

The author is also grateful for the efforts put in by technicians of various laboratories and workshop, particularly Shri Ganga Ram, S.L.A., Power System Lab. and Shri H.D. Sharma, J.L.T., Bio Engineering Laboratory.

(MUKESH CHANDRA)

simple is an important contribution towards getting exact variable phase shift at constant output magnitude.

Fourth chapter includes various test results which have been taken from the instruments developed. Results are plotted to show the various performance characteristics of these instruments. Photograph showing various wave shapes and Lissajous figures are also provided to corroborate the results, wherever necessary.

Various applications of the instruments and comments on their performance are included in the last chapter.

ABSTRACT

The present work applies integrated circuit operational amplifier in the development of null detector and power supplies for bridges and potentiometers. The use of integrated circuit operational amplifier is to achieve higher sensitivity, more reliability, low cost and simplicity for null detector, polar power supply and quadrature supply.

The first chapter introduces various types of null detectors and power supplies which are presently available for use with a.c. bridges and potentiometers. Survey of literature leads to the conclusion that some of these methods have comparatively unreliable operation and high cost whereas some are bulky and hence difficult for handling. In view of this discrepancy, new portable instruments have been presented for getting better performance.

Theory and design of electronic null detector developed by the author have been given in the second chapter. Circuit which has been developed is based on the principle of electronic amplification of unbalance a.c. signal of a particular tuned frequency with the provision of automatic sensitivity adjustment.

Development of quadrature and polar power supplies have been included in the third chapter. Operational amplifiers in conjunction with resistance capacitance network has been used for phase angle adjustment from 0 to 360° in polar power supply. Design though

CONTENTS

1. INTRODUCTION

1.1 Electronic Null Detector

The application of solid state devices to the instrumentation of bridge and other a.c. measurements provides a great advance in the sensitivity with which it is possible to detect a null balance (or amount of unbalance) in a comparison circuit. The telephone receivers (or head phones) ordinarily used as a detector are, as a matter of fact extremely sensitive qualitative detectors for the presence or absence of an a.c. signal. They are not at all as effective, however, in determining the absolute level of a signal for obtaining a clear cut null. The presence of even a slight amount of harmonic content in the oscillator supply is enough to dull the sharpness of a null, since these harmonics generally do not balance out at the same dial setting that cancels the fundamental signal. The expedient of attenuating the harmonics is done by inserting a filter circuit sharply tuned to the fundamental. The problem of obtaining a clear cut null balance becomes more difficult if a visual indication of output is obtained on an ordinary a.c. meter, because of the inherently smaller sensitivity of the meter and rectifier combination. So an effective approach is made to get an satisfactory null by use of electronic amplification.

The present work carries the approach of using operational amplifier in designing electronic null detector, because of its simplicity, low cost and more reliability.

1.2 Power Supplies

The power supplies which have been developed here are quadrature power supply and polar power supply for bridges and potentiometers based on electronic principle. The polar power supply which is presently available for polar potentiometer make use of phase shifter working on the principle of mutual inductance. Also for quadrature power supply phase splitting circuit is being used which consists of RC Networks. The description of these power supplies are given in the next section.

1.3 Literature Survey

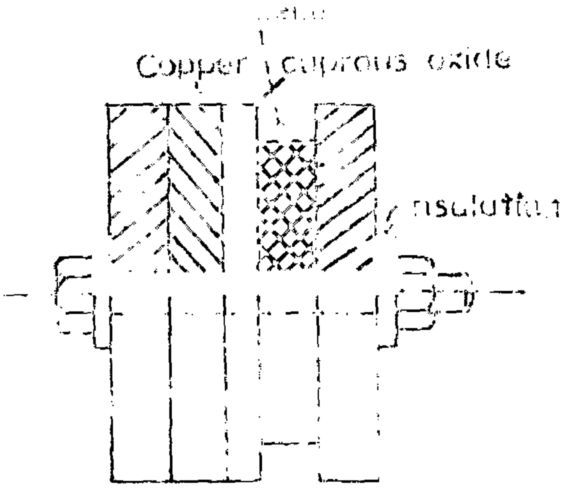
Even the most casual survey of precision d.c. measuring practice will reveal that most measurements will involve either a bridge or a potentiometer circuit. In both, a detector is used to indicate the state of balance. Null detectors indicate relative magnitudes and directions of current flow during the unbalance state. In null measurements the condition of zero current flow is important, magnitude is not. As a consequence it is essential that the null detector have maximum measuring sensitivity around the zero point and minimum tendency for the zero point to drift.

Deflection type as well as null type instruments are used as detectors. Deflection type instruments are used in some phases of d.c. measurement, particularly where small differences are involved. Also a deflection instrument differs from a null type since it indicates a value proportional to the unbalanced condition and therefore fulfils more functions than a null detector. In addition to a zero calibration the deflection instrument has a measuring span which forms a second part of its calibration. Span is the fixed relation between an input change and the change in value indicated or measured by the deflection instrument. Because of this additional function, deflection type devices are inherently less accurate in measuring a finite value than null devices are in indicating a null condition.

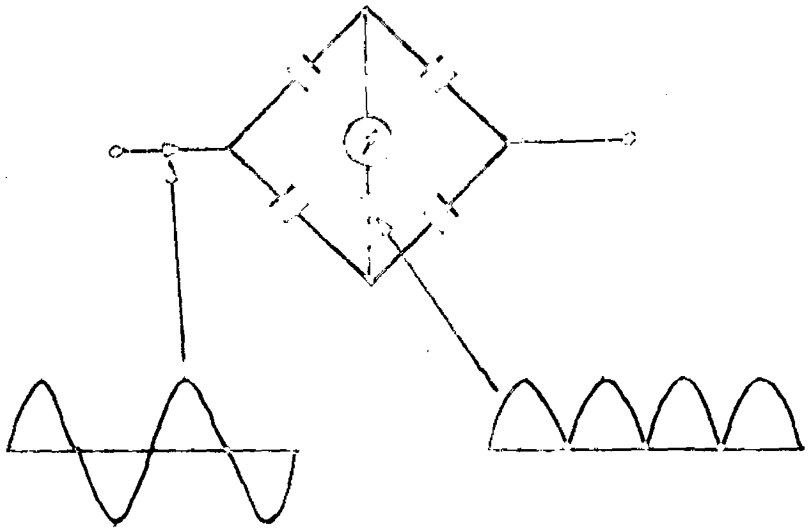
So in order to review the work already done in this field, a brief description of the most important types of null detectors are given in the next section.

1.3.1 Rectifier Detectors [9]

In the earliest a.c. bridges, commutator was used to provide a crude alternating supply, the detector signal was rectified by means of a mechanical commutating device to get unidirectional out of balance signal. This signal was applied to a moving coil ballistic galvanometer, which was the most sensitive d.c. instrument available at that time. The design of suitable commutators which were generally either a segmented cylinder with stationary brushes or a vibrating reed or key, underwent considerable development. The instruments employing them were often tricky to set up and use and were frequently subject to contact troubles. But, with the advent of the semi conductor rectifier, more reliable detectors can be obtained and in that case mechanical operation was restricted to the output indicator. Fig. 1 shows the complete schematic view of the rectifiers.

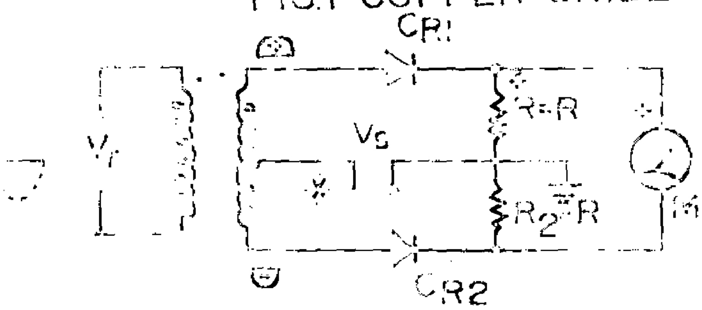


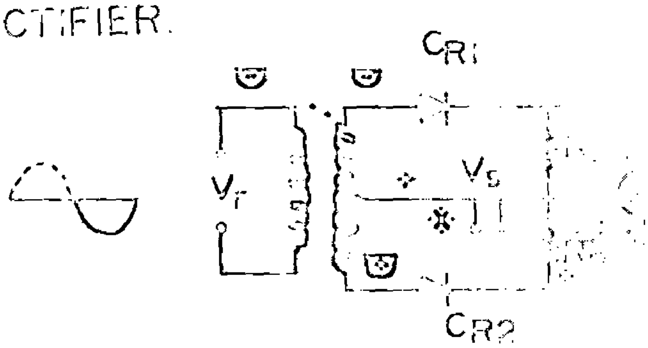
(a) Construction.



(b) Full wave bridge connection

FIG.1 COPPER OXIDE RECTIFIER.





* the inphase condition [illegible] the slarred terminal of Vs is +Vs when the dot terminal of Vr is +Vr

* For the inphase condition, [illegible] terminal of Vs is +Vs when the [illegible] terminal of Vr is [illegible]

[illegible], has described a simple detector consisting of four copper oxide rectifiers connected in a full wave bridge circuit (Fig. 1b). It was found that the sensitivity in the audio range was as good as that of a telephone with the advantage that the rectifiers can be used down to zero frequency or well above the audio limit, with little change of sensitivity. Point contact diodes are incorporated in many [illegible] hand portable instruments. They are also generally used in conjunction with a moving coil meter to provide visual display of the output from electronic amplifier and detectors. But the main drawback with such rectifying devices have a non-linear current/voltage characteristics so that their sensitivity in the region of the balance point is low.

2.3.2 <u>Galvanometers.</u>[9,13]

Any sensitive electrodynamic instrument i.e. one having both fixed and moving coils can be used as a bridge detector, although it is clearly restricted to use at low frequencies. Galvanometers have been classified into several categories according to

1. Moving coil or moving magnet
2. Use and application
3. Type of suspension of the moving elements.

Galvanometers are employed to measure current flow and are considered as a current detected device. They have been used to detect voltage, in these applications their voltage sensitivities are derived on the basis of circuit resistance and galvanometer current sensitivity. In some applications, the galvanometer has been used to measure short bursts of current or impulse flows of current where the duration of impulse is much less than the period of the galvanometer. In these instances, the galvanometer is said to be used ballistically and, hence, carries the name of ballistic galvanometer. Any galvanometer can be used ballistically, but because of the difficulty in reading the maximum deflection (which is a function of pulse magnitude) while moving, special galvanometers (called ballistic galvanometers) having appropriate dampening characteristics to slow down movement, are used to measure the current pulses.

Null type galvanometers are principally used in bridge and potentiometer applications, where their prime function is to detect a null or zero flow of current, such as would occur at the balanced state of the circuit. Deflection type galvanometers are employed to show an indication of magnitude of current in the circuit. Magnitude is determined by the amount of deflection of the galvanometer moving element. This type of galvanometer is exemplified by the millions of indicating voltmeters, ammeters and ohmmeters at work in industry.

High sensitivities can be achieved with moving magnet galvanometers, but because of the resultant high moment of inertia, unfavorable operating characteristics discourage their use. In moving coil devices, construction of the coil without the relatively high and magnet provides improved inertia and allows use of the [illegible] sensitivity characteristics of the galvanometer. It also makes possible reasonable damping and good transient response in comparison to moving magnet instruments.

1.3.3 The Telephone Receiver[9]

The ordinary telephone receiver is also used as an a.c. bridge detector of modest performance. In its simplest form it consists of a thin iron diaphragm, clamped by its rim so that it is close to one pole of a permanent bar magnet. A coil wound near the pole of the magnet carries the current to be detected, the modification of the permanent field by the alternating field of the coil produces periodic attractions of the diaphragm, thus setting it into forced vibration and causing it to emit an audible note. In the more modern form the permanent magnet is of horse shoe form so that both poles act on the diaphragm. Two such flat receivers are fitted to a head band.

The sensitivity of the telephone is far from being constant for currents of different frequencies, because the diaphragm possesses definite natural modes of vibration. When the frequency of the current approaches one of these natural frequencies, the amplitude of vibration of the diaphragm increases enormously owing to resonance, and the sensitivity is correspondingly high. Sensitiveness of a telephone is [illegible] entirely determined by the amplitude of oscillation of the diaphragm, but depends also on the existence of heating of the experimenter. A more uniform response can be obtained in a high impedance telephone receiver using Rochelle salt crystals to drive a small cone diaphragm, or low impedance miniature moving coil instrument. Since a telephone is more sensitive at certain frequencies than others, care must be taken to select an instrument suitable for the work in hand. In addition, its resistance should match the bridge circuit, and this may require the use of a detector transformer of suitable ratio.

Capacitance effects between the observer and the telephone are sometimes disturbing and can best be allowed for by some device such as a Wagner earth circuit. Stray magnetic fields from the bridge may also cause trouble, in this case the instrument may be set up out of inductive range. The sensitiveness of a telephone can be increased by using it with an electronic amplifier, although [illegible] points and certain precautions have to be taken in order to get reliable performance. For example, it is very desirable to use a detector transformer to minimize earthing problems and to use a linear amplifier to avoid intermodulation distortion.

2.0.4 Electrometer Detector[9]

Low value capacitors have very large impedances when used in a.c. circuits at low frequencies. When connected to a bridge they [illegible] of high impedance, to ensure [illegible]. The input impedance of the detector must also be high. [illegible] this reason that Greinacher first developed the vibration electrometer for bridge use. Curtis followed this work by designing an instrument by means of which capacitance of 10^{-8} microfarad could be measured at 50 Hz. with ten times the accuracy then obtainable with a vibration galvanometer as detector.

Curtis's instrument consisted of an aluminium vane mounted with its plane vertical upon a tunable bifilar suspension. Four rectangular plates were placed two in front and two behind the vane and were connected diagonally. The vane was held at a high steady potential, the two pairs of plates were connected to the detector terminals of the bridge. The suspended vane was tuned to resonate at the bridge supply frequency, and to reduce damping the whole instrument was mounted in air at reduced pressure. The sensitivity was of the order of 10000 mm/micro-amp deflection at 1 meter, the deflection being read by reflected light from a mirror carried by the vane.

1.3.3 Phase Sensitive Detector [5,6,9,12,16]

When two a.c. voltages of equal magnitude are compared in a series opposition circuit, the resulting output will be zero only when one voltage is in phase with the other, at all other times there will be an output which will depend upon the phase relationship between the two voltages being compared. This situation applies not only to the a.c. bridge circuits, but also to many other cases where an input a.c. voltage is being compared with another voltage as a reference, as in an error detection circuit. In all these cases the detection of the error requires a phase sensitive circuit arrangement.

The measurement of the absolute phase angle existing between two voltages is generally made either with an oscilloscope or an electronic phase meter. An indication of relative phase, however, can be obtained by a.d.c. galvanometer, without electronic amplification, in a dual rectifying circuit shown in Fig. 3.

A very useful property of this circuit is the fact that the deflection of the zero centre d.c. galvanometer (or voltmeter) will change, depending on whether the two voltages V_1 and V_2 are either in phase or out of phase with each other, thus indicating not only an unbalance, but also the direction of unbalance. In the discussion to follow, the circuit is required to be sensitive only to the extent 1 of distinguishing in phase from out of phase conditions. In this respect the circuit could be more correctly designated as a "phase inversion sensitive" circuit but the shorter name is more commonly used. In the error detecting form in which this circuit is usually used, Vr is a reference a.c. voltage, generally 60 Hz., derived from a power transformer and Vs is a signal that is substantially either in phase with Vr (phase $\phi = 0$), or out of phase with Vr (phase angle $\phi = 180°$).

The other type of phase sensitive detector which gives wide band width incorporates the use of electronic circuitry.

Such types of phase sensitive detectors are also used for improving the signal to noise ratio in electrical measurement circuits. The availability of bipolar and field effect transistors of complementary electrical characteristics has greatly facilitated the construction of simple circuits for this purpose, as well as assisting in the attainment of a high standard of performance over a very wide range of input frequencies. The circuit configuration which has been discussed here have common earth line for signal input, the reference voltage input and the output from the detector.

Although the basic requirement of a phase sensitive detector may be met in several ways, one of the most convenient system for use with active semiconductor elements is that derived from a normal rectifier circuit in which the rectifying element is replaced by some form of controlled switch.

The circuit shown in Fig. 8(b) would clearly operate in a manner identical to that of Fig. 8(a) if the operating frequency and phase of the switch 'S' were appropriately chosen. A similar equivalence would also exist between the circuit shown in Fig. 6(a) and the "Cockcroft Walton voltage doubler circuit" of Fig. 6(b), with the advantage that both halves of the signal input cycle are utilized, to yield a higher output voltage. In this case, however, some arrangements would have to be provided so that the switches could be operated during alternate portions of the input signal cycle.

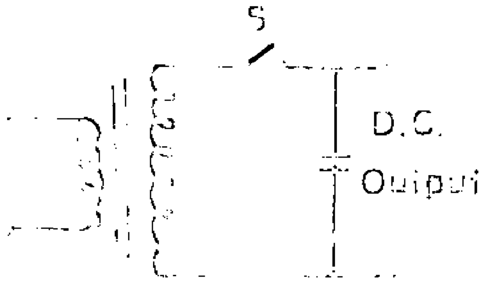


FIG. 3 a

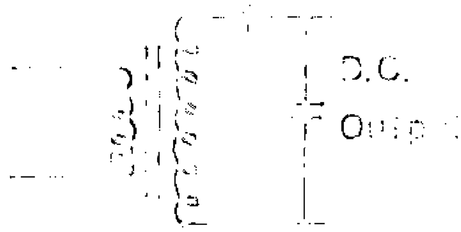


FIG 3 b

NORMAL A.C RECTIFIER CKT. WITH CONTROL SWITCH 3a IN PLACE OF RECTIFIER 3b

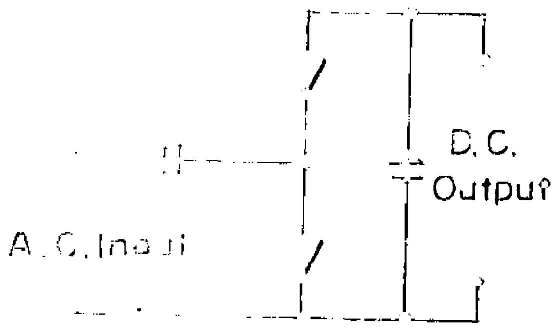


FIG. 4a CONTROL SWITCH CKT.

