ELECTRONIC INSTRUMENTATION
FOR
TESTING OF INSTRUMENT TRANSFORMERS

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

PRAMOD KUMAR SRIVASTAVA

DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE (U.P.) INDIA

December, 1980

CERTIFICATE

Certified that the thesis entitled " Electronic Instrumentation for testing of Instrument Transformers" which is being submitted by Sri Pramod Kumar Srivastava in partial fulfilment of the requirements for the award of the degree of " MASTER OF ENGINEERING" in 'Measurement and Instrumentation", is a record of canidate's own work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree.

This is further certified that the candidate has worked for a period of six months for preparing this thesis.

Dated Dec. 31 ,1980

(Vinod Kumar)
Lecturer
Department of Electrical Engg.
University of Roorkee,
Roorkee

ACKNOWLEDGEMENTS

The author wishes to express his deep sense of gratitude to Sri Vinod Kumar, Lecturer, Electrical Engineering Department, for his invaluable suggestions and guidance at every stage of the work presented in this thesis.

The author is highly grateful to Dr.H.K.Verma, Manager, (R & D) Universal Electrics Limited, Faridabad for his valuable suggestions during the course of this dissertation.

Sincere thanks are also due to Dr.S.C.Saxena, Reader Electrical Engineering Department for his valuable help needed for the completion of work.

Lastly the author wishes to thank one and all, helped him during the whole tenure of this dissertation in one way or the other.

CONTENTS

CHAPTER **PAGE NO.**

SYNOPSIS

3. DEVELOPED INSTRUMENT

SYNOPSIS

The work presented in this report is a contribution towards using electronics devices for instrument transformer testing. An instrument for testing of current transformer has been designed developed and tested. The basic principle is same as generally used for comparision method but the costly variable mutual inductance is replaced by electronic devices. An electronic detector which is a part of the instrument and can be used separately for other purposes also has been designed developed and tested. The test results are given. With some modification given in the report the instrument can be used for Potential transformer testing also. A scheme is also proposed for an automatic electronic instrument for instrument transformer testing.

INTRODUCTION

With the increasing tendency towards higher voltage and higher currents, instrument transformers now play a vital role in power system. The accurate measurement of current and voltages of high values is dependent upon the accuracy of instrument transformers. Therefore, it is necessary that an accurate, simple and compact instrument should be available for testing of instrument transformers. The work described in the report is a step towards achievement of this goal. With the development of electronics instrumentation it is now possible to use electronics for instrument transformer testing also. As the name indicates the device developed here is also an electronic device.

This reports firstly deals with the conventional methods, & methods using current comparators for instrument transfermer testing, Atleast one method commonly used from each type is discussed and references for others are given. Then the work done by different authors using electronics for instrument transformer testing has been given and each scheme is discussed in detail.

In this work an electronic device for C.T. testing with high accuracy, simple operation and lower cost is designed developed and tested. The basic principle used is same as used in comparision method. In this the test C.T. is compared with a standard current transformer. The method uses a variable mutual inductance, and resistances which are costly items. But in the instrument developed here, these, are replaced by electronic devices which are much cheaper than above components. The accuracy and performance obtained from this instrument is also very high. Design and detail of this instrument with test results and performance is given in third chapter of this report. The instrument is basically developed for C.T. but with some modification discussed in this report, it can be developed for P.T. testing also.

Design and detail of an electronic detecter which is a part of the above instrument and can be used separately for other purposes is discussed in chapter fourth. The test results and performance of the detector is also given.

The fifth chapter deals with scheme for an automatic C.T.testing device. This is automatic in the sense that it directly reads of the errors without any adjustment for balance. The device can also be developed for P.T. testing. The modification needed for this are given.

The last chapter concludes the report,having conclusions from the work done, suggestion for further work and applications of the developed instrument.

2. REVIEW AND LITERATURE SURVEY

There are several methods for instrument transformer testing. The generally used methods in laboratory etc. are conventional methods. But with the development of current comparators and electronic devices, these are also used for testing instrument transformer. The commonly used conventional methods, one method using current comparator with principle of current comparator and the electronic instruments developed so far have been described below:

2.1 Conventional Methods [1]

The testing methods may be divided into two classes

(a) absolute methods and

(b) secondary or comparision methods.

In the absolute methods the transformer errors are determined in terms of the constants - resistance, inductance and capacitance of the testing circuits whereas in the secondary methods, the errors of the transformer under test are compared with those of a standard transformer.

The absolute methods commonly used for C.T. testing are listed below:

1. Mutual Inductance Methods
2. Biffi Method.

The most commonly used method for C.T. testing is Arnold method. It is a secondary method, i.e. the C.T. under test is compared with a standard C.T. The set up as given in figure 1.

S & X are the standard and test transformers respectively, these being of the same nominal ratio. T is a C.T. having negligibly small errors and is for the purpose of isolating the measuring circuit from the main secondary circuit. M is a variable astatic mutual indictor with a range of ± 2.4 microhenries. R consists of three resistors of 0.01, 0.10 and 1 Ohm respectively connected in series, fitted with short circuiting plugs so that only one can be had in circuit at a time depending upon the sensitivity and range. r is a variable resistor of ± 500 micro Ohms.