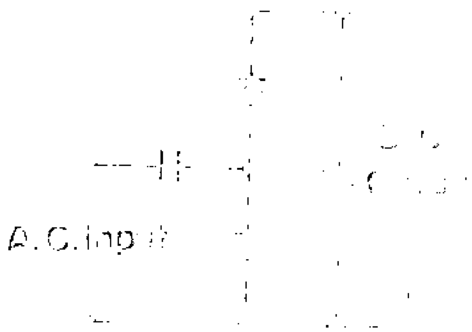
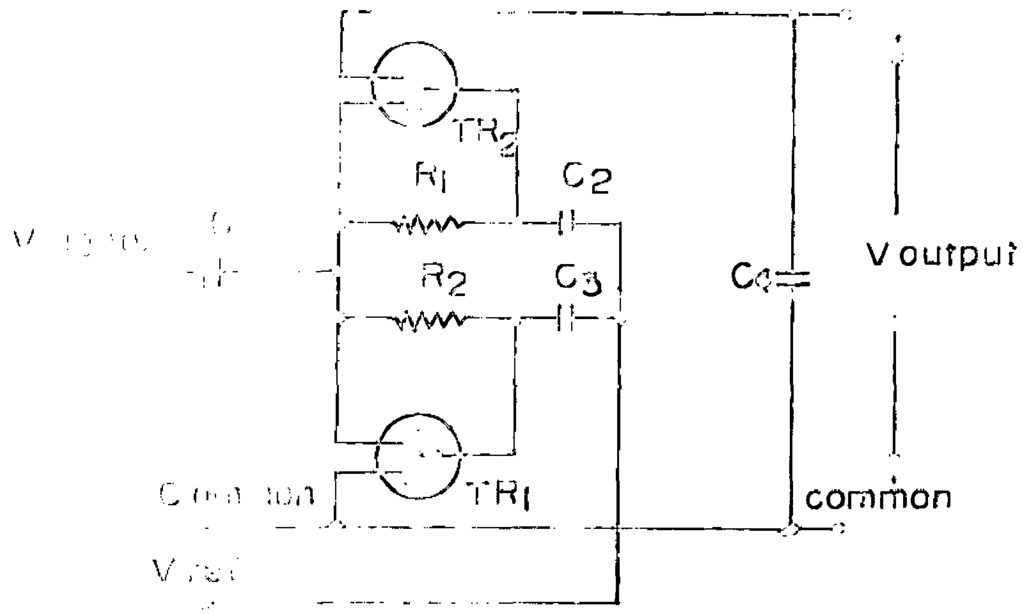


FIG. 4b COCKROFT WALTON CKT.



TR1 n channel fet , TR2 — P channel fet

FIG.5 PHASE SENSITIVE DETECTO USING COMPLEMENT

FET's.

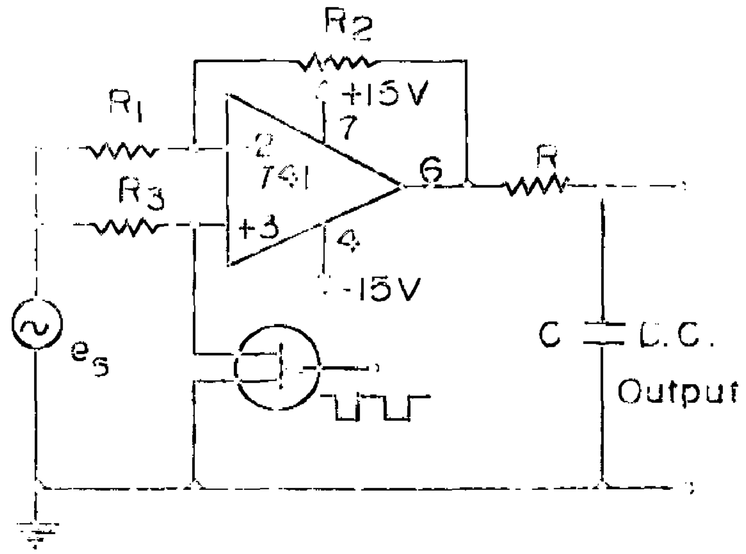


FIG.6 OP. AMP. AS PHASE SENSITIVET DETECTOR

The junction field effect transistor is an attractive circuit element for use as a switching device, because of the effective isolation of the gate control voltage from the current flowing through the channel, and because of the lack of any intrinsic rectifying action in the current carrying element. Also because of the availability of complementary n channel and p channel field effect transistors having closely similar electrical characteristics. The required alternate operation of the switching elements, may in this case, be accomplished with the reference voltage applied to the two gates in parallel. The schematic circuit is shown in Fig. 5.

The operational amplifier can also be used as a phase sensitive detector. The simple circuit diagram using operational amplifier is shown in Fig. 6.

2.3.6 Differential Detector

Differential detector has been used for detecting the level of the difference between two input signals. This detector is used in conjunction with a.c. bridges where the level of voltage of one point with respect to other is to be detected. The simplest scheme which can be used for such detector is shown in Fig. 7. Here one input is being considered as reference input Vr and other input as signal input Vs. Both the input are applied to the operational amplifier input terminals. Operational amplifiers are used to have maximum sensitivity and zero reliability. The output of both the operational amplifiers is applied to the two different bridge amplifier circuits. The output of the bridge amplifier is applied to the output meter (centre top minimum [illegible]). The connections are made such so that the output of the bridge amplifiers gives the difference of two voltage input signals. The deflection of output meter depends upon the level of both signal input and reference input.

1.2.7 Electronic Amplifier detector [9,13,16]

For precision d.c. measurements of small voltage and current quantities electronic detector is being used. Also increase in sensitivity can be obtained by interposing some broad-band electronic amplifier between bridge and the visual or audio balance detector. But the following point must be kept in mind when selecting such amplifier.

1. No incompatibility between the coupling conditions of the bridge circuit and those of the amplifier.
2. Amplifier must have a linear characteristic ensured by RC coupling and negative feed back.

Wide transistor tuned amplifier and null detector is being discussed using as a general purpose bridge detector. It has a wide continuous range of operating frequency, 20 Hz. to 20 KHz., with additional fixed tuned frequencies of 100 and 500 KHz. [illegible] noise level [illegible] in the amplifier by judicious choice of the transistor in the preamplifier stage [illegible] operating it at [illegible]

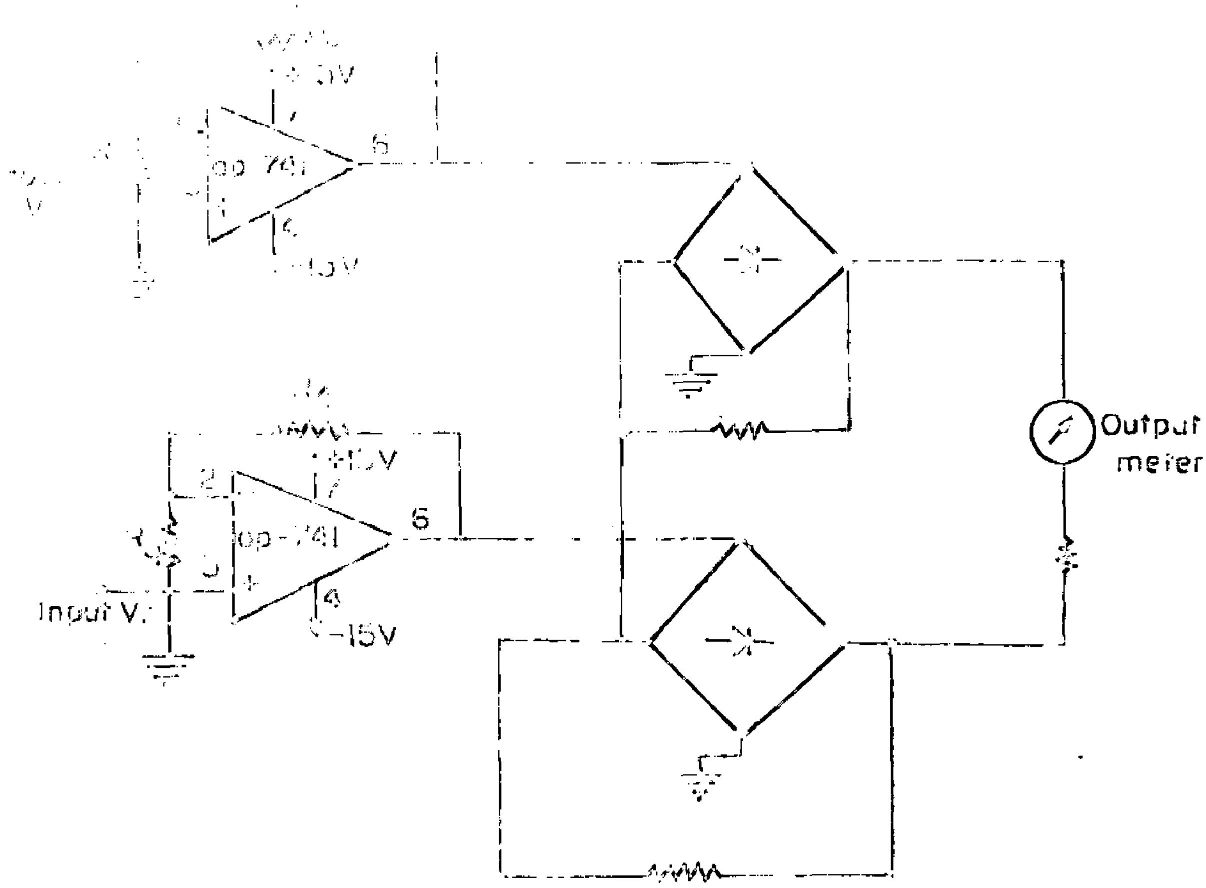


FIG.7 DIFFERENTIAL DETECTOR

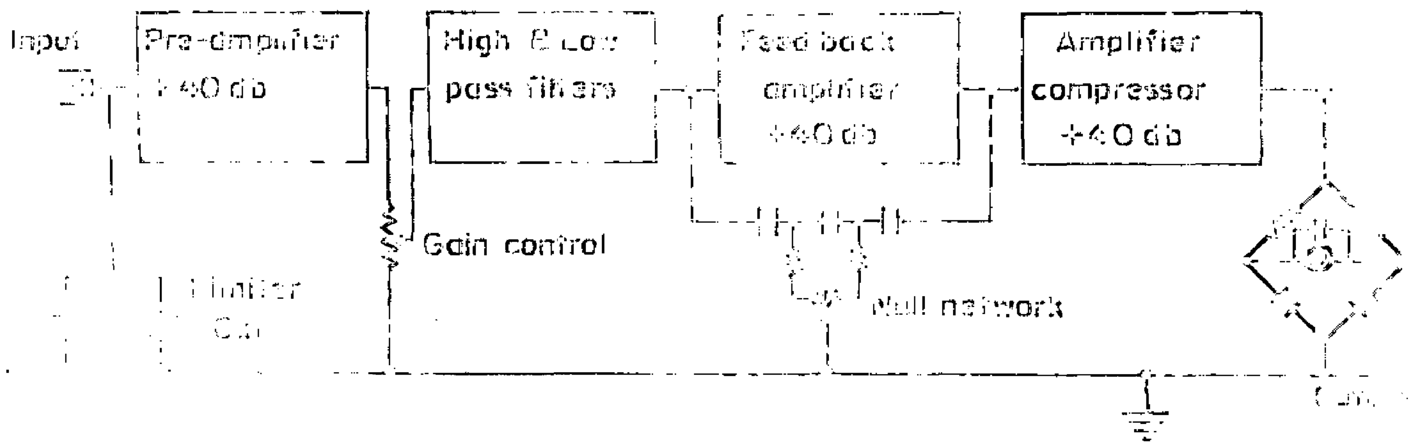


FIG.8 TUNED TRANSISTOR AMPLIFIER & NULL DETECTOR.

unusually low collector current. This feature, together with the total gain of the amplifier of 120 dB, enables a sensitivity of 1 microvolt to be achieved. A schematic block of each detector is shown in Fig. 6.

The limiting circuit at the input end of the amplifier comprises a capacitor and two silicon diodes, and prevents signal greater than 1 volt being applied to the preamplifier. Shunt and series capacitors connected between the preamplifier and the feed back amplifier act as simple filters and define the limits of the tuning range. The output amplifier provides a gain of 40 dB, and silicon diodes connected between this amplifier and earth, because of their non linear V/I characteristics, compress the sensitivity over the upper part of the scale of the indicating meter. Thus the effective range of the meter is increased without affecting the maximum sensitivity, which occurs when the meter pointer is at or near zero.

[illegible] Drysdale phase shifter [10,11]

The Drysdale phase shifter is also known as phase shifting transformer. It is used in conjunction with a.c. potentiometer which is used for accurate measurement of alternating currents and voltages. Here unknown voltage is measured in polar form i.e. in terms of its magnitude and relative phase difference. The theory of Drysdale phase shifter is as under :-

It consists of a ring shaped stator within which, fitting closely inside it, is a rotor which carries a winding supplying the potentiometer slide wire current. The stator is wound with either a three phase or two phase winding. A rotating field is produced when currents flow in the stator winding, and the phase of the secondary, or rotor current can be changed, relative to the stator supply voltage, by rotating the rotor through any desired angle, the phase displacement of the secondary e.m.f. being equal to the angle through which the rotor is moved from its zero position. The winding are so arranged that this alteration of phase is not accompanied by alteration of the magnitude of the rotor induced e.m.f. The phase alteration produced is measured on a divided scale fixed to the top of the instrument. Fig. 8 shows, diagrammatically the connections of the phase-shifter arranged for operation from a single-phase supply, using a phase-splitting device consisting of a capacitor and resistor as shown. By successive adjustment of the capacitor and resistor exact quadrature between the currents in the two stator windings may be obtained. This method, using a single phase supply, forms a very convenient means of supplying the stator windings. This type of phase shifter is used in conjunction with Drysdale - Tinsley a.c. potentiometer.

2.3.0 Phase Splitting Circuit for Quadrature Power Supply [10,11]

Such type of circuit is used alongwith Gall-Tinsley A.C. Potentiometer, which consists of two potentiometer circuits enclosed in a common case. One is called the "in phase" potentiometer and the other the "Quadrature" potentiometer. The circuit diagram of phase splitting circuit is shown in Fig. 10. Here Transformer T_1 (supply phase 1) is connected to "in phase" potentiometer circuit and Transformer T_2 (supply phase 2) is connected to "Quadrature" potentiometer circuit. RC network is included in series with supply phase 2 circuit which gives the 90° phase displacement with respect to supply phase 1. The action of the phase splitting circuit may be understood by referring to Fig. 11, which gives an equivalent circuit for the two potentiometers. R_1 and L_1 are the equivalent resistance and inductance of the in-phase potentiometer circuit, and R_2 and L_2 those of the Quadrature potentiometer. When the potentiometer currents are equal and in quadrature,

$$I_2 = j I_1$$

or

$$\frac{V}{R + R_2 + j\left(\omega L_2 - \frac{1}{\omega C}\right)} = \frac{jV}{R_1 + j\omega L_1}$$

Therefore

$$R_1 + j\omega L_1 = j(R + R_2) - \left(\omega L_2 - \frac{1}{\omega C}\right)$$

By separating real and imaginary parts, we obtain the following conditions for phase splitting as

$$R_1 + \omega L_1 = \frac{1}{\omega C}$$

$$\omega L_1 + R_1 = R$$

The phase splitting is adjusted by means of R and C.

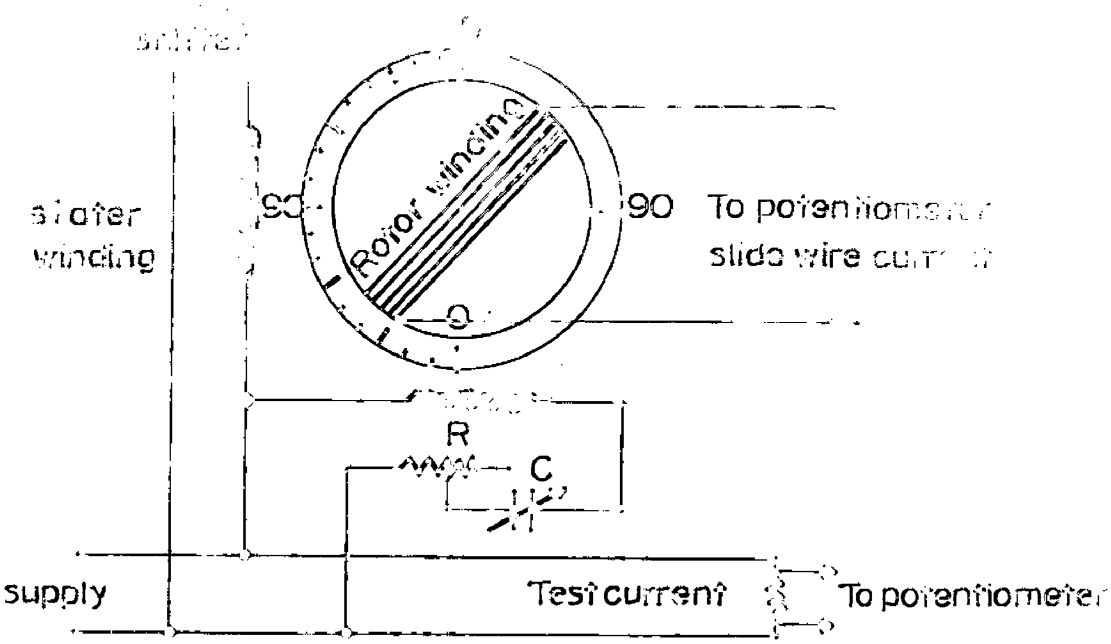


FIG.9 CONNECTIONS OF THE DRYSDALPHASE SHIFTER.

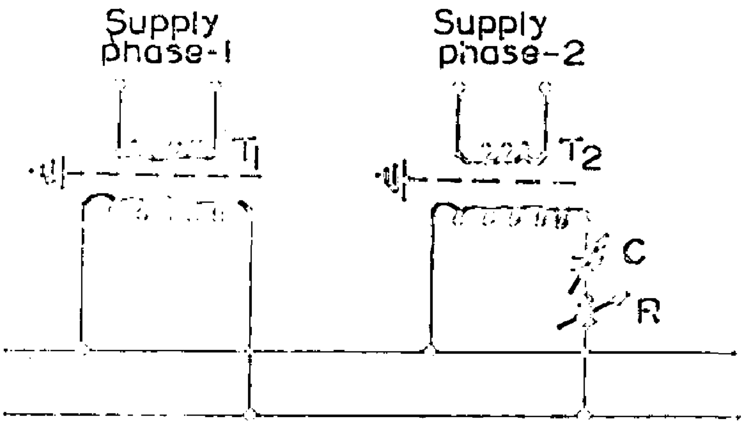
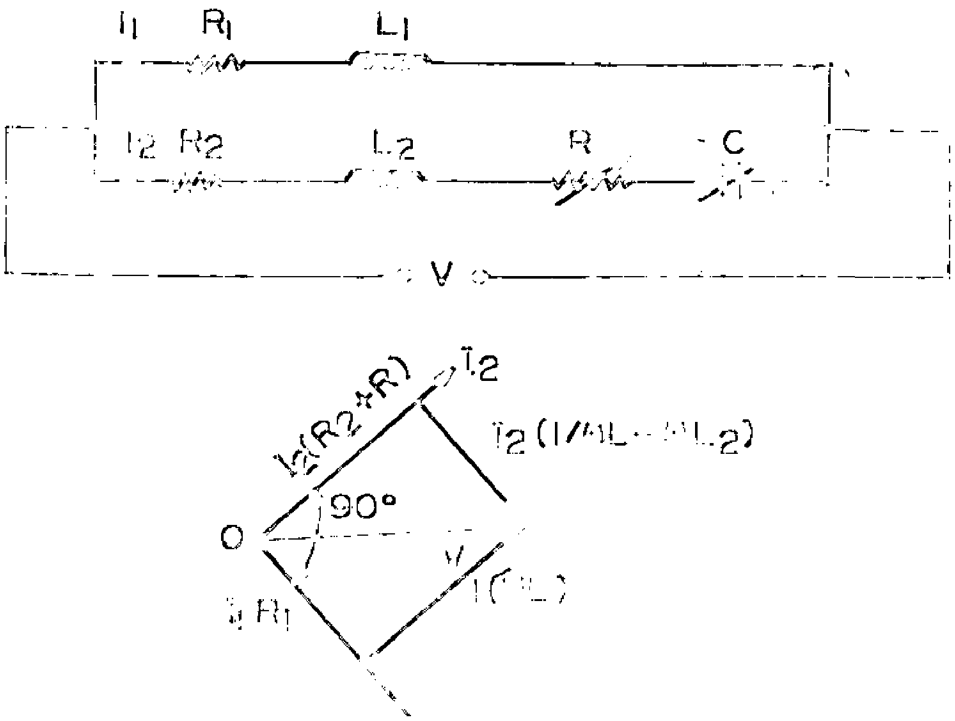


FIG.10 PHASE SPLITTING CKT.



By separating real and imaginary parts, we obtain the following conditions for phase splitting as

$$R_1 + wL_1 = \frac{1}{wC}$$

$$wL_1 = R_2 = R$$

The phase splitting is adjusted by means of R and C.

III. DETAILS OF ELECTRONIC NULL DETECTOR DEVELOPED

The electronic null detector using integrated circuit operational amplifier have been developed here. Each null detector is having microvolt sensitivity. The details of which have been discussed in different parts as under. The total gain which has been taken with each circuit is about 10^6.

3.1 Operational Amplifier

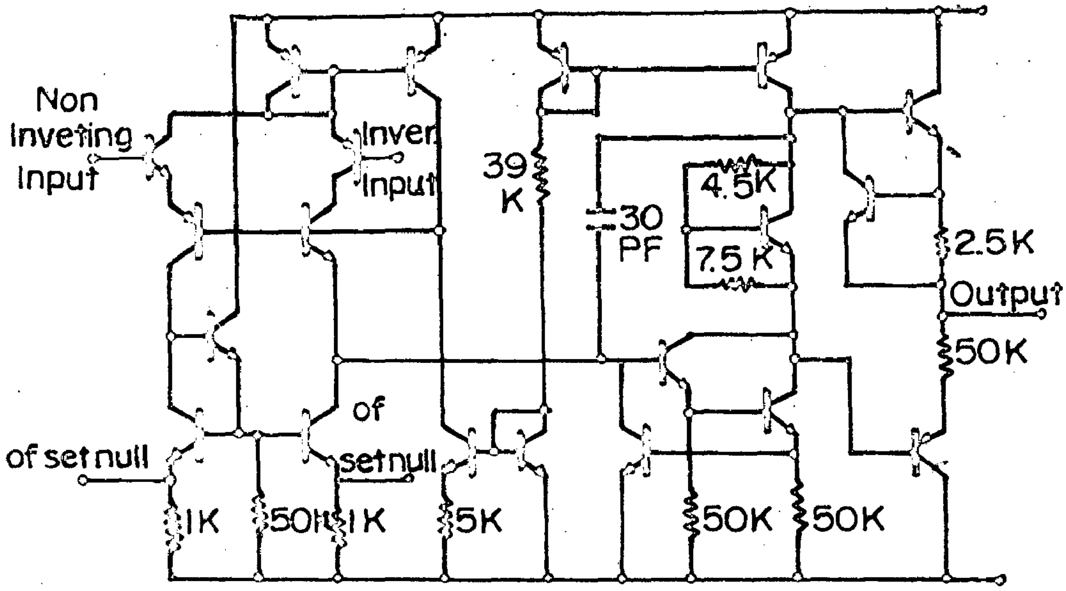
The µA 741 is a high performance operational amplifier with high common mode voltage range and absence of "Latchup" make it ideal for use as a voltage follower. The high gain and wide range of operating voltage provide superior performance in integrator, summing amplifier and general feedback applications.

Design Features:

Open loop gain DC0741	200,000
Input impedance	2 M.Ohm
Output voltage swing	± 14 Volt
Input offset voltage	1.0 millivolt
Common mode rejection	90 db.

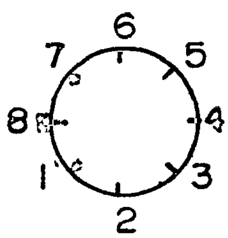
Absolute Maximum Rating:

Supply voltage DC0741	± 18 Volt
Internal power dissipation	500 milliwatt
Differential input voltage	± 30 Volt
Input voltage	± 15 Volt
Operating temp. range	− 55° C to + 125° C



Schematic Diagram

Top view of EC0741



Pin connections

1. of set null.
2. Inverting Input.
3. non-Inverting Input.
4. V –
5. of set null
6. output.
7. V +
8 non connected.

FIG. 12

The ideal operational amplifier is assumed to have the following characteristics :

1. Infinite gain makes the performance entirely dependent on input and feedback networks.
2. Infinite input impedance ensures that no current flows into the amplifier input terminals.
3. Infinite Band-width is a bandwidth extending from zero to infinity, ensuring a response to d.c. signals, zero response time and no phase change with frequency.
4. Zero output impedance ensures that the amplifier is unaffected by the load.
5. Zero voltage and current offset ensures that when the input signal voltage is zero the output signal will also be zero, regardless of the input source resistance.

The foregoing aspects of ideal performance are called the summing point restraints, which are :

1. When negative feedback is applied to the ideal amplifier, the differential input voltage approaches zero.
2. No current flows into either input terminal of the ideal amplifier.
3. The circuit configuration of μA741 is shown in Fig. 11.

8.0 Null Detector Principle

The principle on which each detector works is as follows :

The output signal of unbalanced alternating current bridge is pick up through a shielded cable. The shielded cable is used to avoid unwanted stray signals. Such signal is applied to the preamplifier stage. The output signal is then amplified at particular tuned frequency, the signal other than the required frequency is rejected. The signal from the tuned amplifier is precisely rectified. Such d.c. signal is applied to log amplifier stage with an intermediate d.c. amplifier stage, and then to the output meter which shows how much signal is unbalanced and accordingly A.C. bridge components are adjusted so that the output meter shows zero deflection for null balance.

9.0 Block Diagram

The complete block schematic is shown in Fig. 10. The description of various blocks is as follows :

Limiter and Coupling Circuit

The limiter is used to avoid any wrong polarity signal to be applied to the input terminal. Two diodes are used for such purpose in back to back fashion.

Coupling capacitor is used to block d.c. signal to be applied at the input terminal of operational amplifier.

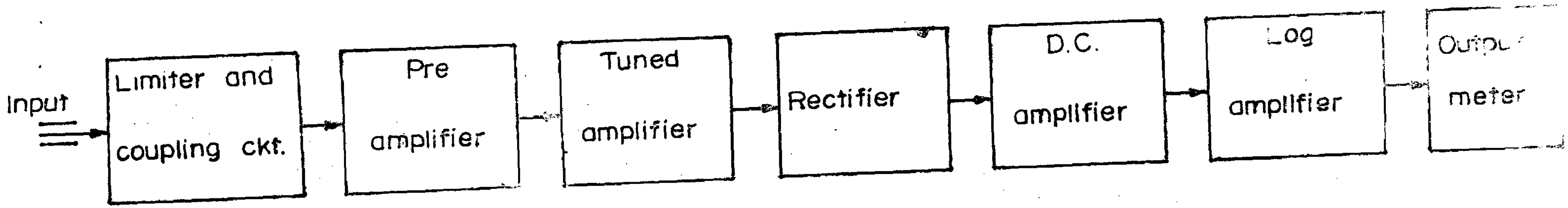


FIG.13 BLOCK DIAGRAM FOR ELECTRONIC NULL DETECTOR.

Pre-amplifier

The pre-amplifier is an high input impedance amplifier, operational amplifier is used for such purposes. Though operational amplifiers are basically high gain d.c. amplifiers, but they are equally suitable for applications not requiring a d.c. response. Since here operational amplifier are used for a.c. amplification, d.c. blocking capacitors are placed in the signal path and in that case amplifier offset and drift specifications are not so important.

Tuned Amplifier

Tuned amplifier is a frequency selective amplifier. The response of the tuned amplifier is maximum at a particular frequency so as to get maximum sensitivity at this frequency and will be minimum at all other above and lower frequencies. To reject the frequencies other than the required filter circuit is used in the feedback path of operational amplifier circuit. The filter used here is Twin "T" filter.

Rectifier Circuit

The rectifier is used to convert the a.c. output signal of tuned amplifier in to d.c. signal. The rectifier circuit consists of combination of diode and operational amplifier for precise rectification, as an germanium diodes shows pronounced non-linearity at low forward voltages, and silicon diode shows no appreciable conduction until forward voltage exceeds 0.3 V(1).

Due to this non-linearity diode gives rise to appreciable error when used to rectify small signals in a conventional rectification circuit. Here half wave rectification circuit of operational amplifier diode combination is used.

D.C. Amplifier

It is used to amplify the output signal of rectifier.

Log Amplifier

Log amplifier is used for deliberate non-linearity amplification. The logarithmic amplification is obtained with the use of solid state diode and transistors along with operational amplifier. The advantage of getting logarithmic null detection is to allow greater dynamic range without switching scales, while still retaining practically full sensitivity on weak input signals. With the help of log amplifier, amplification of input signal applied to the log amplifier can also be achieved.

Output meter

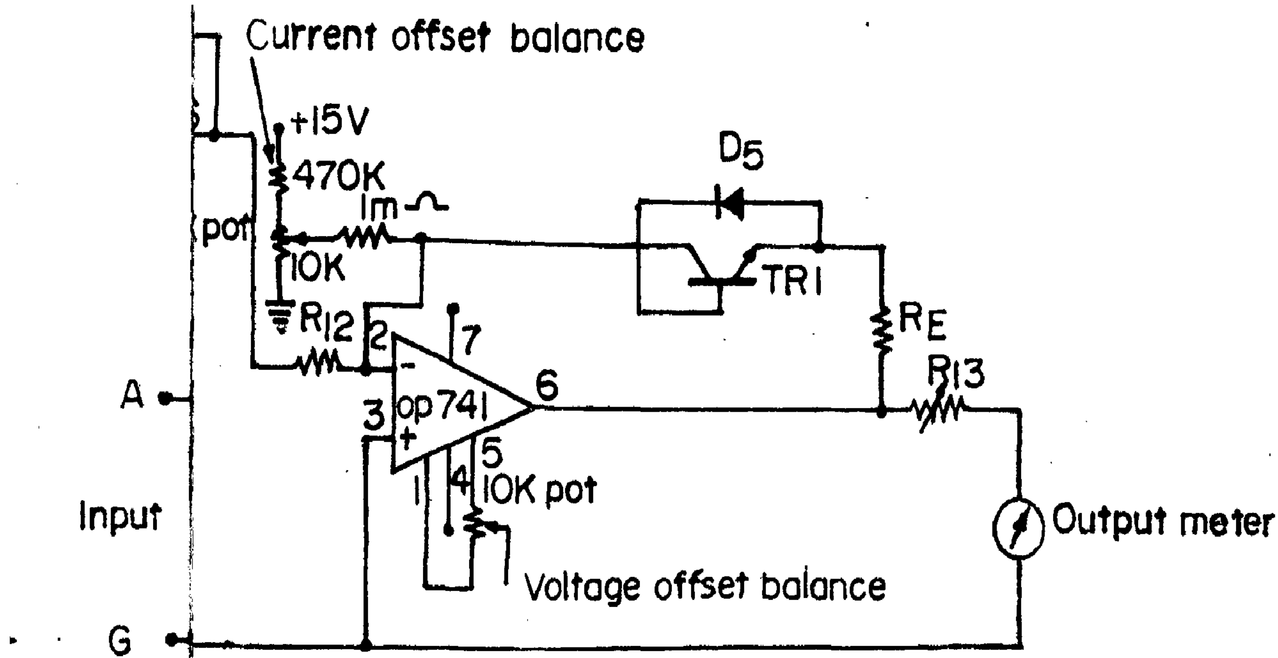
The output meter is a moving coil microammeter which is calibrated in log fashion. A series resistance of appropriate value is included in the meter circuit so as to obtain maximum deflection of meter for maximum input signal applied to the null detector.

3.0 CIRCUIT DETAILS

The complete circuit diagram of electronic null detector which has been designed and fabricated is shown in Fig. 21.

The input signal to the detector is applied at the terminal A through a shielded cable. Since the magnitude of signal is in microvolt, care must be taken to avoid any unwanted signal, both a.c. and d.c. Diode D_1 and D_2 are used to avoid any signal to be applied of wrong polarity and of excessive voltage. As first stage of detector is high input impedance d.c. amplifier and it is obtained due to positive feed back applied via R_1, C_1 and R_2 to the lower end of R_3. Since operational amplifier is used in noninverting mode the output will be in same phase as the input signal with amplification of about 10 times input signal. This signal is applied to the next stage i.e. tuned amplifier (frequency selective amplifier) through a coupling capacitor C_3 to avoid any unwanted d.c. signal and to pass only the a.c. signal. The circuit uses the inverting feed back configuration, the feed back path incorporates a twin 'T' network (rejection filter) and feed back resistance R_5. The property of such twin 'T' filter is that it offers a maximum impedance at its characteristic frequency (1000 Hz.) and hence the gain will be maximum at this frequency. R_4 is the input impedance to the amplifier. Final tuning of the network is done by varying the resistance R_7. The total gain obtained with this amplifier is of about 100.

The output of the selective amplifier is coupled to the next stage by a coupling capacitor C_6 to avoid any d.c. signal to be passed. The



Log-amplifier

no 4 = -15V & Pin no7 = +15V

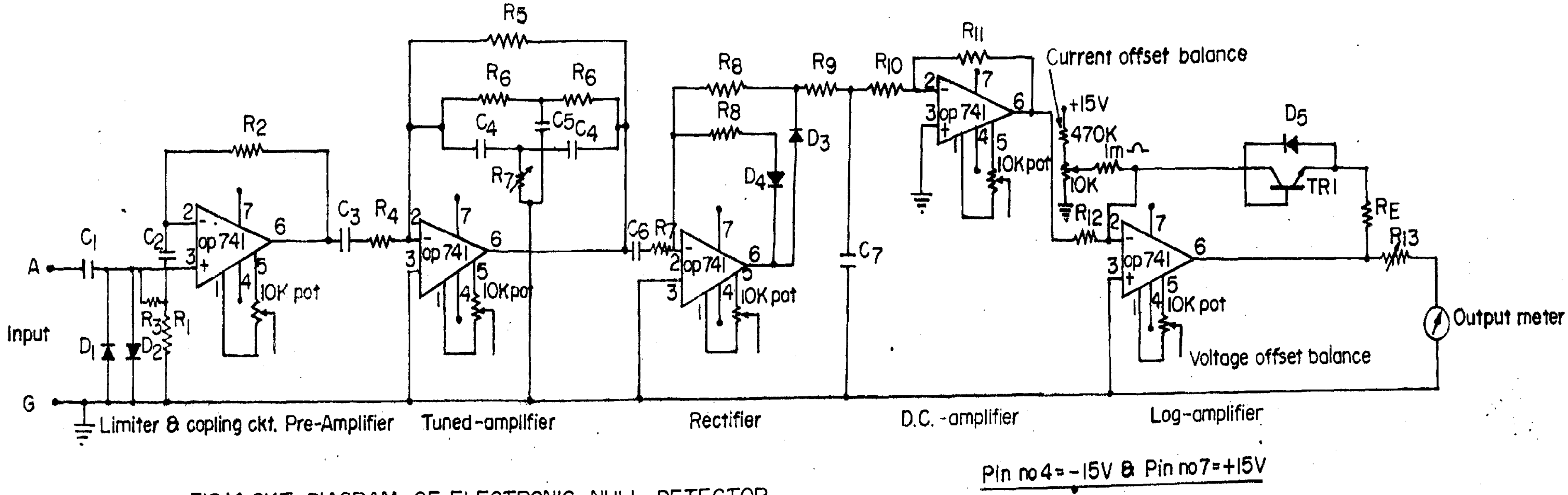


FIG.14 CKT. DIAGRAM OF ELECTRONIC NULL DETECTOR.

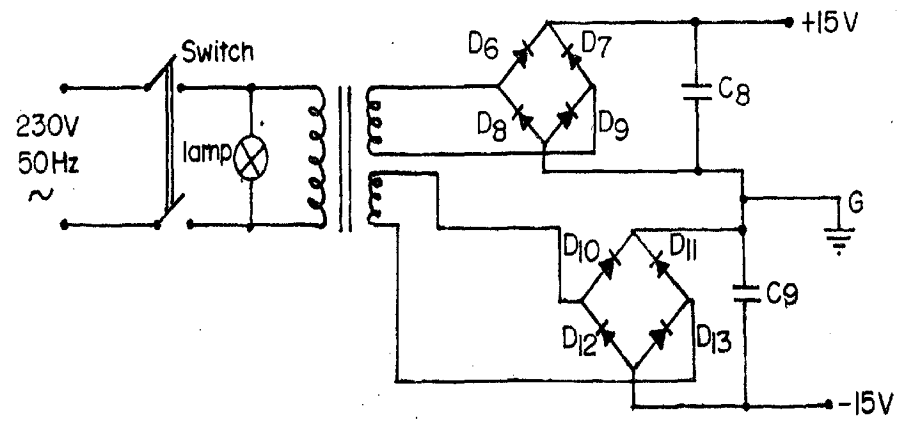


FIG.15 CKT. DIAGRAM OF DUEL POWER SUPPLY FOR OP.-AMP.

signal applied to the rectifier stage is sinusoidal tuned at 1 KHz. As can be seen from Fig. 14 the diode D_3 is connected in the feed back path of the amplifier so that the initial forward voltage drop required to make the diode conduction is supplied by the amplifier output voltage. Before diode conduction starts the amplifier acts virtually open loop so that signal required at the input to cause diode conduction is very small. Once the diode D_3 is conducting the effect of its nonlinearities on the rectified output is effectively divided by the loop gain. The second feed back path through diode D_4 is included in the circuit to prevent amplifier output saturation on the input half cycles for which D_3 is reversed biased. The gain of the circuit is decided by the resistances R_3 and R_4. The output of the rectifier is taken from the cathode of diode D_3. This rectified output is connected to an R C filter (R_5, C_1) to get pure d.c. signal which is applied to the next stage i.e. d.c. amplifier. D.C. amplifier is being used to amplify the rectified signal by two times.