It can be derived taking error of standard current transformer zero, at balance if value of r is r and mutual inductance is M. then

$$\text{Ratio error} = \frac{r}{R}$$

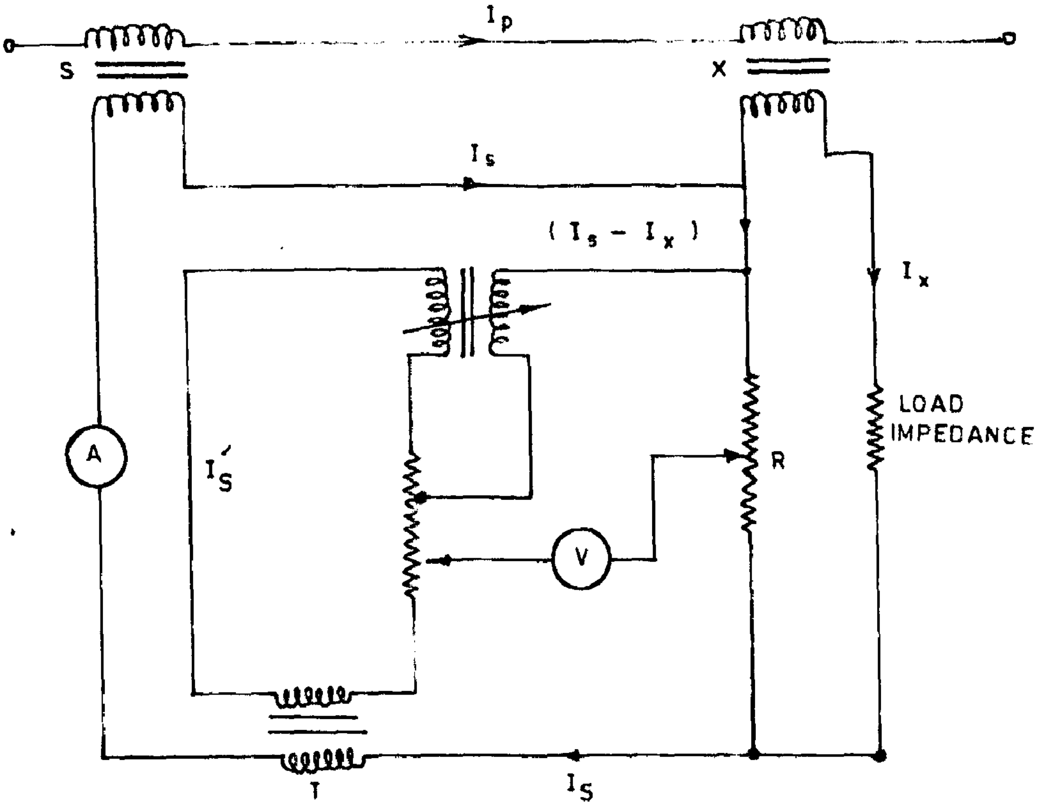


FIG 1 _ ARNOLD METHOD FOR C.T. TESTING

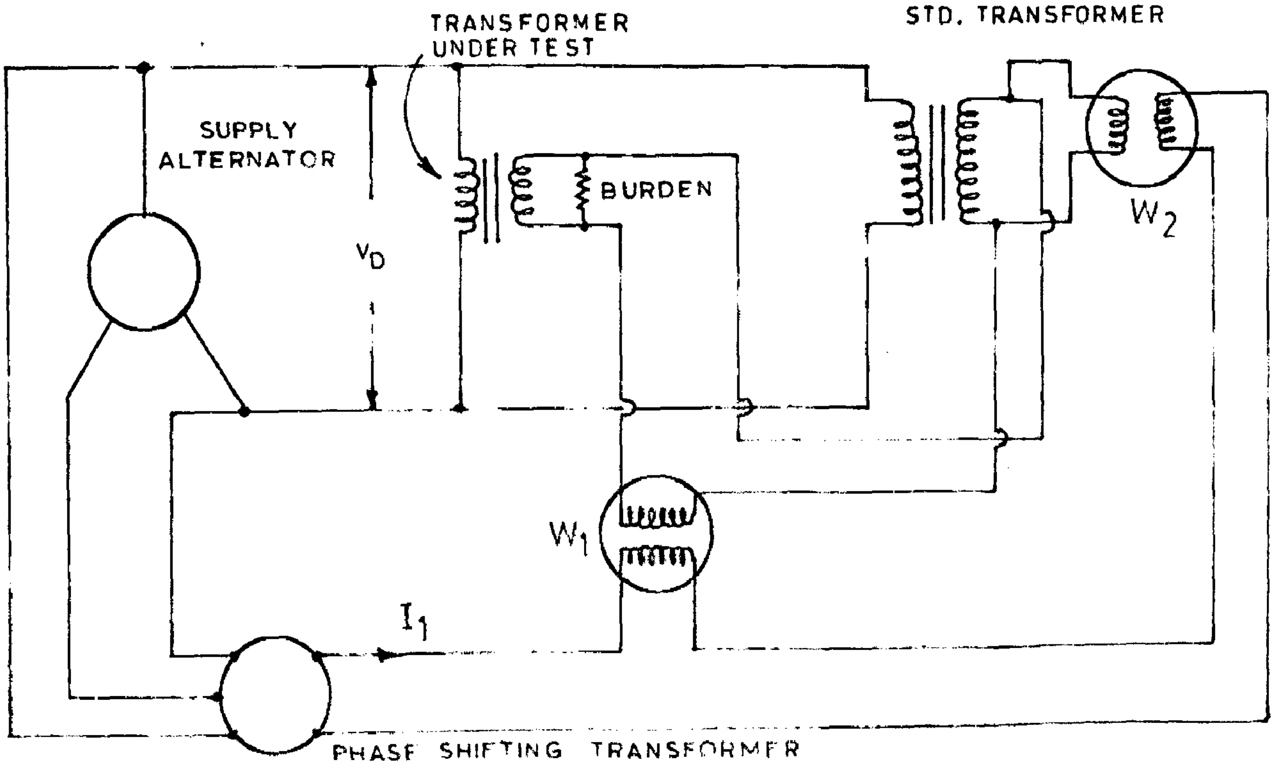


FIG. 2 _ A METHOD FOR P.T. TESTING USING COMPARISON PRINCIPLE and Phase angle error = $\frac{\omega M}{R}$

Therefore, r and M can be directly callibrated in terms of Ratio and Phase angle errors.

Similarly for Potential transformer the methods are (a) Absolute methods : There are several absolute methods for this purpose. These methods are essentially the same in principle, the transformer secondary voltage being in such methods balanced by a fraction of the primary applied voltage, a Vibration galvonameter being used as a detector to indicate exact balance and various adjustable impedence being used to vary the magnitude and phase of the fraction of the primary voltage until such a balance is obtained.

The voltage divider for comparision may be made by capacitance. These are having advantage of accuracy and low power consumption but of high cost.

(b) The Clothier and Medina Method

(c) Comparision methods:

The connection for one such method are given in figure-2. As used in this test, Wattmeter W is essentially a voltmeter and its deflection per volt applied to the voltage coil corresponding to some given current in the current coil must be known. Let k be the volts per division for a current I in the current coil, this current being in phase with the applied voltage.

The operation of the methods of testing consists in observing the reading D of wattmeter W, when the current I in the current coil is in phase with the secondary voltage of standard transformer. The phase of this current is altered by phase shifter, until the wattmeter W_2 gives maximum reading. This is D_1. The phase shifter is then adjusted until wattmeter W_2 given zero reading when the current I must be 90° out of phase with the voltage Vs. The reading Do of the wattmeter W_1 is then again observed.

Then if Rs and Rx are the ratios of the standard and test tranformers respectively

$$Rx = \frac{Rs \cdot Vs}{Vs - KD_1}$$

$$\Theta x = \Theta_s + \tan^{-1} \frac{KDo}{Vs}$$

Where Θ x and Θ s are the phase angles of the test and standard transformers respectively.

2.2 C.T. Testing Using Current Comparators

The current comparator is essentially a three winding differential current transformer - it is an ampere turn balance detector and two ratio winding carrying currents to be compared.

2.2.1 Principle of Operation [2,3]

The voltage developed in a uniformly distributed coil wound upon a magnetic toroidal core is known to be a ahighly sensitive indicator of whether the sum of the alternating currents flowing through the torroid window is zero or not. Fundamentally, the current comparator is nothing but more than a detector based on this principle. It is nothing but a toroidal transformer which when properly designed and constructed becomes an accurate stable current ratio standard.

In this basic form of the current comparator consists of a magnetic toroidal core upon which there are four windings. Two of these carry currents to be compared while the third detects the average flux density in the core. The fourth winding provides a means of fine adjustments in the effective magnetization of the core.

In operation the two current to be compared are passed through their respective windings in such a way