The output of d.c. amplifier is applied to input of log amplifier stage. The log amplifier is an operational amplifier transistor feed back circuit used to perform logarithmic conversion. It is to be kept in mind that logging performance obtained with an operational amplifier log element combination is influenced both by the characteristics of the amplifier and by the characteristics of the logging element. As it can be seen from Fig. 14 negative feed back is applied to the operational amplifier through a diode connected transistor TR_3. This type of circuit is suitable for positive input voltage. Diode D3 is connected in parallel with the logging transistor against the excessive reverse voltage which would arise if the input signal of wrong polarity were inadvertently applied. The series resistance R_E is connected in series with the logging transistor to reduce the effective loading on the amplifier output at the higher value of feed back current. The output voltage of the circuit which is taken from the emitter of the logging transistor can be given by the following relation :

$$e_o = V_{BE} = -K_o \log_{10} \frac{I_c}{I_o}$$

where,

e_o = output voltage

I_o = theoretical reverse saturation current

I_c = collector current

= I_i = e_i / R

K_o = constant

For achieving widest logging range from the log amplifier both the input voltage offset and the bias current of the amplifier are separately balanced. To make these adjustments the transistor with its protective diode are disconnected from the circuit and large value resistor (say 1 M.Ohm) is connected in their place. Input offset voltage is balanced first. This is done by shorting pin '3' of the amplifier to earth and adjusting the offset voltage balance potentiometer for zero amplifier output. Now the shorting of pin '3' is removed and input voltage to the circuit is set to zero and the bias current potentiometer is adjusted so that the amplifier output is again zero. Now for operation of log amplifier the transistor with its protective diode is again connected in the path. The output of the log amplifier is connected to the moving coil microammeter through a series resistance R_{10}. The deflection of the meter varies in the log fashion as the input signal applied to the detector is varied. The input power supply for operational amplifier is of ± 15 Volt.

3.0 Design

Limiter and Coupling Capacitor

Two diode are used in back to back fashion to avoid input signal of wrong polarity or excessive input voltage. The diode used here are [illegible].

The value of coupling capacitor is based on the magnitude of input impedance of source from which input signal is taken. The value of coupling capacitor is calculated as follows :

Let the input impedance of preamplifier = 1 M.Ohm

Then X_c = 1 M.Ohm

f = 1000 Hz.

Therefore, $\frac{1}{2 \pi f C_1} = 1 \times 10^6$

or $C_1 = \frac{1}{10^6 \times 2 \times 3.14 \times 1000}$

= 160 PF.

The value chosen C_1 = .001 MF.

$R_0 = 1 / \sqrt{0.20 \times 100 \times 0.000 \times 10^{-6}}$

R_0 = 4.0 K.Ohm.

The Gain of Tuned amplifier can be given by

Gain = R_4 / R_3

where

R_4 = feed back resistance

R_3 = input resistance

If Gain = 100

R_4 = 100 K.Ohm.

then R_3 = 1 K.Ohm.

The value of C_3 is so chosen so that

$C_3 R_3$ $C_4 R_0$

Let us take C_3 = 10 MF

The values of circuit components used in the Tuned Amplifier circuit are as follows :

C_3 = 10 MF, R_0 = 4.0 K.Ohm, C_4 = 0.000 MF

R_3 = 100 K.Ohm, R_4 = 1 K.Ohm

$R_7 = R_0 / 2$ = 2.0 K.Ohm, $C_5 = 2 C_4$

Rectifier

Three operational amplifier alongwith solid state diode are being used for precise rectification and also gain of 10 is being taken from this rectifier, the values of resistances are calculated as follows :

The Gain can be given by = R_8 / R_7

Let R_7 = 1 K.Ohm, Gain = 10

then R_8 = 10 K.Ohm.

<u>Preamplifier</u>

Since it is an simple high input impedance non-inverting a.c. amplifier. The operational amplifier used is LM0741.

Let the gain of pre-amplifier is about 11.

Also for the given circuit diagram the gain can be described by the following formula :

Gain = $1 + R_3 / R_2$

If R_3 = 100 K.Ohm

Then R_2 = 100 / 11 - 1 = <u>10 K.Ohm</u>

The resistance R_1 used here is d.c. biasing resistance. The value of d.c. biasing resistance is taken

R_1 = <u>1M.Ohm.</u>

<u>Tuned Amplifier</u>

This type of amplifier consists of an resistance capacitance feed back network. The feed back is simple Twin-T filter. The value of different components of filter are calculated as follows :

For Twin-T filter

$$f_0 = \frac{1}{2\pi C_4 R_6}$$

where

f_0 = characteristic frequency

Since f_0 = 1 KHz.

If C_4 = 0.033 μF

Then R_6 = 1 /(2π [illegible] C_4 f_0)

The diode used are simple silicon diode [illegible].

The coupling capacitor C_0 is connected in series between the two stages i.e. Tuned amplifier and Rectifier circuit to suppress d.c. signals. The value of coupling capacitor being used is 10 MF.

$$C_0 = 10 \text{ MF}.$$

To null the offset voltage of operational amplifier, 10 K pot. is being connected between the pin '1' and '5' of operational amplifier (as specified by the manufacturer).

D.C. Amplifier

The gain which is being taken from this amplifier is 1.

Gain $= R_{10} / R_9$

If R_{10} = 10 K.Ohm.,

then R_9 = 10 K.Ohm.

Log Amplifier

Log amplifier used is diode connected transistor type. The transistor must have high h_{fe}. The value of R_{11} is being so selected so that close loop stability can be maintained.

The transistor used is [illegible] and Diode [illegible].

The value of R_{11} taken as = 10 K.Ohm.

The offset voltage is being balanced by 10 K potentiometer connected between pin '1' and '5' of operational amplifier, variable point of potentiometer is connected to negative of power supply.

The bias current is then injected to the collector terminal of transistor, so as to reduce current offset to zero. The value of resistances are being selected as specified by the manufacturer.

Transformer for Operational Amplifier

Transformer for dual power supply of operational amplifier is designed for following specifications :

Primary voltage = 220 Volt (P to P)

Secondary voltage = 12 Volt - 0 - 12 Volt (P to P)

The number of turns for primary winding is calculated as under :

$E_p = 4.44 f \phi A N_p$ Volt

where

E_p = 220 Volt

ϕ = 1 Wb/m^2

A = Area of former = 4 sq.cm.

N_p = Number of primary turns

f = 50 Hz.

Therefore,

N_p = 2480 turns

Also we know the relation

$$\frac{N_p}{N_s} = \frac{E_p}{E_s}$$

Therefore, N_s = 120 turns

Total number of secondary turns will be 240.

The bridge rectifiers which are used for rectification purposes are silicon diode <u>SR 304</u>.

The filter is simple RC filter. The value of capacitor is being taken.

$C_2 = C_3 =$ <u>1000 MF</u>, 25 V D.C.

The diagram of dual power supply for operational amplifier is shown in Fig. 15.

The details of size of wire and stamping are given in Appendix A1.

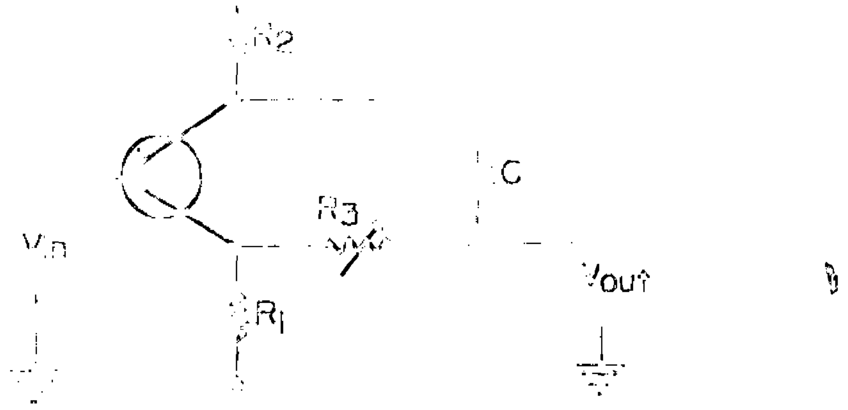


FIG.16a PRINCIPLE OF CONSTANT AMPLITUDE PHASE SHIFTER.

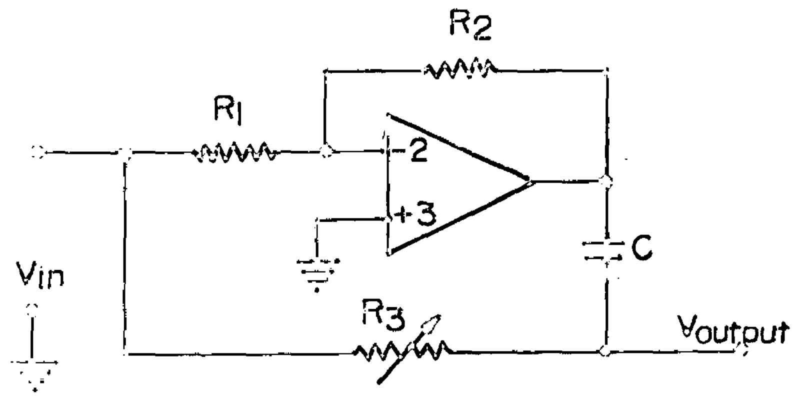


FIG.16b COFIGURATION OF PHASE SHIFTER USING OPERATIONAL AMPLIFIER.

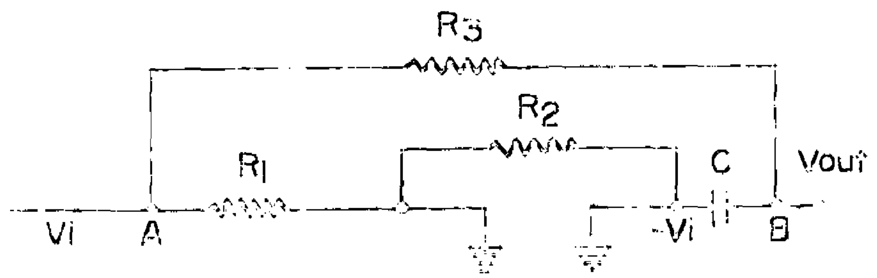


FIG.16c. EQUIVALENT CKT. OF PHASE SHIFTER.

III. DETAILS OF ELECTRONIC POWER SUPPLIES DEVELOPED

3.1 Pulse Power Supply

3.1.1 Working Principle

For pulse power supply the main requirement is to get output with phase angle variation from 0 to 360°, without changing the amplitude of output voltage. The simple circuit using transistor is shown in Fig. 1(a).

The calculation of the output to input voltage ratio yields

$$\frac{V_{out}}{V_{in}} = \frac{(g_m R_1) \times (1 - R_2/R_1)\, j\omega CR_2}{(1 + g_m R_1) \times (1 + j\omega R_2 C)} \quad \ldots \quad (1)$$

where g_m is the transconductance of the transistor.

If $R_1 = R_2$, and g_m is sufficiently large, then

$$\frac{g_m R_1}{1 + g_m R_1} = 1$$

Equation (1) shows the transfer function of an all pass filter. The amplitude accuracy which can be obtained with the help of above circuit is not satisfactory. The circuit using operational amplifier based on the above principle gives better results in respect of amplitude accuracy.

For the ideal case :

Open loop gain G_0 =

Source resistance R_0 = 0

Load resistance R_L =

Condition $R_1 = R_2$

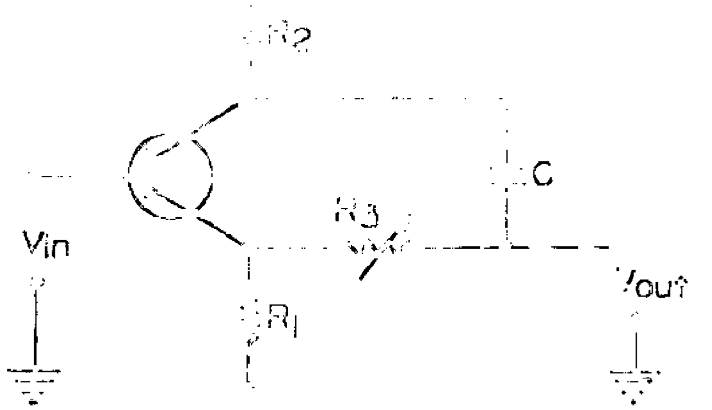


FIG.16a PRINCIPLE OF CONSTANT AMPLITUDE PHASE SHIFTER.

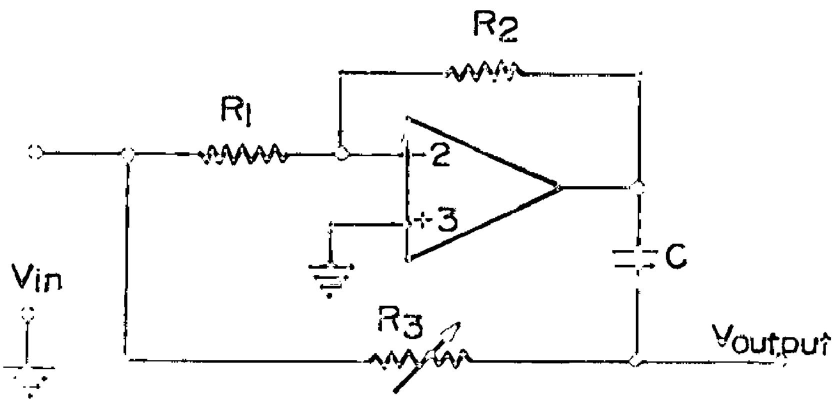


FIG.16b. COFIGURATION OF PHASE SHIFTER USING OPERATIONAL AMPLIFIER.

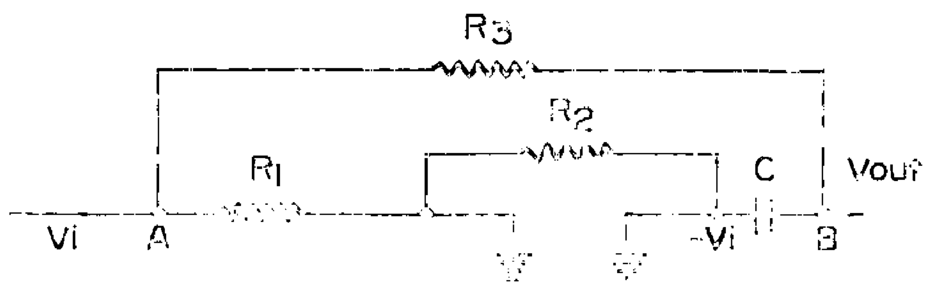


FIG.16c. EQUIVALENT CKT. OF PHASE SHIFTER.

The circuit using operational amplifier is being shown in Fig. 10(b). The equivalent circuit is shown in Fig. 10(c).

Applying Kirchoff's current law at point B

$$\frac{V_i - V_o}{R_1} + \frac{-V_i - V_o}{Z_c} = 0$$

or $\quad V_i \left(1/R_1 - 1/Z_c \right) = V_o \left(1/R_1 + 1/Z_c \right)$

or $\quad V_i \left(1/R_1 - j\omega C \right) = V_o \left(1/R_1 + j\omega C \right)$

or $$\frac{V_o}{V_i} = \frac{1 - j\omega C R_1}{1 + j\omega C R_1} \qquad \ldots \qquad (1)$$

or $$\left| \frac{V_o}{V_i} \right| = 1$$

and $$\angle \frac{V_o}{V_i} = \frac{\tan^{-1} \omega C R_1}{\tan^{-1} (-\omega C R_1)}$$

Therefore, angle between V_{in} and V_{out} = $\tan^{-1} 2\omega C R_1$.
The ideal conditions at the input and output can be reasonably approximated to by adding two further operational amplifiers in buffer stage. As it can be seen from equation (1) that output amplitude is constant when the phase angle is varied from 0 to 180°. Since for the phase shift of 180° the value of R_1 becomes infinity hence two phase shift networks are being used for getting exact phase shift of 180° for pulse power supply at constant output amplitude. The phase shift from 180° to 360° is being achieved by changing the input terminals of supply.

3.1.2 Block Diagram

The complete block schematic using the above principle for changing the phase angle between input and output of pulse power supply is shown in Fig. 17.

The buffers at the input and output of the phase shifter are used to get high input impedance and low output impedance. These buffers are internally connected voltage follower I which draws only 10 nA. input current and provides a amplification of approximately unity. Care must be taken in selecting the passive circuit elements. As seen from the block diagram two phase shift networks are being used, one phase shift network for varying the angle roughly and other phase shift network is being used to correct the required value of phase angle having fine adjustment knob. After second phase shift network as seen from the block diagram buffer stage is again used to achieve the required condition. The next stage is booster follower which is used to get the increased current output from an operational amplifier. Also phase angle meter is connected across the output of booster follower to read the phase angle between the signal output and reference input signal.

3.1.3 Circuit Diagram

The complete circuit diagram of pulse power supply is shown in Fig. 18.

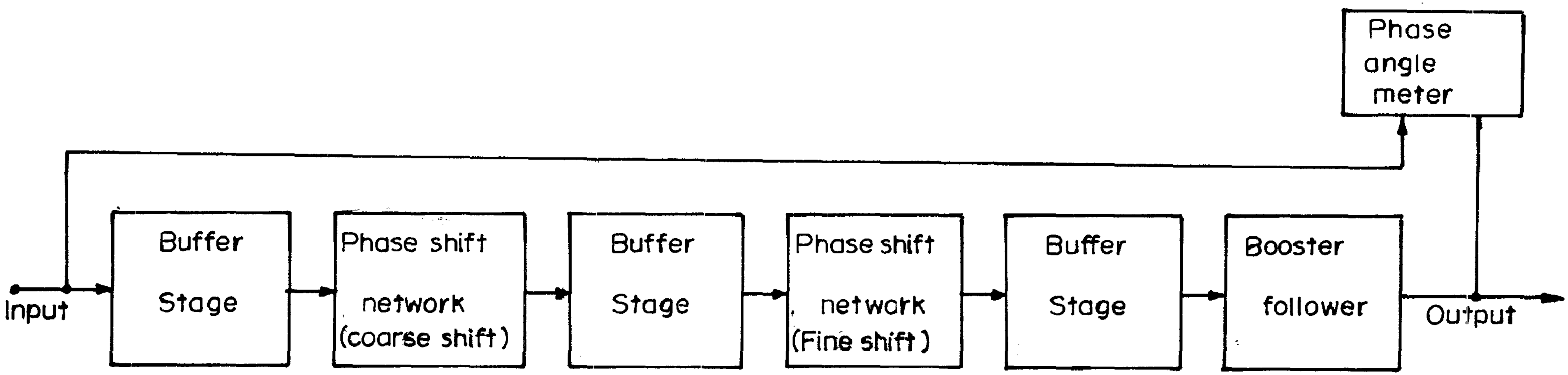
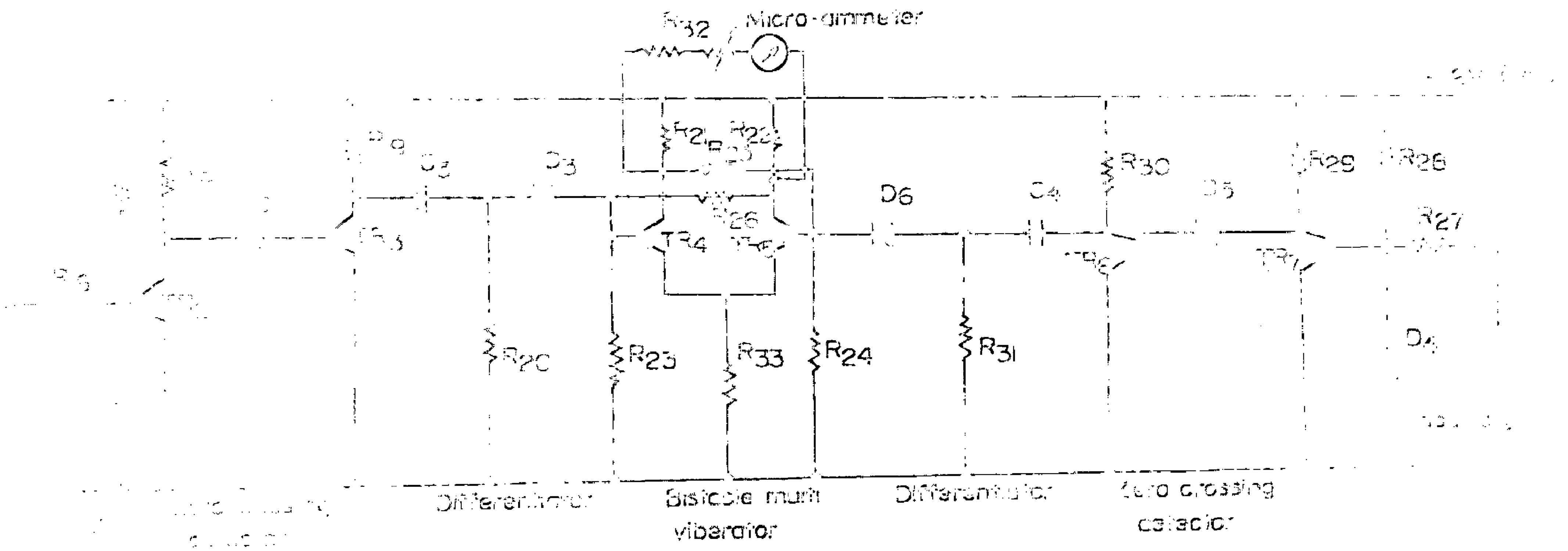


FIG.17 BLOCK DIAGRAM OF POLAR POWER SUPPLY.

The input applied to the OA_1 is of 8 Volt approximately, which is taken from a step down power transformer. Operational amplifier used is in non-inverting mode so that requirement of high input impedance and low output impedance can be achieved. The gain of amplifier is being unity. The output of OA_1 is applied to the phase shift network I. The value of R[illegible] and R[illegible] are approximately equal but for constant output at various phase angle as discussed in article 3.1.1, small resistances R[illegible] and R[illegible] (variable) are being added in series with R[illegible] and R[illegible] respectively, to make the total feed back resistance equal to total input resistance. The phase angle of input signal can be varied with the help of resistance R[illegible]. The output is taken from the point A not from the pin '6' of OA[illegible]. The next stage is again an voltage follower. The output of voltage follower is applied to the phase shift network II which is being used for fine angle adjustment. The total resistance of feed back path is made equal to the total input resistance with the help of R[illegible]. The phase angle can be varied with the help of R[illegible]. Here again the output is taken from point B and not from the pin '6' of OA[illegible], which is being applied to the pin '3' of OA[illegible]. A single emitter follower circuit is included in the feed back loop of operational amplifier '3' to get increased current output. The output is taken from the emitter of an power transistor which is connected to the step up power transformer so as to get required output of 110 V.[illegible] and as required for polar potentiometer.

The input applied to the OA_1 is of 8 Volt approximately, which is taken from a step down power transformer. Operational amplifier used is in non-inverting mode so that requirement of high input impedance and low output impedance can be achieved. The gain of amplifier is being unity. The output of OA_1 is applied to the phase shift network I. The value of R_2 and R_3 are approximately equal but for constant output at various phase angle as discussed in article 3.1.2, small resistances $R_{[illegible]}$ and $R_{[illegible]}$ (variable) are being added in series with $R_{[illegible]}$ and $R_{[illegible]}$ respectively, to make the total feed back resistance equal to total input resistance. The phase angle of input signal can be varied with the help of resistance $R_{[illegible]}$. The output is taken from the point A not from the pin '6' of $OA_{[illegible]}$. The next stage is again a voltage follower. The output of voltage follower is applied to the phase shift network II which is being used for fine angle adjustment. The total resistance of feed back path is made equal to the total input resistance with the help of $R_{[illegible]}$. The phase angle can be varied with the help of $R_{[illegible]}$. Here again the output is taken from point B and not from the pin '6' of $OA_{[illegible]}$, which is being applied to the pin '3' of $OA_{[illegible]}$. A simple emitter follower circuit is included in the feed back loop of operational amplifier '4' to get increased current output. The output is taken from the emitter of an power transistor which is connected to (step up) power transformer so as to get required output of 110 Volt, 50 c/s as required for polar potentiometer.



PHASE ANGLE METER CKT. DIAGRAM.

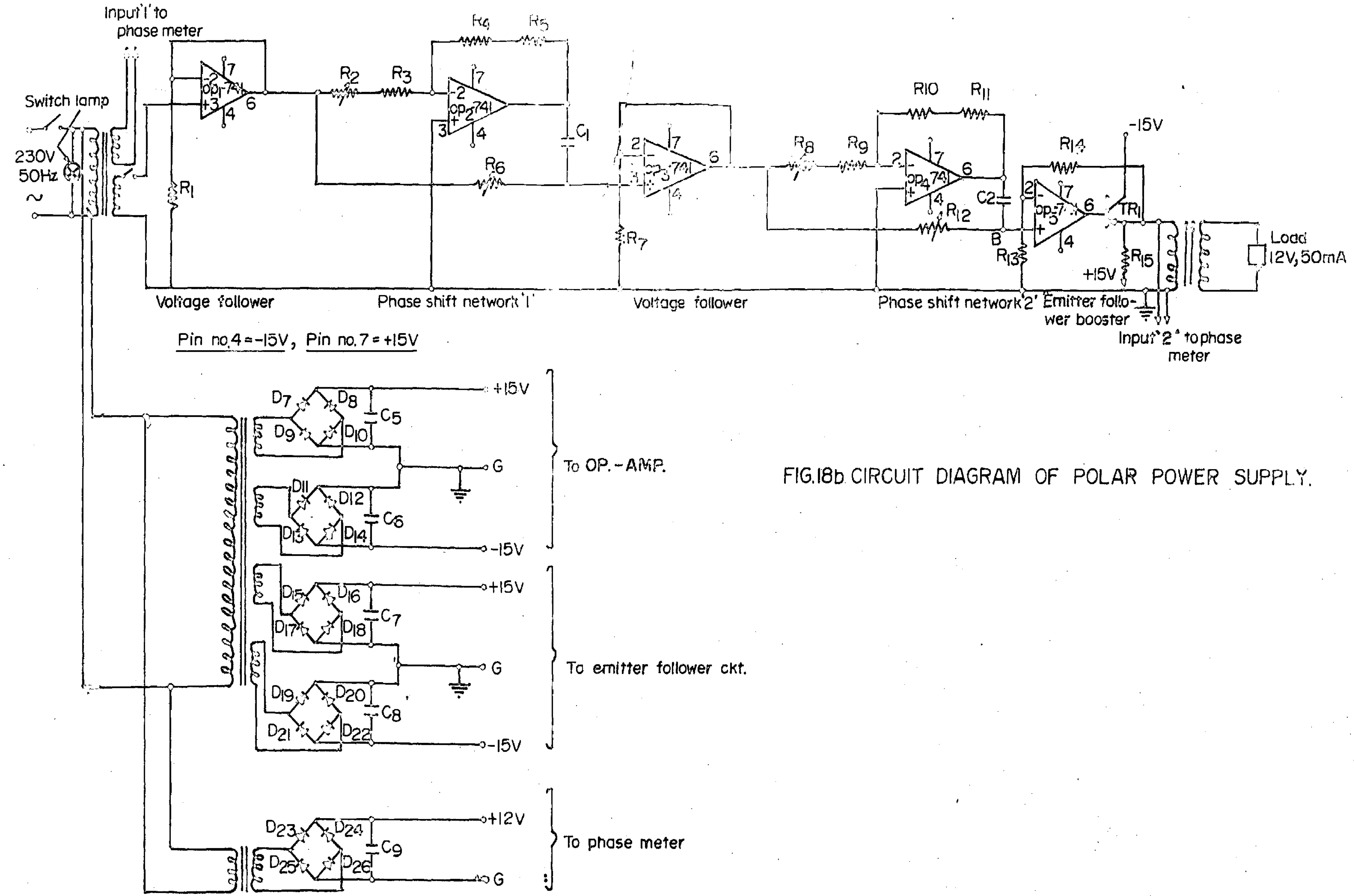
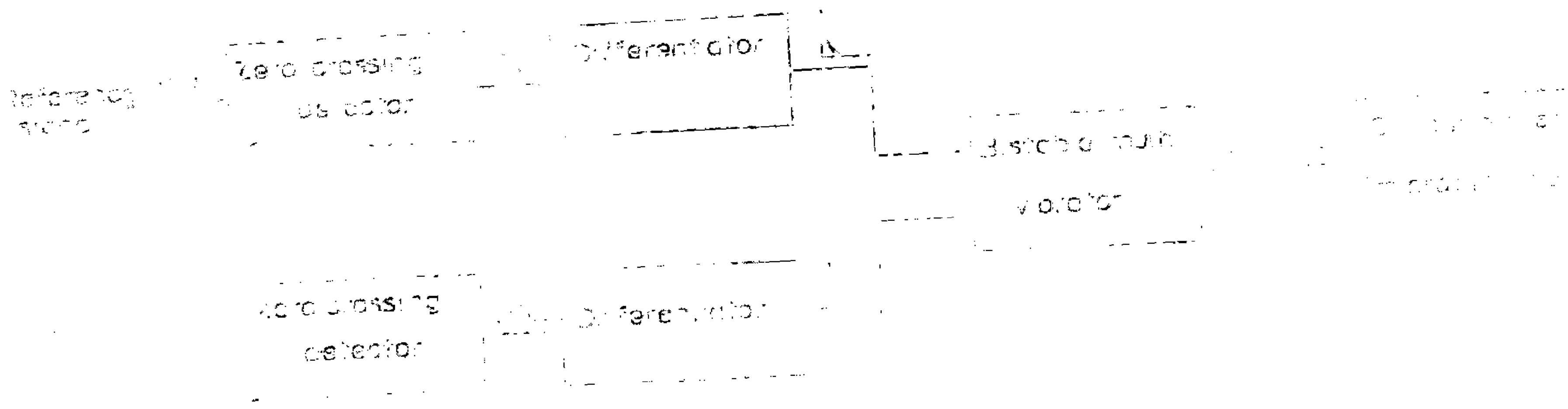


FIG.18b CIRCUIT DIAGRAM OF POLAR POWER SUPPLY.



BLOCK DIAGRAM OF

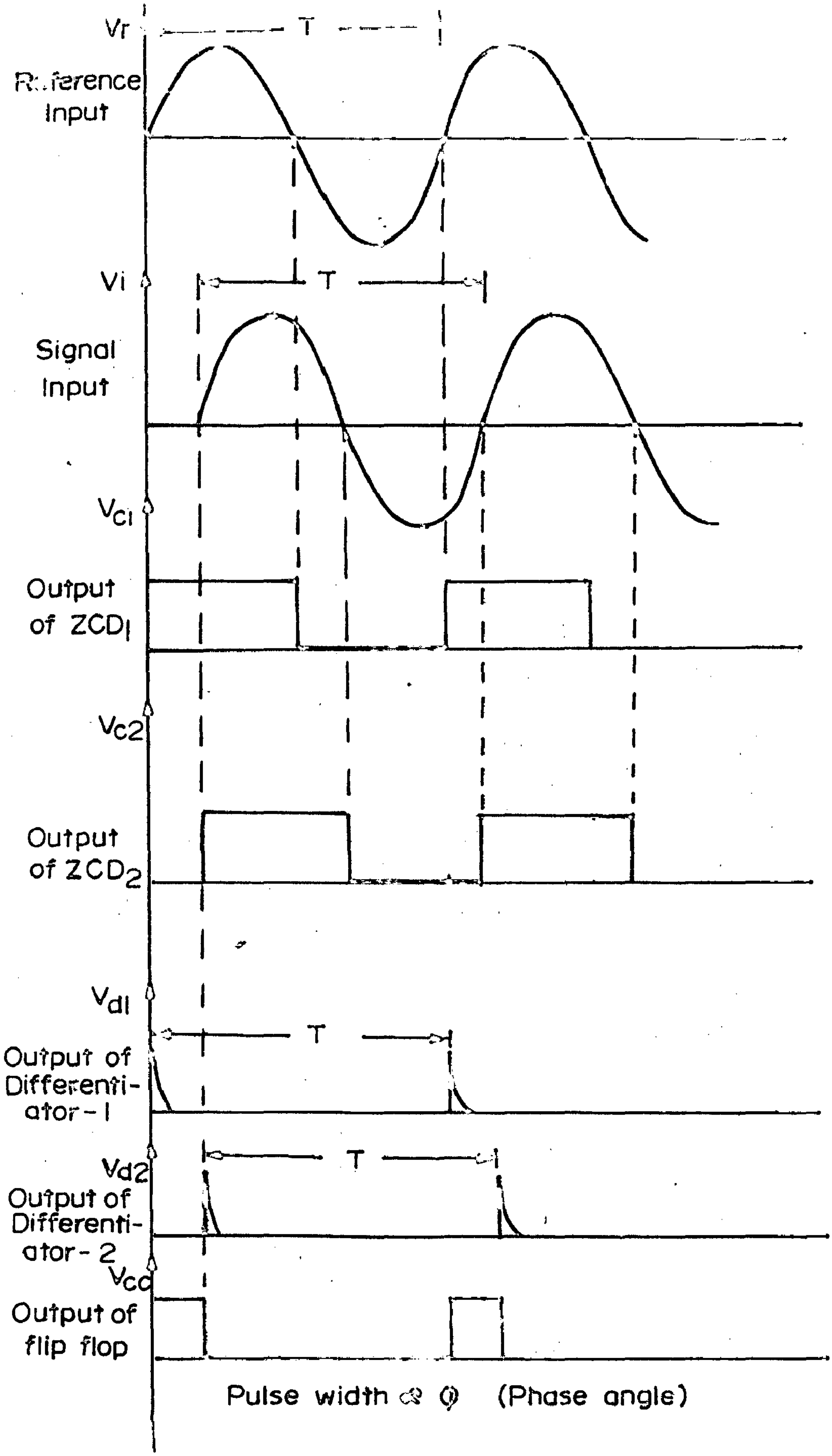


FIG.20 WAVE FORMS OF PHASE ANGLE METER.

To measure the phase angle between output and input phase angle meter has also been included in the circuit. The block diagram of phase angle meter is shown in Fig. 19. Here two signals one of which is reference input signal and other is output signal from the pulse power supply, is applied to the two separate zero crossing detectors. The output from the zero crossing detectors is square wave which is being differentiated by differentiator. The pulse from differentiator is passed through switching diode so as to obtain only positive pulses. These pulses are applied to flip flop circuit. The conduction period of T_{r6} and T_{r9} depends on the width of two switching pulse applied successively to the base of T_{r6} and T_{r9}. The output taken from the collector of T_{r6} and T_{r9} is a square wave whose time period varies according to the phase difference between the input signal and reference signal applied to the two separate zero crossing detectors. This output is applied to a microammeter through a series resistance R_{33} which reads the phase displacement between the two signals. The complete wave forms for phase angle meter are shown in Fig. 20. Fig. 21 (photograph) also shows the output taken from flip flop whose pulse width is directly proportional to the phase angle.

3.3.6 Phase Shift Network

Two phase shift networks have been used to get the total phase shift of 180° with respect to the reference input signal.

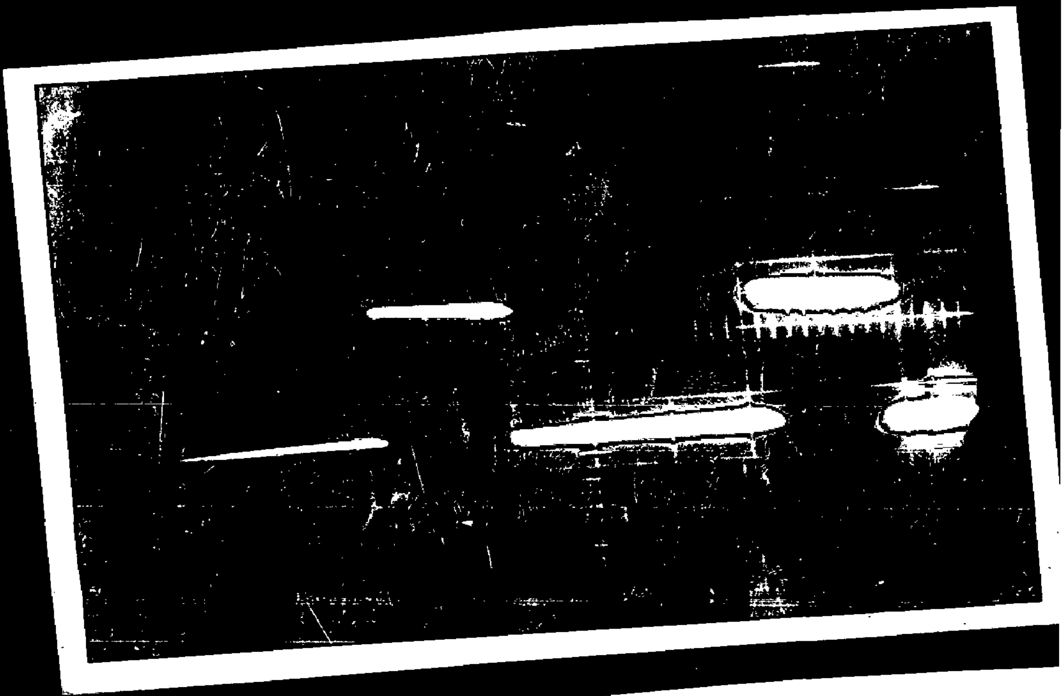


Fig. 32 PULSE WIDTH & PHASE ANGLE

Phase Shift Network I

The total phase shift between input and output can be expressed by

$\theta = \tan^{-1} 2\omega C_1 R_6$ (as derived from equation (2))

For $\theta = 30^\circ$

$C_1 = 1$ MF

then $R_6 = \dfrac{\tan\theta}{2\omega C_1}$

$= \dfrac{0.57735}{2 \times 2 \times 3.14 \times 50 \times 1 \times 10^{-6}}$

$R_6 = 12$ K (Approx.)

Since R_6 is being kept variable to vary the angle, the value of potentiometer being selected is 50 K.Ohm.

R_6 = <u>50 K.Ohm.</u> (Pot.)

Phase Shift Network II

The total phase shift between the two signals can be represented by

$\theta = \tan^{-1} 2\omega C_2 R_{12}$

For $\theta = 50^\circ$ and $C_2 = 0.2$ MF

$R_{12} = \dfrac{1.19175}{2 \times 2 \times 3.14 \times 50 \times 0.2 \times 10^{-6}}$

$R_{12} = 10$ K (approx.)

The value of potentiometer being selected is

R_{12} = <u>10 K.Ohm.</u> (variable Pot.)

Booster Amplifier

It is an simple emitter follower included in the operational feed back loop. Total gain from this amplifier has been taken 3 which can be varied with the help of R_{34}.

Since this has been used in non-inverting mode the gain can be represented by

Gain $= 1 + R_{34}/R_{33}$

If $R_{33} =$ 10 K.Ohm. , Gain = 3

then, $R_{34} =$ 20 K.Ohm.

The value of R_{35} is so selected so that total 500 mA current can flow in the load circuit.