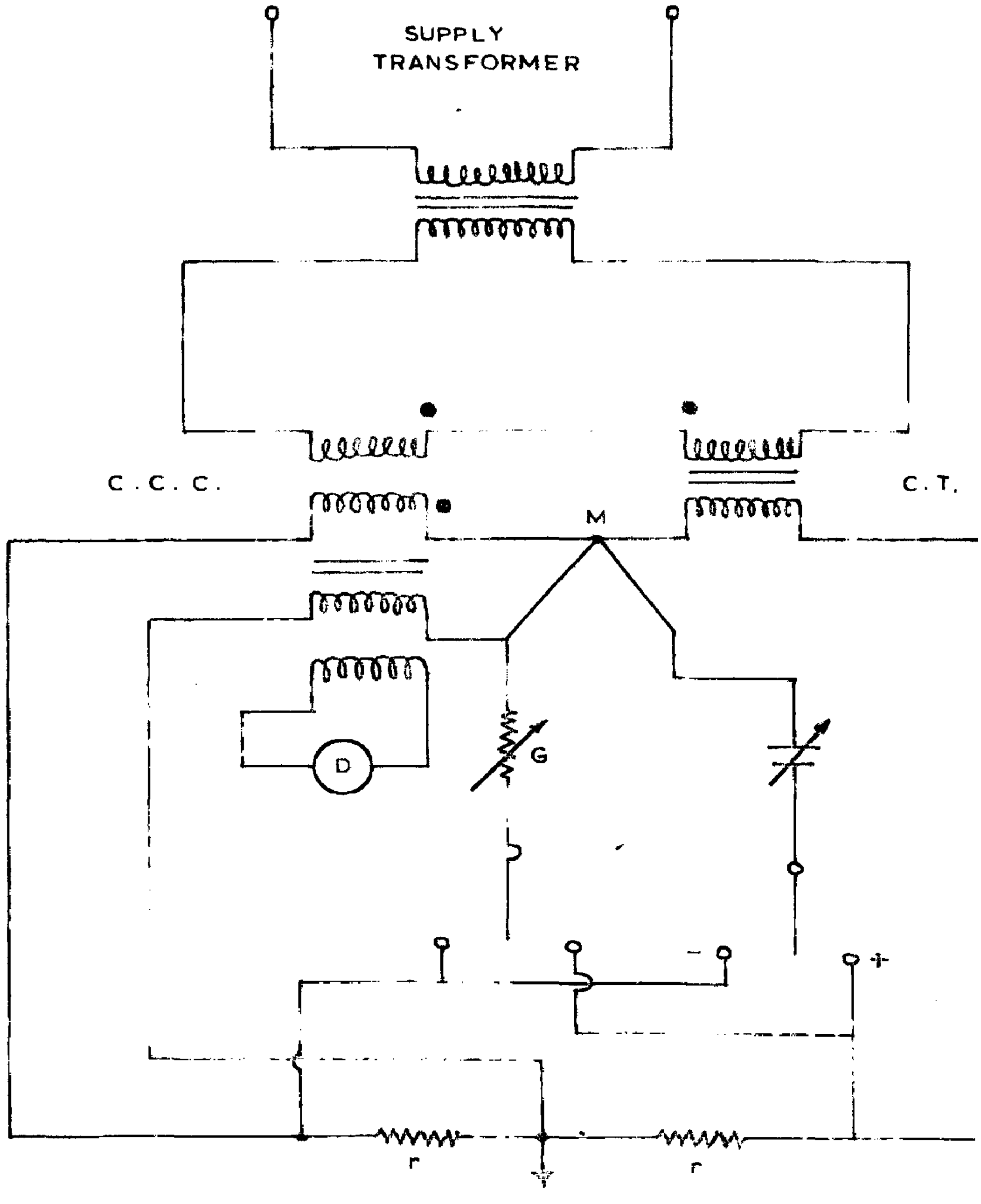


FIG. 3 _ C.T CALIBRATION CIRCUIT USING COMPE
CURRENT COMPARATOR

that the two magnetizing forces on the core oppose each other. An additional current of measured value and phase is then passed through the fourth winding to bring the third winding to a null indicating zero flux in the core. Current comparators can be used for testing of C.Ts.

A current transformer callibration circuit using compensated current comparator is shown in fig.3 . A current δI_s of appropriate magnitude and phase is injected at M through the G-C circuit in order to correct error in the curr nt transformer The potential difference across r is propotional to Is ($\simeq Ip/kt$) where kt is ~~one~~ turns ratio.

At balance $\delta Is = r \frac{Ip}{kt} (G + jWC)$

$\therefore$ Fractional error of the current transformer is given by

$$\epsilon_T = \frac{\delta Is}{(Ip/Kt)} = (G + jwc)^r$$

The balance procedure is thus simple and direct There are however some errors which become predominent for higher ratio.

The first error is caused by the compensating winding current by passing the referece resistor r.

The injected current is thus a function of the difference between the compensating winding current and the secondary current not the secondary current.

The second error is caused by the impedance of the compensating winding. The flow of current through this impedance means that the voltage between points M & N is not exactly zero and although it is quite small it may be appreciable with respect to the voltage accorss r for higher currents. The injected curreet then will not therefore be exactly proportional to the secondary current.

Control of these two errors is achieved by designing for minimum impedance in the compensation winding and for low compensation - a winding of current.

2.2 The current comparators are also used in placed of standard C.T.s. They have compensating winding to compensate the errors involved and therefore they are very useful to compare with the test C.T. for detail idea and specific use reference [4]-[can be contacted.

2.3 <u>Electronic Methods</u>: With the development of different electronic devices it is now possible to measure the errors of instrument transformences with the help of electronic devices. The basic principle is same as in comparision method. The test tranformer is compared with a standard transformer. With the help of electronic devices costly standard mutual inductances and resistances can be replaced. Direct display of errors in both the forms analog and digital has also been possible by using electronic devices. Different schemes using electronic circuitry for instrument transformer testing which have been developed so far are given below:

2.3.1 An Electronic Self Balancing Instrument transformer Testing Device [9]

By this device the ratio and phase angle errors of instrument transformers can be read off or recorded directly with a printer or digital instrument. In this also the test transformer is compared with a standard transformer. The voltage difference between the secondary voltages of the test and the standard transformer is balanced by a voltage that is seperated into two component one being in phase with the voltage of the standard transformer and the other in quadrature. The direct voltages with which the references voltages are multiplied to generate the balancing voltage are a measure of the errors and the phase displacement of the instrument transformers.