If the total supply voltage = $\pm$ 20 Volt

and $I_L =$ 1000 mA

then, $R_E = \frac{20}{1000 \times 10^{-3}}$

or, $R_E =$ 20 Ohm.

The power transistor is mounted on the aluminium plate of square size so that proper heat dissipation may take place.

Phase Angle Meter

(a) Zero Crossing Detector

[illegible] transistor be used [illegible].

$T_{?}$ and $T_{?}$ are being used for zero crossing detector.

Given, $V_{cc} =$ 12 V, V_{BE} sat = 0.6 V

Assume, $I_c =$ 3 mA, $h_{fe} =$ 60

Then, $I_b = 3 \times 10^{-3} / 60 =$ 50 micro Amp.

Also $R_{[illegible]} = \frac{V_{[illegible]} - V_{[illegible]}}{I_{[illegible]}}$

$= [illegible] - 0.[illegible] / [illegible] \times 10^{-[illegible]} = [illegible]$ K.Ohm.

$R_{[illegible]} =$ [illegible] K.Ohm. ([illegible])

As $V_{[illegible]} = [illegible]$ V

So $R_{[illegible]} = \frac{V_{[illegible]} - V_{[illegible]}}{I_{[illegible]}}$

$= [illegible] - 0.[illegible] / [illegible] \times 10^{-[illegible]}$

$R_{[illegible]} =$ [illegible] K.Ohm. (approximately)

Also $R_{[illegible]} = \frac{V_{[illegible]} - V_{[illegible]}}{[illegible] \times 10^{-[illegible]}}$

$=$ [illegible] K.Ohm. (approx.)

Similarly,

$R_{[illegible]} =$ [illegible] K.Ohm.

The other zero crossing detector consisting of transistor $T_{[illegible]}$ and $T_{[illegible]}$ the values will be same as calculated above i.e.

$R_{[illegible]} = R_{[illegible]} = [illegible]$ K

$R_{[illegible]} = R_{[illegible]} = [illegible]$ K

$R_{[illegible]} = R_{[illegible]} = [illegible]$

(c) Differentiator

The maximum frequency to which the differentiator has to respond is [illegible] Hz. Hence

[illegible] $T_{[illegible]}$ can be represented by

$[illegible] = [illegible] = [illegible]$ m.sec.

Then the time constant $R_{[illegible]}C_{[illegible]}$ = 1/[illegible] T_p = 0.[illegible] m.sec.

If $R_{[illegible]}$ = 40 K

then $C_{[illegible]}$ = 0.[illegible] x 10^{-3} / 40 x 10^{3} = 0.0[illegible] microfarad (app.)

$C_{[illegible]}$ = [illegible] microfarad

Also, $C_{[illegible]}$ = $C_{[illegible]}$ = 0.0[illegible] microfarad

and $R_{[illegible]}$ = $R_{[illegible]}$ = 40K

[illegible] diode [illegible] are being used to get only positive pulses from differentiator.

(c) [illegible]

The bistable multivibrator comprises of $Tr_{[illegible]}$ and $Tr_{[illegible]}$.

The transistor used is [illegible]

Given, V_{CC} = 10 V, V_{CE} = 0 (approx.)

I_c (sat) = [illegible] mA, h_{FE} = [illegible]

When Tr_1 saturated

I_c = $V_{CC}/(R_{[illegible]} + R_{[illegible]})$

Let V_o = 1 V (approx.)

then $R_{[illegible]} \times I_c$ = 1.[illegible] V

and $\frac{R_{[illegible]} + R_{[illegible]}}{R_{[illegible]}} = \frac{V_{CC}}{V_o}$

$R_{[illegible]}/R_{[illegible]}$ = [illegible]

Therefore, $I_c = \frac{V_{CC}}{R_{[illegible]} + R_{[illegible]}} = \frac{V_{CC}}{[illegible] R_{[illegible]}}$

or $R_{[illegible]}$ = [illegible] Ohms. (approx.)

Now h_{FE} = 100 (approx.)

Since Tr_1 and Tr_2 are same transistors,

So, R_{B1} = R_{B2} = [illegible]

Now, V_C with only R_C and R_{G1}

Therefore

$$V_C = V_{CC} \times 0.0[illegible] / [illegible] + 0.[illegible] = 1.1\,V$$

For Tr_2 OFF, B - C junction is reversed biased and it should be generally of 0.6 Volt i.e.

$$V_{BE} = -0.6\,\text{Volt}, \quad V_C = -1.1\,\text{Volt}$$

$$V_{B} = V_{BE}\ \text{OFF}$$

So, $$\frac{R_{1} + R_{2}}{R_{2}} = \frac{V_{G1}}{V_{B2}} = \frac{1.1}{0.6}$$

$$= 2\ \text{(approx.)}$$

Therefore, $R_{B1} = R_{B2}$

For Tr_1 (ON)

$$V_{CE} = 0\ \text{(approx.)}, \quad \text{So}\ V_{B1} = 1.1\,V$$

$$I_B \geq I_C / h_{FE} \geq 5 \times 10^{-3}/50 \geq 10^{-4}$$

$$I_B \geq 0.1\,mA$$

Also $R_{B2}/R_{B1} = R_{B2}/R_{B2} = 1$

Since, $$I_{B1} = \frac{V_{CC} - V_{B1}}{R_{C2} + R_{B1}} - \frac{V_{B1}}{R_{B2}}$$

$$= \frac{[illegible] - 1.1}{R_{C2} + R_{B1}} - \frac{1.1}{R_{B2}} \geq 0.1\,mA$$

Since, $R_{B2} \gg R_{B1}$

hence, $0.9 / R_{18} \gg 0.1$ mA

or $R_{18} \leq 6K$

Take $R_{18} = R_{19} = R_{20} = R_{21} = 6K$

Transformers :

The following transformers have been designed for [illegible] power supply :

(1) Transformer for Operational Amplifier Supply.

Specification

Primary voltage 220 V (P to P)

Secondary voltage 11 V - 0 - 11 V (P to P)

To get dual output, one primary and two separate secondary windings are used.

$E_p = 4.44 f \phi A N_p$ Volt

Given : $f = 50$ Hz. , $\phi = 1$ wb/m^2

$A = 2.54 \times 2.54$ cm^2

$E_p = 220$ Volt

So $N_p = 1000$ turns

Also $N_s = 70$ turns

Total number of secondary turns for two secondary windings will be 140.

(2) Transformer for [illegible] Supply

Specification :

Primary voltage 220 V (P to P)

Secondary voltage 9 V (P to P)

Given : A = 6 sq.cm.

ϕ = 1 wb/m^2

Then N_p = [illegible] turns

Also N_s = [illegible] turns

(c) Transformer for Pulse Amplitude and Phase Angle [illegible]

Specifications :

Primary voltage [illegible] V (P to P)

Secondary voltage (0 - [illegible] V) and (0 - [illegible] V) (P to P)

Given : A = [illegible] sq.cm.

ϕ = 1 wb/m^2

Then N_p = [illegible] turns

Also for V_{s1} = [illegible] Volt, N_{s1} will be [illegible] turns.

and for V_{s2} = [illegible] Volt, N_{s2} will be [illegible] turns.

(d) Transformer for Pulse Supply Output Circuit.

Specifications :

Primary voltage [illegible] Volt

Secondary voltage [illegible] Volt

Given : A = [illegible] sq.cm.

ϕ = 1 wb/m^2

Then N_p = [illegible] turns.

Also N_s = [illegible] turns.

The details of size of wire and type of stampings are given in Appendix [illegible].

Output Meter.

The output meter used for phase angle measurement is permanent moving coil microammeter of range 100 - 0 - 100 microamp. The output of bistable multivibrator taken from collector terminal of transistor Tr_4 and Tr_5 is applied to moving coil microammeter through a series resistance R_{SE}. The series resistance is so adjusted so as to give full scale deflection for 180° and zero deflection for zero degree. The value of R_{SE} calculated is,

R_{SE} = 57K (Pre-set)

3.3 QUADRATURE POWER SUPPLY

3.3.1 Working Principle

The Quadrature power supply presently developed works on the following principle.

The phase shift of 90° is obtained with the help of two RC networks. Each RC network gives phase shift of 45°. Care must be taken in selecting these passive circuit elements. Only paper capacitors are used which are very much insensitive to temperature, and resistors used should be of metal film. But due to non-availability of metal film resistor, the resistors have been made of manganin wire which are being wound on plastic bobbins. The output signal of the second stage of RC network is very much attenuated so it is further amplified. The output of amplifier is applied to booster emitter follower circuit to get large current output.

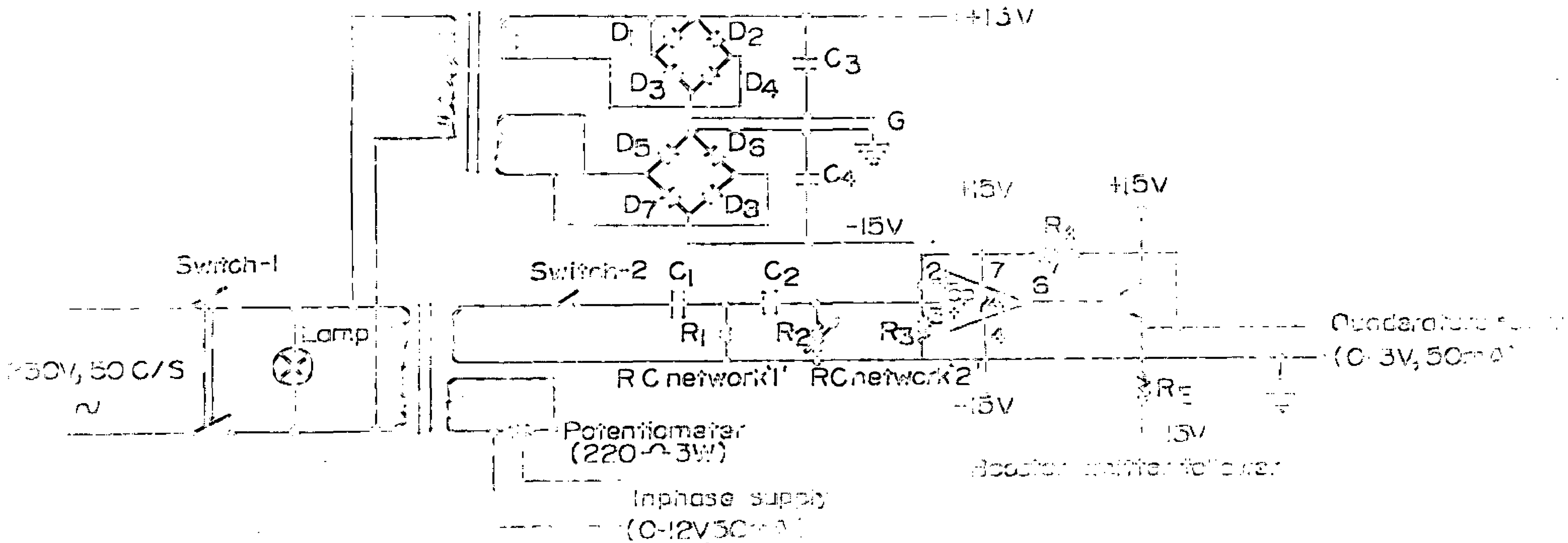
3.3.2 Block Diagram

Fig. 31 shows the complete block diagram of electronic instrument developed. It consists of different stages. The function and description of each stage is as follows :

Phase Shift Network

The phase shift network is an simple RC network combination. The output is taken from the common point of R and C elements. Two such RC networks are being used to get total 90° phase shift from the reference input signal.

FIG.21 BLOCK DIAGRAM OF QUADRATURE POWER SUPPLY.



Preamplifier:

It is used to amplify the output signal of RC network.

Emitter Follower:

Since large current cannot be drawn from the output of preamplifier stage, emitter follower circuit is included in the feed back path of the operational amplifier circuit to meet the above requirement.

3.2.0 Circuit details

The complete circuit diagram with component details is shown in Fig. 11. The input to the RC network is applied through a step down transformer. The value of paper capacitor used must be large enough so that signal attenuation is less. Resistive element of the second RC network is kept variable, so that exact phase shift of 60° can be achieved. The output signal is so attenuated that it requires amplification of the signal. The amplification is achieved with the help of preamplifier. The preamplifier is an operational amplifier used in non-inverting mode. The advantage of using the operational amplifier in non-inverting mode is to achieve high input impedance and low output impedance. The gain of each amplifier is $(1 + R_4/R_3)$. The resistance R_4 is kept variable to adjust the gain according to the required specifications of [illegible] power supply. Since for d.c. [illegible] potentiometer at least 50 mA current is being required (0 to 5 volt) so for getting increased current output from an operational amplifier, an emitter follower circuit is being included in the operational feed back loop. The resistance RE is connected in series with the emitter of the transistor, whose value is so selected so that at least 20 mA current can pass through the load circuit. The d.c. supply to the operational amplifier and transistor circuits is given from a single dual supply. The magnitude of d.c. supply is ± 15 volt.

3.4.4 Design

Phase shift network:

For single RC network

$\omega C_1 R_1$ = tan θ

For θ = 60°

$\omega C_1 R_1$ = [illegible]

If C_1 = [illegible] MF , f = 50 Hz.

Then R_1 = [illegible]

= [illegible] K (approx.)

R_1 = [illegible] K (selected)

C_1 = [illegible] MF

The value of R_2 and C_2 for second phase shift network [illegible] of phase shift network I.

Pre-amplifier.

The gain of the amplifier can be given by

$$\text{Gain} = 1 + R_f/R_1$$

For $R_1 = 1\,K$ and $R_f = 4.7\,K$ (variable)

Max Gain = 5.7

The above gain can be varied from unity to the limit of 5.7.

Transformer Design

Specification :

Primary voltage 230 Volt (P to P)

Secondary voltage 12 V - 0 - 12 V (P to P)

To get dual output, one primary and two separate secondary windings are being wound.

Given : $\phi = 1\ wb/m^2$

$A = 4$ sq.cm.

The number of primary turns calculated from the above given data are :

$N_p = 2590$ turns

Therefore, $N_s = 135$ turns

Total number of secondary turns will be 270. The details of size of wire and type of stampings used are given in Appendix A1.

Rectifier

Bridge type rectifiers are being used for full wave rectification in the power supply. The diodes used are [illegible].

VI. [illegible]

6.1 Electronic Null Detector

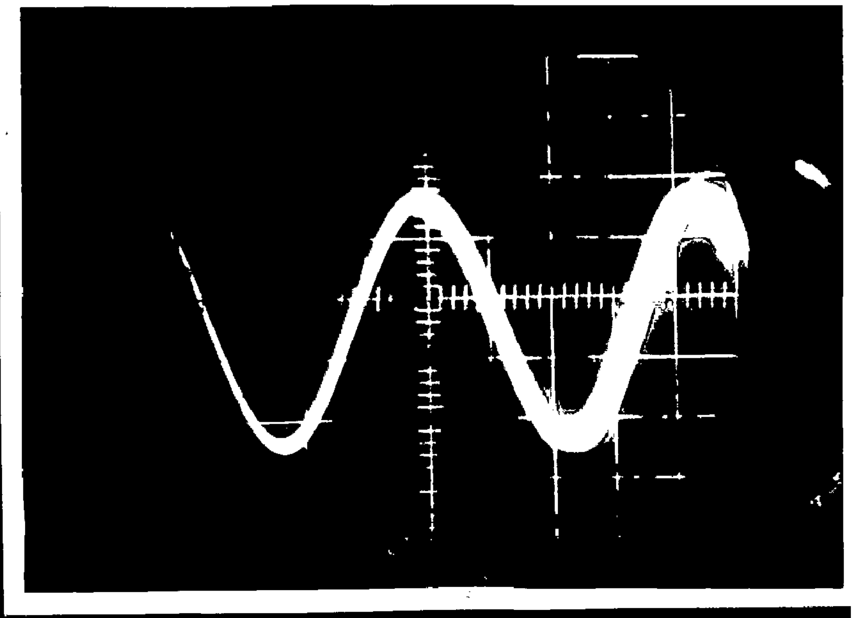
The graphs and photographs attached herewith shows the response characteristics of electronic null detector. The graphs are plotted for the following parameters :

1. The graph shown in Fig. 23 is plotted between the gain of the tuned amplifier and the frequency variation of the input signal applied to the preamplifier while the input signal to the preamplifier remains constant. Since the detector is tuned at a particular frequency (here 1 KHz.) so the output will be maximum at this frequency and will be attenuated very much at other frequencies, which resembles the practical curve. The photographs (Fig. 24(a), 24(b) and 24(c)) havealso been taken for frequencies 1010, 1000 and 900 Hz., which further verifies the result.

2. The graph shown in fig. [illegible] is plotted for the output of the log amplifier versus input to the preamplifier. Since the variation is in log fashion (will be linear when traced on log paper) between input and output, which approximately resembles the plotted curve.

The test results obtained from null detector are given in Appendix A-II.

Fig. 24(a) SINE WAVE AT 990 Hz



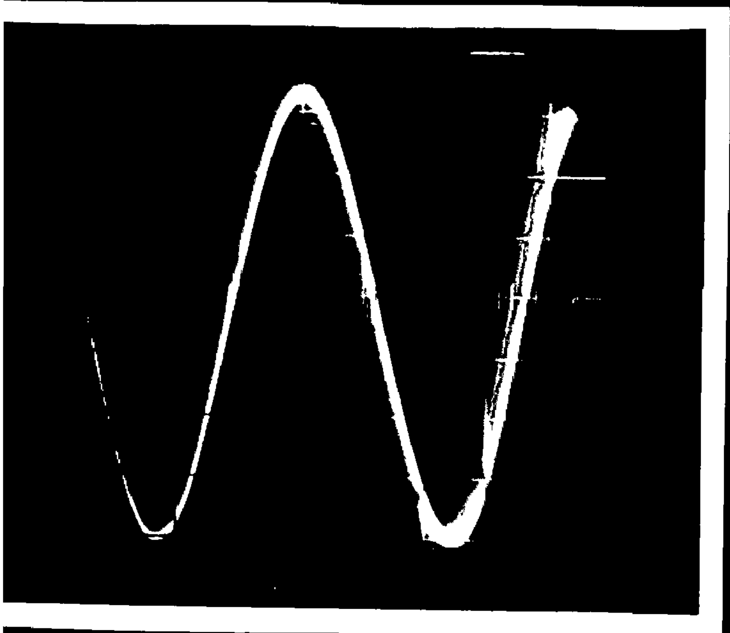


Fig. 24(b) SINEWAVE TUNED AT 1 KH

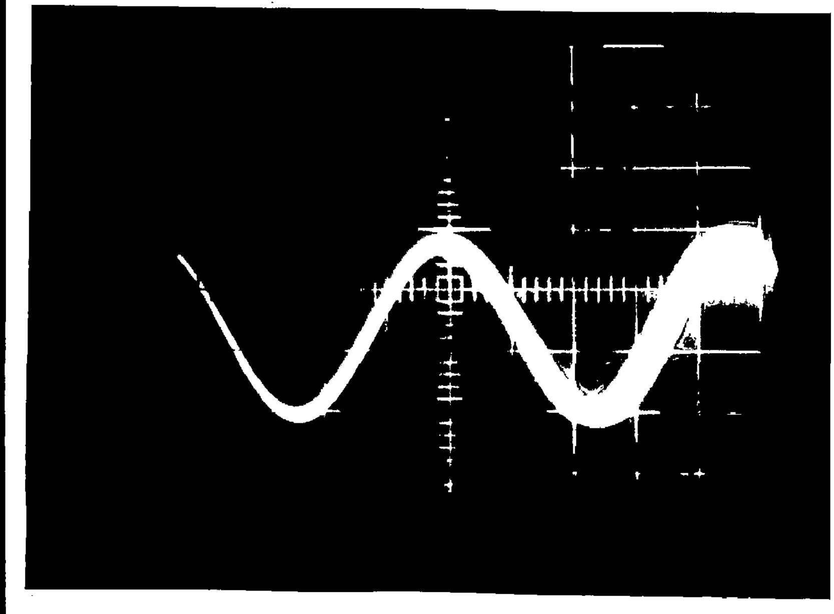
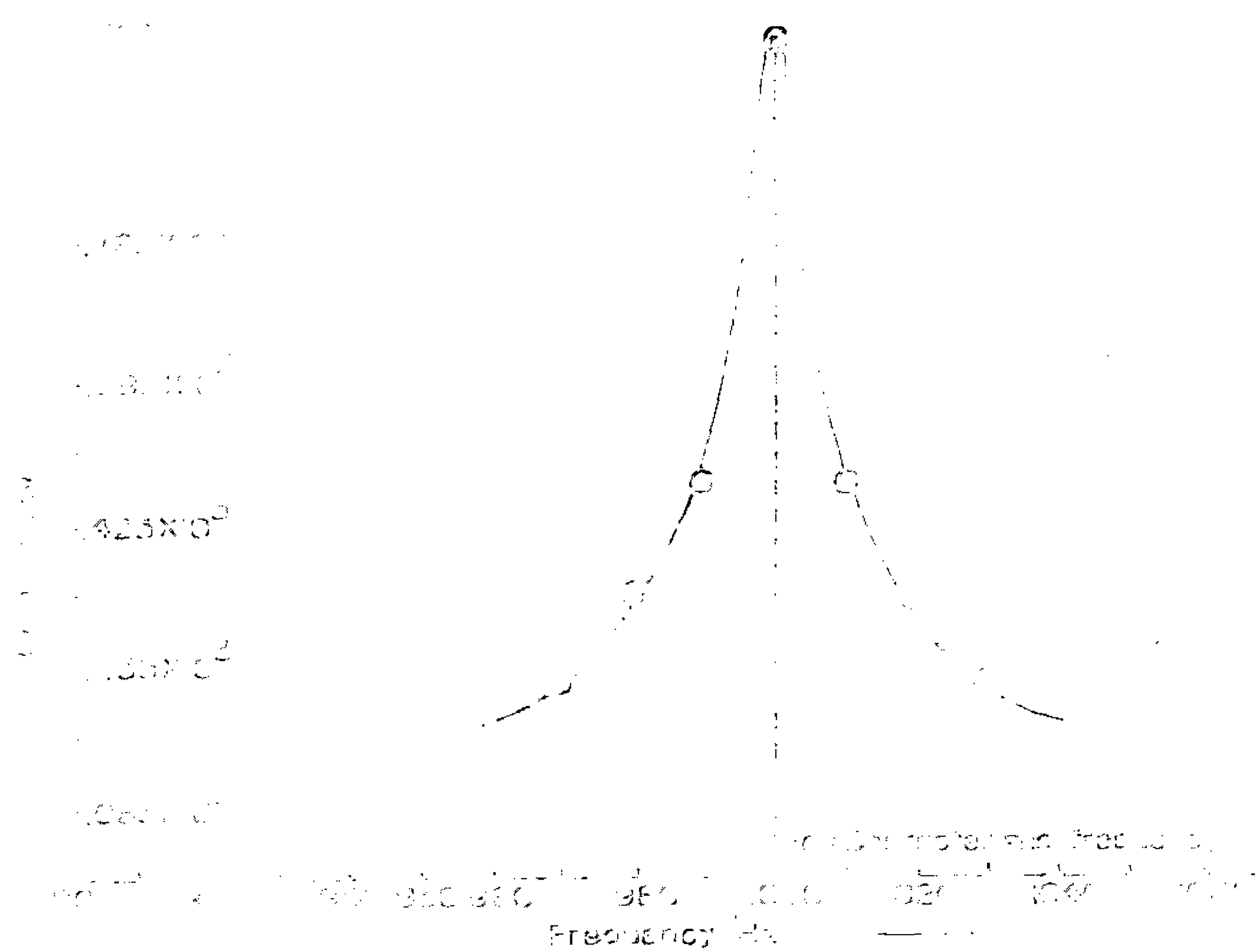
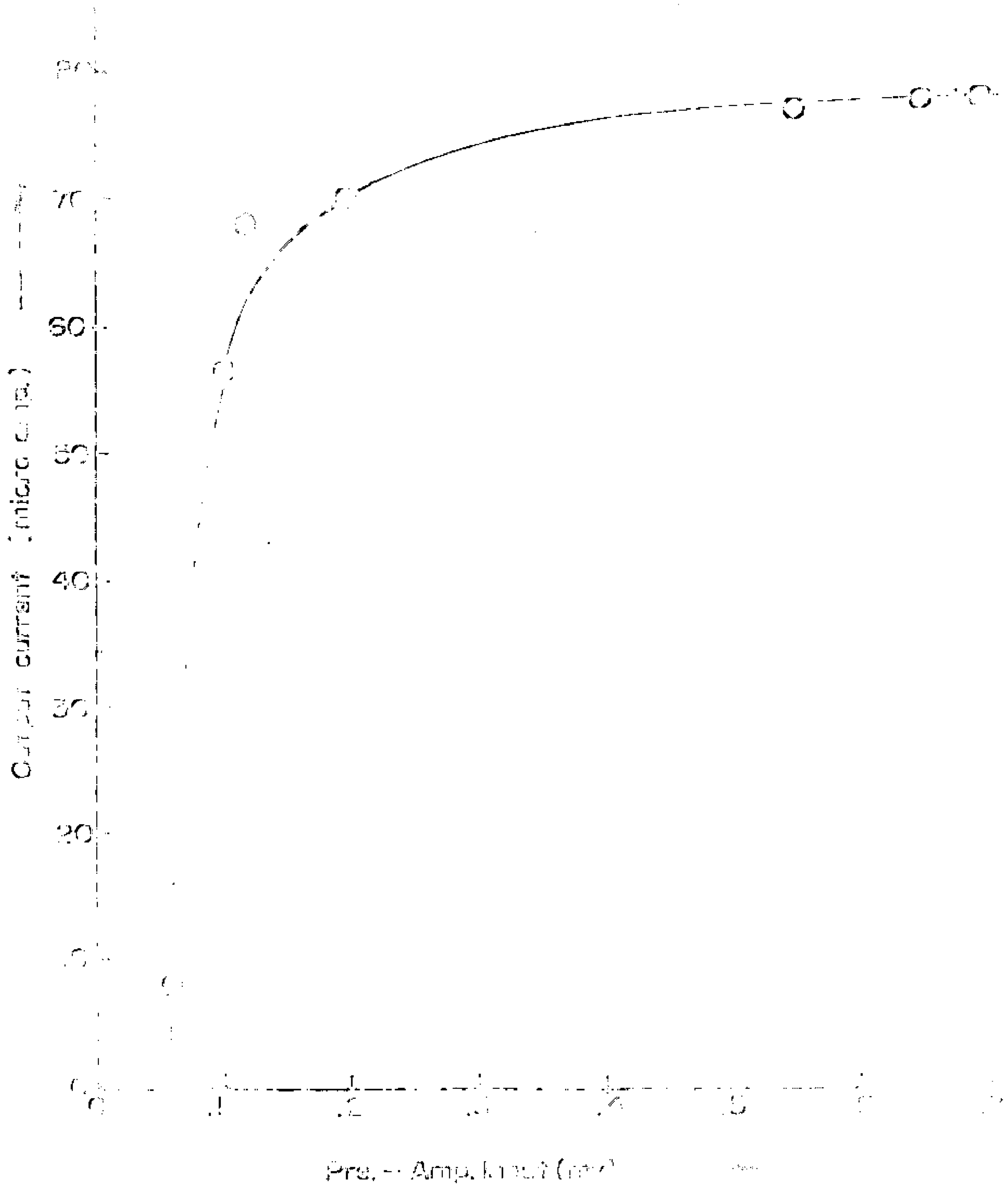


Fig. 24(c) SINE WAVE AT 1010 Hz


Frequency



CHARACTERISTICS

6.2 Pulse Power Supply

The plot graphs and graph papers attached herewith shows the [illegible] characteristics of electronic power supply. The test results are plotted for the following parameters :

1. The calibration curve shown in Fig. 33 is plotted for the output reading of meter and phase angle variation. Since the output varies linearly with the phase angle variation which approximately resembles the plotted graph.

2. The graph shown in Fig. 34 is plotted between the ratio of output magnitude to the input magnitude and phase angle while input magnitude remains constant.

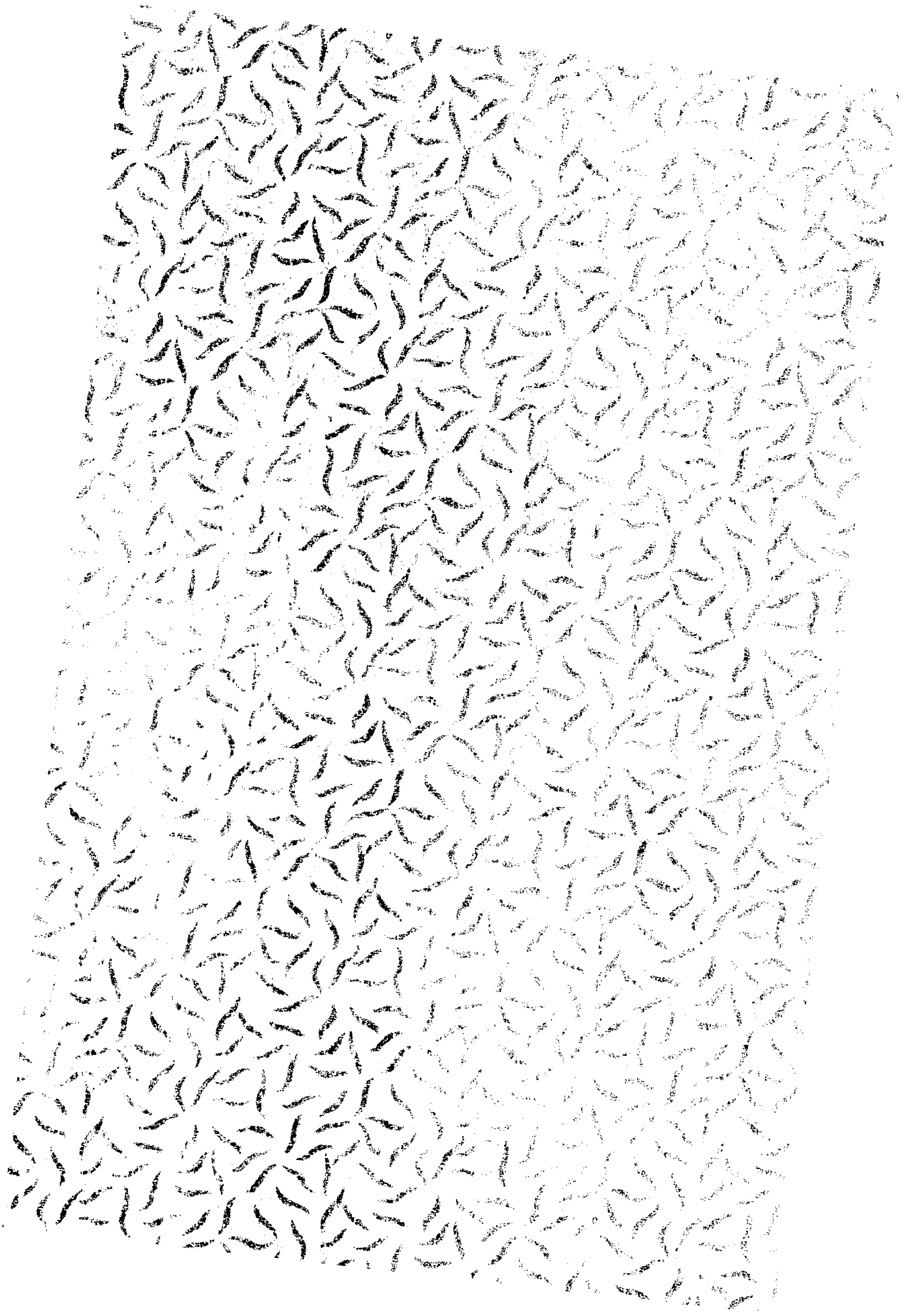
3. The photographs attached herewith shows the Lissajous figures (Fig. 35) and wave shapes showing phase difference between the two signals i.e. reference input signal and output signal.

The test results taken from pulse power supply are given in Appendix A-III.

6.3 Quadrature Power Supply

Following photographs have been taken for electronic quadrature power supply, which shows its characteristic response.

1. Fig. 36(a) shows the wave-shapes having phase difference of exactly 90° between reference input signal and



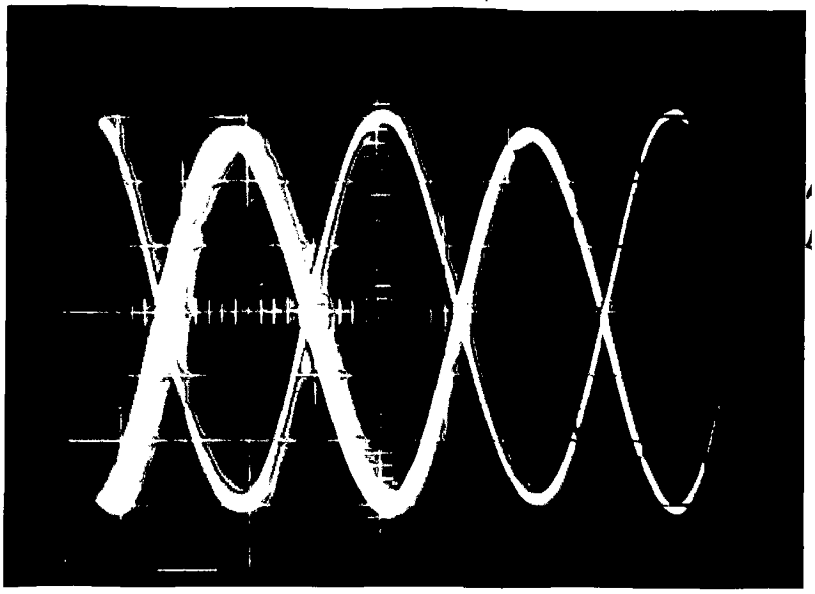


Fig. 28(b) WAVE SHAPE 'A' - REFERENCE SIGNAL, WAVE SHAPE 'B' - OUTPUT SIGNAL, PHASE DIFFERENCE -180°

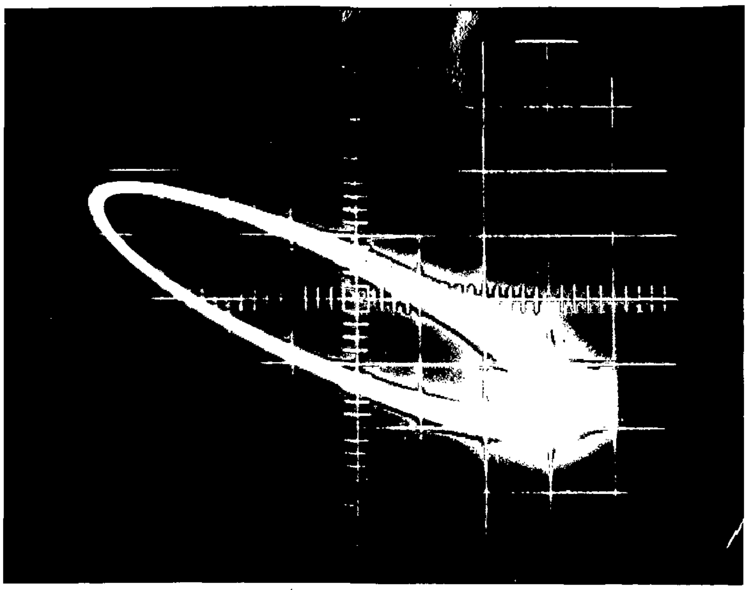
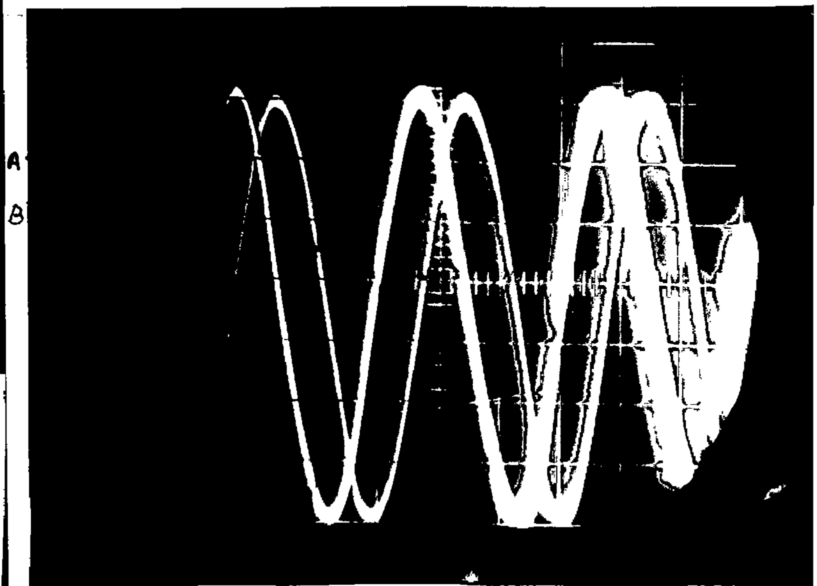