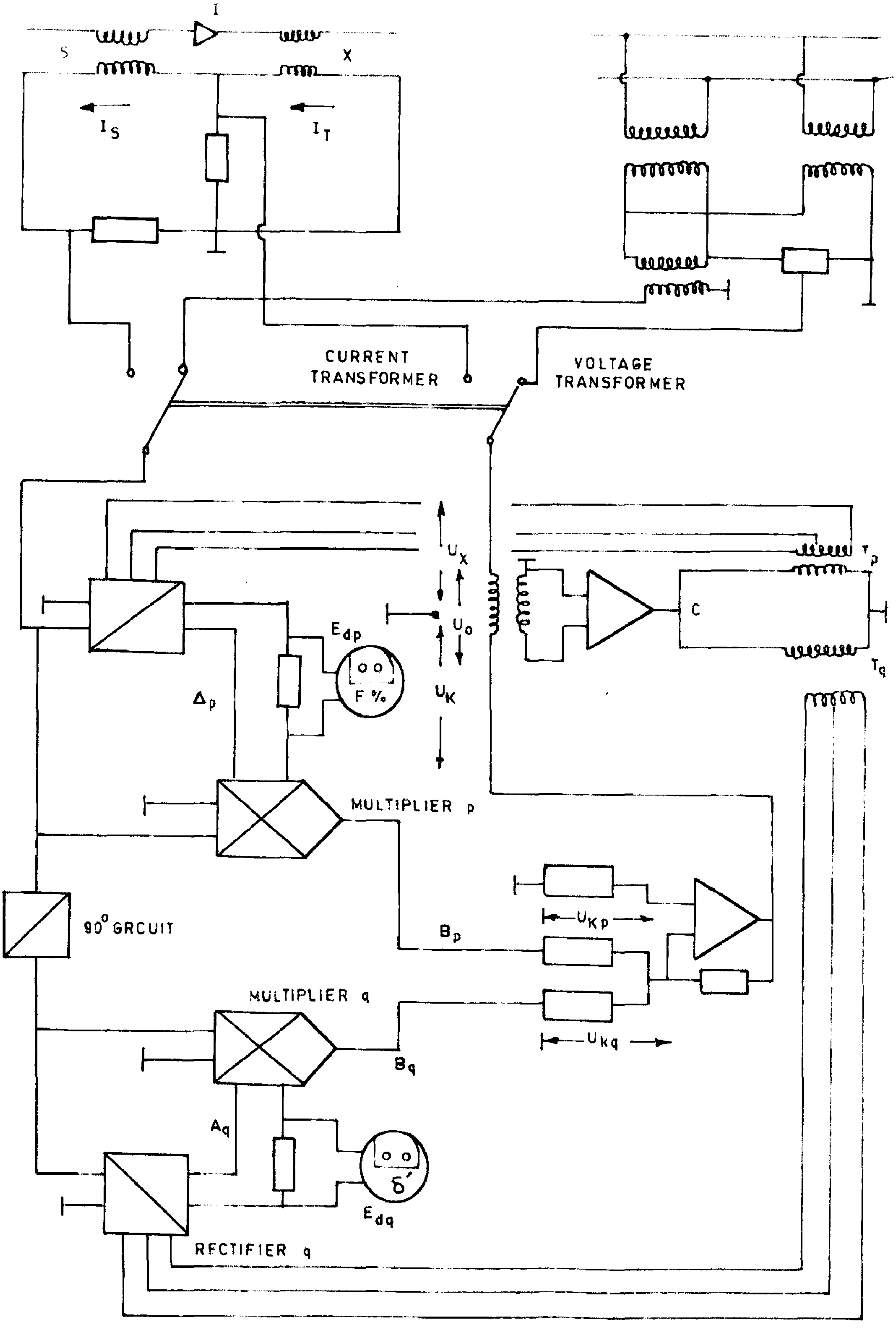


FIG. 4 _ AN ELECTROINIC SELF BALANCING INSTRUMENT TRANSTORMER TESTING DEVICE

Figure 4 shows the used circuitly for the above scheme. A voltage difference in case of P.T. Ux = (UT - US) is obtained.

Where UT is the secondary voltage of test transformer and U_S is the secondary voltage of standard transformer. It may be separated into two components.

$$U_{xp} = U_x \cos\alpha$$

$$\text{and} \quad U_{xq} = U_x \sin\alpha$$

U_{xp} is in the direction of Up and Uxq is in the direction of U_q. U_p and U_q are the reference voltages, Up being proportional to and in phase of Us and Uq is equal to Up in magnitude but is in quadrature with Us.

$$Up = j\, Uq \propto Us \quad - \quad ....(1)$$

Similarly for C.T. circuit

$$Ux \propto (I_T - Is)$$

I_T is secondary current of test C.T. and Is is secondary current of standard C.T. This can also be separated into two compnents. Ux_p and Uxq in quadrerature to each other. As in the case of P.T. reference voltages Up is generated in phase of with Is and Uq in quadrature with Is. By suitable adjustment it is possible to make Up and Uq referred to a rated current of 5 A in the C.T. Circuit equal in magnituide of Up and Uq referred to a rated voltage of 100V in the voltage transformer ciruit. Thus in the C.T. circuit or in the P.T. circuit the voltage Ux represents the same error refrred to 5A rated current or a 100 V rated voltage, respectively. Therefore the same device can be used for measuring errors of C.Ts and P.Ts without restriction.

In the balance circuit the error voltage

$$U_x = |U_x| \cos\alpha + j\,|U_x| \sin\alpha = |U_{xp}| + j\,|U_{xq}| \quad \text{----} \quad (2)$$

is connected in opposition to the balanced voltage

$$U_k = |U_k| \cos \quad + j\,|U_k| \sin \quad = |U_{xp}| + j\,|U_{xq}| \ldots\ldots (3)$$

As long as the measuring device is not balanced the voltage at the input of zero amplifier is

$$U_o = U_x - U_k \qquad \ldots\ldots\ldots (4)$$

The amplified voltage is connected to the phase sensitive rectifiers p & q by means of the transformers Tp and Tq.

The multiplication of the direct voltage Edp at the output of the rectifier p by the reference voltage U_p with the multiplier p gives the voltage U_{kp}.

Similarly multiplication of E_{dq} at the output of rectifier q by the multiplier q. gives U_{kq}. Direct voltages E_{dp} and E_{dq} control the voltage U_k in such a way that $U_k = U_x$ and the device is balanced.

Therefore from (2) & (3)

$$U_{kp} = k_1 \, E_{dp} \, |U_p| = |U_x| \, \text{Cos}\,\alpha = U_{xp} \qquad \text{.......}(5)$$

$$U_{kq} = K_2 \, E_{dp} \, |U_q| = |U_x| \, \text{Sin}\,\alpha = U_{xq}. \text{......}(6)$$

Than from (5) (6) and (1)

$$E_{dp} = \frac{|U_x| \quad \text{Cos}\,\alpha}{K_1 \; |U_p|} \propto \frac{|U_x| \, \text{Cos}\,\alpha}{|U_s|} \qquad \text{.....}(7)$$

$$E_{dq} = \frac{|U_x| \quad \text{Sin}\,\alpha}{K_2 \; |U_s|} \propto \frac{|U_x| \; \text{Sin}\,\alpha}{|U_s|} \qquad \text{......}(8)$$

According to International Electro Technical Commission (I E.C.) the voltage error of a Voltage transformer is defined as

$$6_v = \frac{|U_T| \, . \, K_n - |U|}{|U|} \times 100 \quad \text{in percent} \; \text{...}(9)$$

Where U_T =secondary voltage of the test transformer.

ø U Primary voltage

Kn rated transformation ratio

Assuming standard transformer's error equal to zero. The voltage error is

$$e_v = \frac{|U_T| - |U_s|}{|U_s|} \quad x\ 100 \text{ in percent}$$

Or $$e_v = \frac{|U_x|}{|U_s|} \quad \cos\alpha .100 \text{ in percent} \quad ......(10)$$

Where α being the angle between US & Ux.

Us is the secondary voltage of standard transformer.

Similarly equation for phase error is

$$\beta_v \ \alpha \frac{|U_T| - |U_s|}{|U_s|} \ . \sin\alpha = \frac{|U_x|}{|U_s|} . \sin\alpha ..(11)$$

Also according to (I.E.C.) ratio error of C.T. is

$$e_c = \frac{|I_T| \ K_n - |I|}{|I|} \ . \quad 100 \text{ in percent} \ ....(12)$$

Where

I_T secondary current of test transformer Kn is rated transformation ratio

I primary current.

Assuming that standard transformer is free of error.

$$e_c = \frac{|I_T| - |I_s|}{|I_s|} \ . \quad 100 \text{ in percent}$$

or $$e_c = \frac{|I_x|}{I_s} \ . \quad \cos\alpha \quad 100 \text{ in percent} \quad ...(13)$$

Where α is the angle between Ix and Is & Is is the secondary current of standard transformer.

For the phase displacement

$$\beta_c \propto \frac{|I_T| - |I_s|}{|I_s|} \cdot \sin\alpha = \frac{|I_d|}{|I_s|} \cdot \sin\alpha \text{ ......(14)}$$

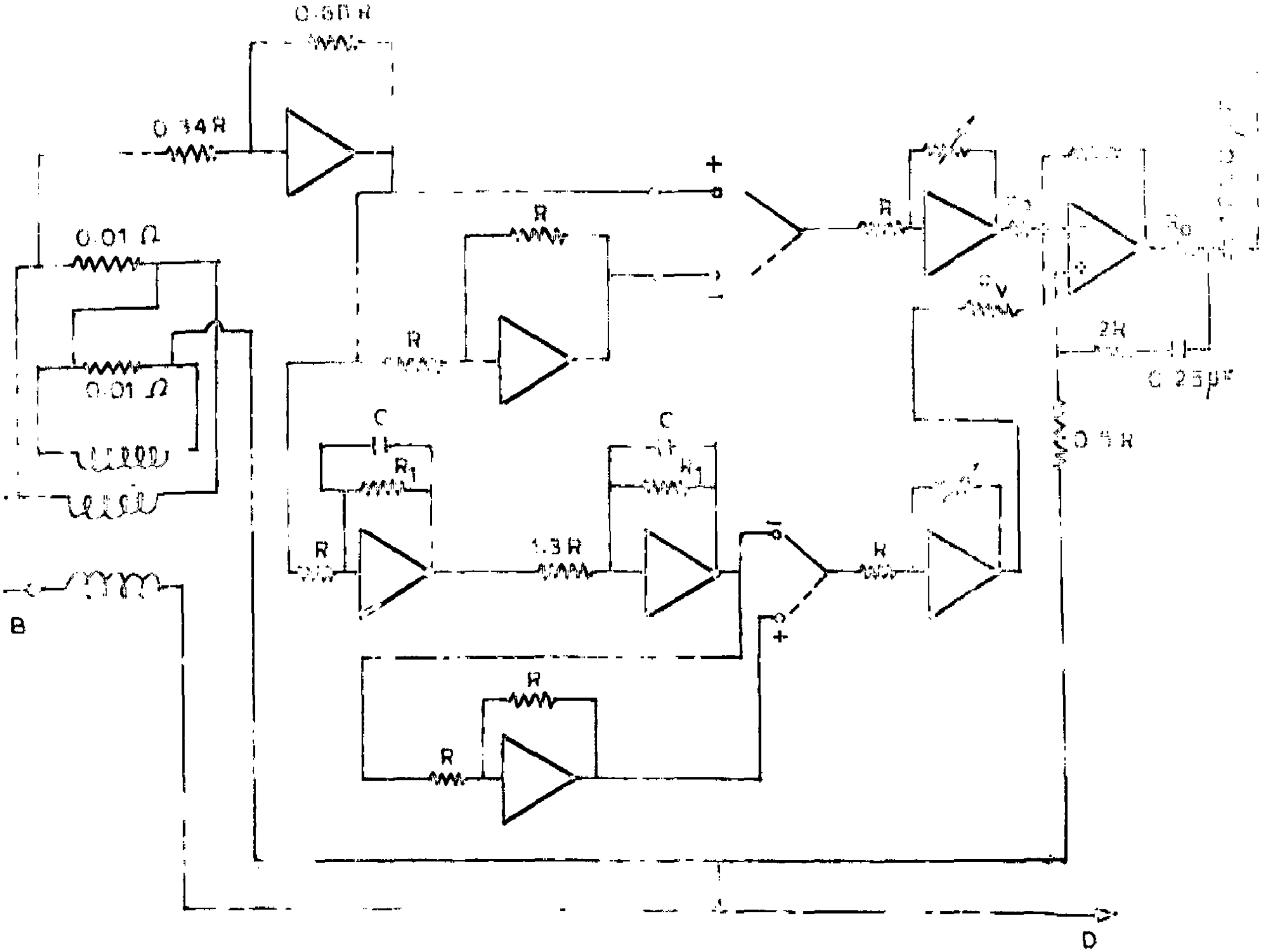
Comparing (7), (10), & 13) as well as (8), (11) and (14) we see that the direct voltage E_{dp} is measure of voltage and current error and the direct voltage E_{dq} is a measure of phase displacements. Therefore, the indicating instruments can directly be callibrated in terms of ratio and phase angle errors, or those voltages can be converted in to digital form and displayed.