Fig. 28(a) LISSAJOUS FIGURE FOR PHASE SHIFT 20°



9(a) WAVE SHAPE 'A' - REFERENCE SIGNAL, WAVE SHAPE 'B' - OUTPUT SIGNAL, PHASE SHIFT - 90°

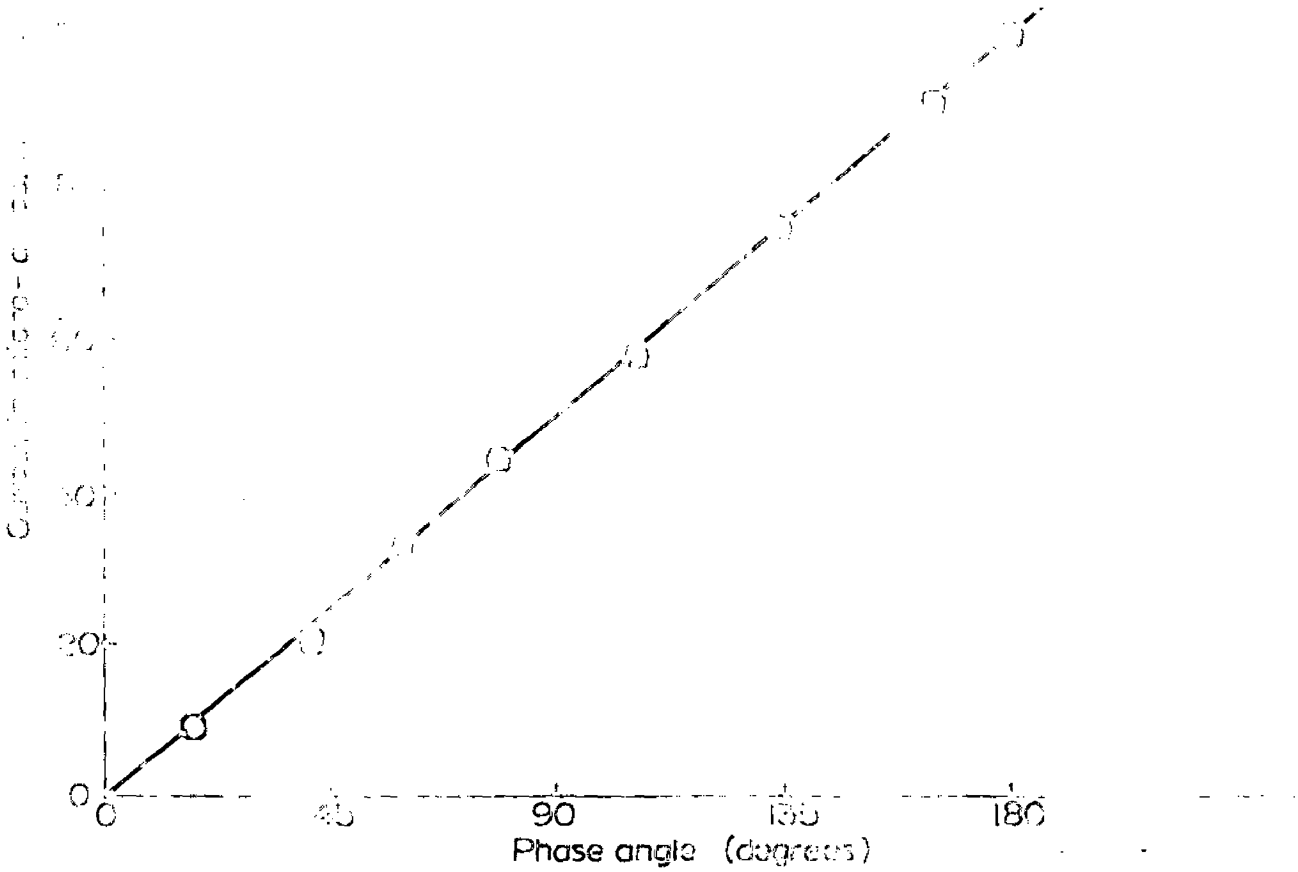
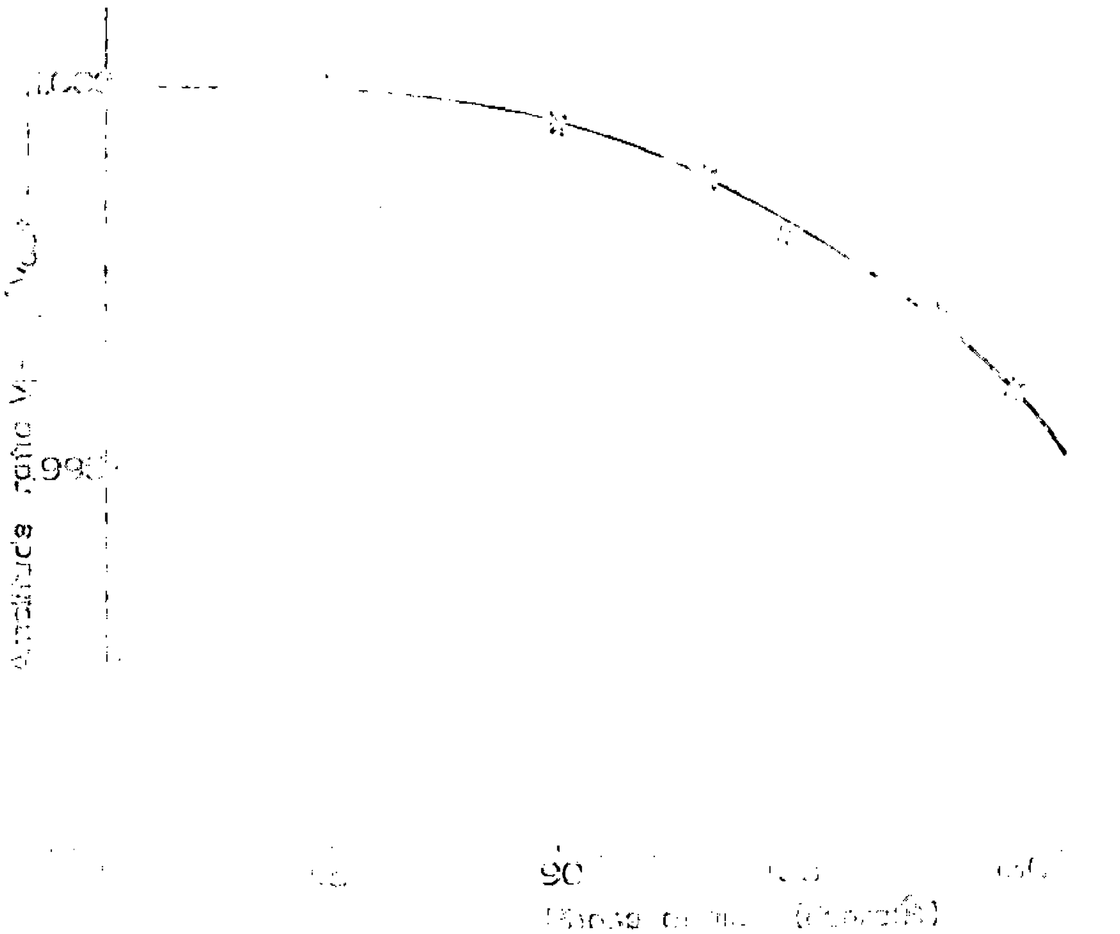


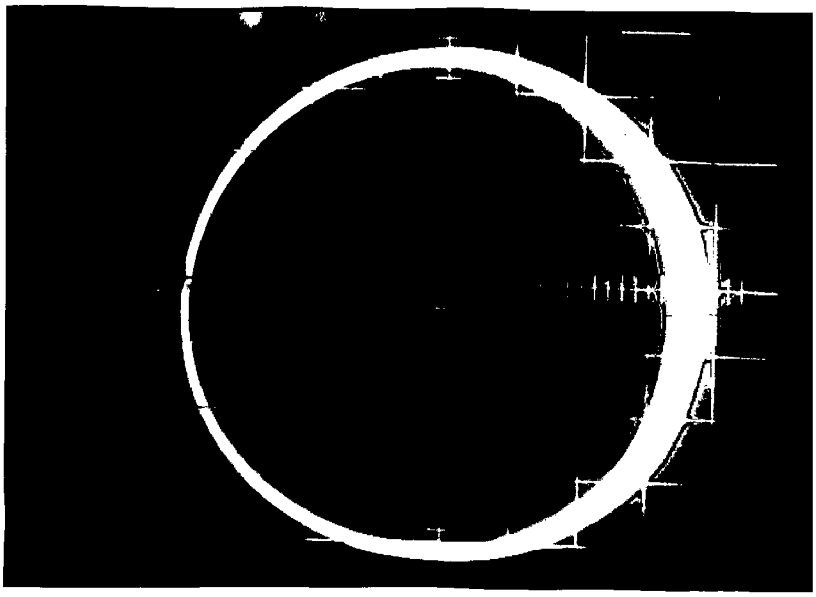
FIG.26 CALIBRATION CURVE FOR PHASE ANGLE METER.



output signal. Also Lissajous figure 29(b) shows the phase difference of 90°.

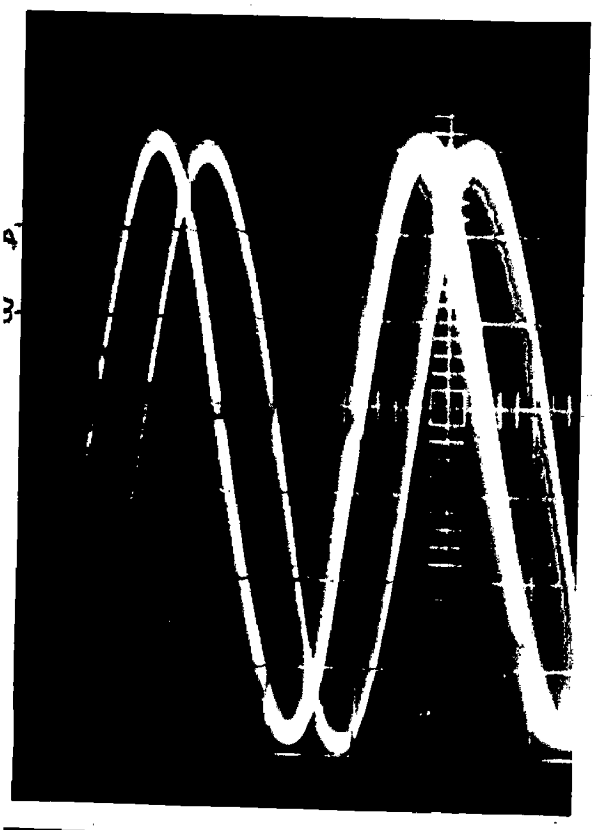
2. Fig. 30 shows the wave shapes having phase difference of 85° between reference input signal and output signal.

3. Fig. 31 shows the wave shapes having phase difference of 95° between reference input signal and output signal.



.29(b) LISSAJOUS FIGURE FOR PHASE SHIFT 90°

30 WAVE SHAPE 'A' - REFERENCE SIGNAL,WAVE SHAPE 'B' - OUTPUT SIGNAL,PHASE SHIFT-85°



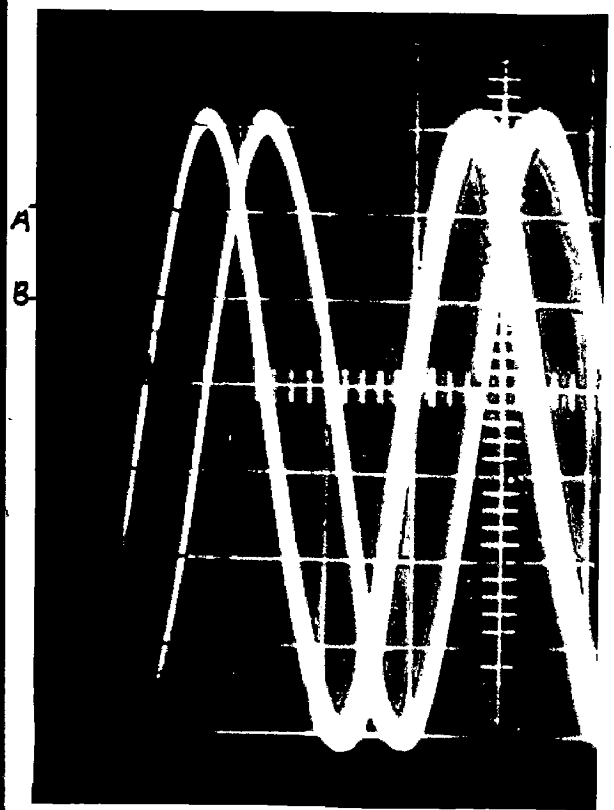


Fig. 31 WAVE SHAPE 'A' - REFERENCE SIGNAL,WAVE SHAPE 'B' - OUTPUT SIGNAL,PHASE SHIFT - 95°

V. CONCLUSIONS

5.1 Performance

The performance of electronic null detector has been found satisfactory. The sensitivity of each detector is few tens of microvolt. Sensitivity can be further improved by providing proper shielding and filtering arrangement. Sensitivity of instrument does not remain constant with change in atmospheric conditions, as these changes affect the passive component values (particularly temperature). Log amplifier increases the dynamic range of instrument as seen from the test results, but effect of temperature change can not be neglected. So to get better dynamic range the temperature compensation in log amplifier must be provided by use of complementary transistors.

Pulse power supply shows very good results as regard to the output magnitude constancy. Only 0.4 % change in output magnitude takes place for 180° phase change with respect to reference signal. The following improvements can be made when no amplitude deviation is required at all phase angles.

(i) Experimenter may keep calibration curve of amplitude error at the time of performing experiment and accordingly he can correct the output magnitude of pulse power supply.

(ii) Provision of inserting a fixed resistance of appropriate value in the feedback loop of operational amplifier circuit can be made to increase the overall gain. The resistance can be included or excluded in the feedback path by a mechanical switch or push-button as and when required without affecting the overall operation of power supply.

Use of single turn potentiometer does not give high resolution as regard to phase angle variation so to get very high resolution, 10 or 40 turn potentiometers must be used instead of single turn potentiometers.

The output of power supplies no longer remains constant , when there is some fluctuations in the input supply voltage. Better performance can be obtained by use of stabilised input supply.

The other improvements which can be further made in these instruments are as under:

1. Highly stabilised power supply whose regulation is better than 0.1 % must be used.
2. The printed circuitry is used with detachable circuit unit.

6.3 <u>Merits and Demerits.</u>

Null detectors and power supplies which have been developed by using integrated circuit operational amplifier have following advantages:

1. Higher sensitivity
2. Fast response
3. Insensitive to mechanical shock and vibrations.
4. Less weight
5. Compact in size
6. Reliability is more
7. High input impedance.

Remarks.

1. Due to high sensitivity electronic detector is sensitive to electrical interference and from time to time require extensive measuring circuit precautions against the noise sources in their external power supplies.
2. Detection of signal approaching the Johnson noise level.
3. Accuracy may be deviated due to internal effects, such as transistor noise, amplifier drift etc.

6.3 Application of electronic null detector and power supplies

1. The usual application of null detector in bridges is that it senses the state of unbalance between appropriate corners of the circuit.
2. Null detector can be used in potentiometer to monitor the current exchange between the known and unknown voltage sources.
3. Null detector can also be used as an amplifier to amplify very small signals at a selective frequency.
4. Pulse power supply can be used as a phase shifter with high amplitude accuracy.

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APPENDIX A1

Following are the details of various transformers which were designed for [illegible] and power supplies :

S.No.	Transformer Details	Stamping size	N_p	N_s	Size of wire (SWG)
1.	Primary – [illegible] V		3700		30
	Secondary – 0 – 11 V	30		124	30
	0 – 11 V			124	30
2.	Primary – 230 V		3700		40
	Secondary – 0 – 11 V	30		124	30
	0 – 11 V			124	30
3.	Primary – 230 V		1000		30
	Secondary – 0 – 11 V	10		70	30
	0 – 11 V			70	20
4.	Primary – 230 V	30	3700		40
	Secondary – 0 – 9 V			100	30
5.	Primary – 230 V		4200		40
	Secondary – 0 – [illegible] V	[illegible]		40	30
	0 – 8 V			68	30
6.	Primary – 230 V		4200		40
	Secondary – 0 – [illegible] V	[illegible]		40	30
	0 – 1[illegible] V			240	30
7.	Primary – 0 – [illegible].5 V	[illegible]	33		30
	Secondary – 0 – 1[illegible] V			203	30

APPENDIX AII

The components which have been used for fabrication of Null detector and power supplies are as under :

S.No.	Name of components	Rating	Quantity used
1.	Power Transistor (PNP)	AD149	1
2.	Power Transistor	AC?17 (PNP)	1
3.	Operational Amplifier	IC0741	11
4.	Transistors	2N3053 (PNP)	[illegible]
		BC158 (PNP)	2
		2SB75 (PNP)	2
5.	Silicon Diode	IN4004	23
6.	Switching Diode	SN183	[illegible]
7.	Microammeters	Range (100-0-100)	1
		Range (0-100)	1
8.	Potentiometers	50K, 5W	1
		10K, 5W	[illegible]
		1K, 5W	1
		220 Ohm, 5W	1
9.	Resistances	1M	4
		400K	1
		220K	4
		100K	3
		68K	3
		47K	3
		10K	1
		10K	11
		2.2K	4
		1K	3
		220 Ohm	1
		100 Ohm, 1W	1
		100 Ohm, 5W	3
		50 Ohm, 10W	3
		33 Ohm, 5W	[illegible]
		10 Ohm, 10W	1

S.No.	Name of components	Rating	Quantity reqd
10.	Capacitors	1000 MF, 25 V	[illegible]
		[illegible] MF, 25 V	1
		10 MF, 1[illegible] V	[illegible]
		1 MF, 100 V	1
		0.1 MF, 100 V	[illegible]
		0.001 MF, 100 V	[illegible]
		0.005 MF	[illegible]
11.	Preset Resistances	22 K	[illegible]
		10 K	[illegible]
		4K7	[illegible]
		1K[illegible]	[illegible]
12.	Winding Terminals		[illegible]
13.	Toggle Switch		[illegible]
14.	Neon Lamp	230 V	[illegible]
15.	Knobs		[illegible]
16.	Transformer Stampings	No. 33	Three sets
		No. 74A	Three sets
		No. 10	One set

APPENDIX A-III

ELECTRONIC NULL DETECTOR

(I) OBSERVATION DATA FOR OUTPUT VS. INPUT

S.No.	Input (Microvolts)	Output (Micro Amp.)
1	.060	0.[illegible]
[illegible]	.22[illegible]	[illegible]
[illegible]	.2[illegible]	[illegible]
[illegible]	.[illegible]	[illegible]
[illegible]	.[illegible]	[illegible]
[illegible]	.[illegible]	77.[illegible]
[illegible]	.[illegible]	[illegible]
[illegible]	.[illegible]	[illegible]

(II) OBSERVATION DATA FOR TUNED AMPLIFIER OUTPUT VS FREQUENCY [illegible]

Input to Pre Amplifier = [illegible] Micro Volt

S.No.	Frequency (Hz)	Output (milli volt)	Gain V_{out} / V_{in}
1	[illegible]	50	[illegible] $\times 10^{3}$
2	[illegible]	100	0.[illegible] $\times 10^{3}$
3	[illegible]	140	0.[illegible] $\times 10^{3}$
4	1000	200	1.00 $\times 10^{3}$
5	[illegible]	140	0.[illegible] $\times 10^{3}$
6	[illegible]	100	0.[illegible] $\times 10^{3}$
7	[illegible]	50	0.[illegible] $\times 10^{3}$

APPENDIX A-IV

POLAR POWER SUPPLY

OBSERVATION DATA FOR CALIBRATION OF PHASE ANGLE METER

S.No.	Phase Angle (degrees)	Out Put (Micro Amp.)
1	0	0.0
2	20	[illegible]
3	40	21.00
4	60	33.00
5	80	45.00
6	100	55.00
7	135	75.00
8	150	91.00
9	180	100.00

OBSERVATION DATA FOR OUTPUT MAGNITUDE VS. PHASE ANGLE

Input Magnitude = [illegible] Volt

S.No.	Output Magnitude (Volt)	Phase Angle (Degrees)	Ratio V_{in} / V_{out}
1	[illegible].000	0	1.000
2	[illegible]	[illegible]	1.000
3	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	.0000
6	[illegible]	[illegible]	.0070
7	.089	[illegible]	[illegible]