The advantage of this method is that it gives automatic indication of the different errors, no null balance is required and that is why it is called self balancing. The disadvantage is this that a complicated and costly device.

2.3.2 Direct reading Electronic Ratio error set [10]

This set is only for Current Transformer but similar arrangement can also be made with some modification for potential transformers also.

This also is based on the comparision technique.



$R_1 = 2.6R$, $C = 1/RW$, $R = 10000\,\Omega$, $R_0 = 4/40/400\,\Omega$

FIG 5 _ DIRECT READING ELECTRONIC RATIO ERROR SET

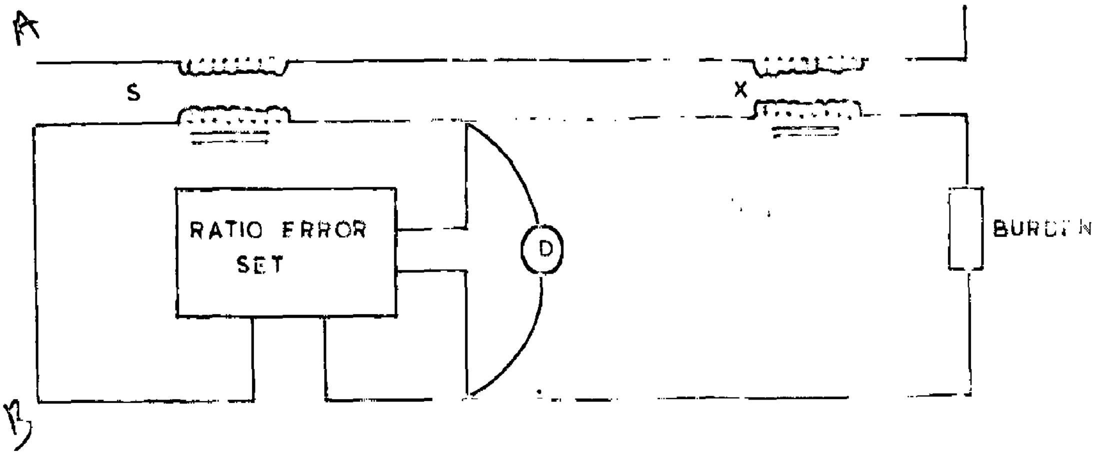


FIG 6 _ CIRCUIT FOR C T TESTING USING RATIO ERROR SET

The ratio error set is made capable of supplying a current equal to the difference of currents of secondaries of standard and test transformers so that the detector gives a zero deflection. Two elements of Ratio error set are related to the current injected in such a way that they can be callibrated in terms of ratio and phase angle error. Fig. 6 shows the block digrams of the instrument.

The circuit diagram of an electronic type ratio error set is shown in fig. 5. It consists of a two stage current transformer with a resistive burden for current to voltage conversion and isolation a voltage gain stage , a phase shifter, two variable gain stages, and an output voltage to current power amplfier. A two stage current transformer was chosen as this enables the design to be more compact for a given accuracy. The 90^o phase shift is obtained in two 45^o steps thus realizing improved stability and simplicity at the expense of permitting phase as well as amplitude shifts with the variable in frequency.

The operation of the output stage is defined by the equation

$$i = -2\ (ep + eq)\ /\ Ro\ (\ 1 + Z\ /Rd) \quad ....(1)$$

Where

i is the output current injected to point M.

e_p, e_q are the voltage outputs from the inphase and quadrature variable gain stages,

R_o is the output current measuring resister,
Z is the inpedence of the 1000 μF decoupling capacitor plus any other equivalent impedence through which the current i must pass before reaching a point whose potential is the same as point N,
R_d is the resistance of the potential divider connected to the positive input terminal of the operational amplifier (shown as2R in series with 0.5R in Fig.5.)

The effect of the 25 μF decoupling capacitor is negligible, at the operating frequencies. Divider ratio is the only parameter that must be fixed. The total resistance may be of any convenient value.

The circuit has a systematic error equal to Z/R_d. This is a compromise that permits R_o to be varied indepently for range multiplication.

The burden imposed by the electronic circuit is almost entirely due to the winding impedence of the input circuit transformer and consequently can be made very low. Ignoring the effect of the decoupling capacitors, the equivalent shunt impedance at the output is given by

$$2.5R \;/\; (1+12.5\ R/\mu R_o)$$

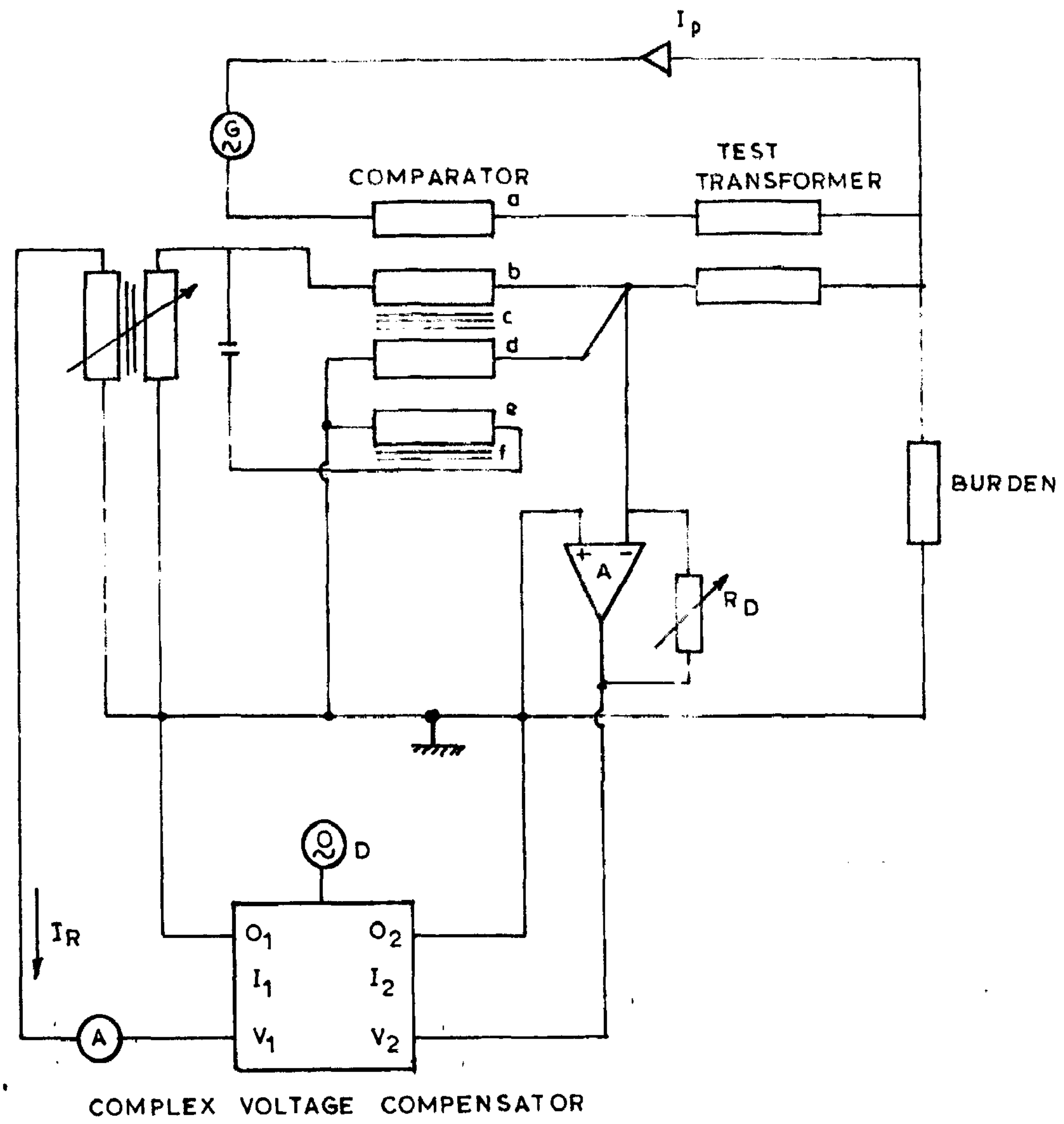


FIG. 7 _ C.T. TESTING INSTRUMENT DEVELOPED BY ANDREWS BRAUN

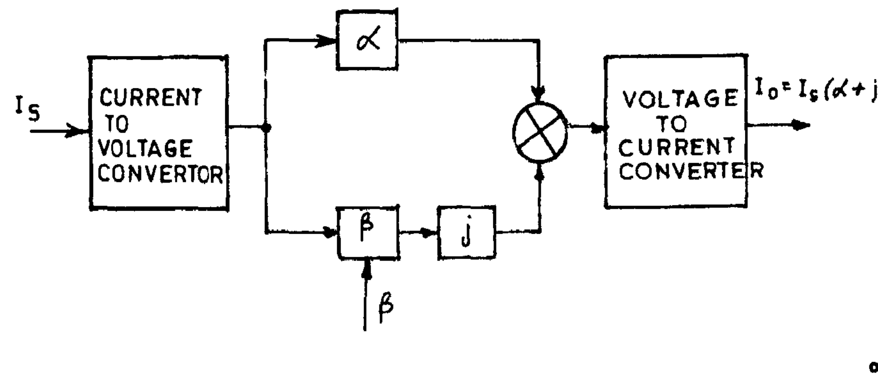


FIG. 8 _ BLOCK DIAGRAM OF RATIO ERROR SET

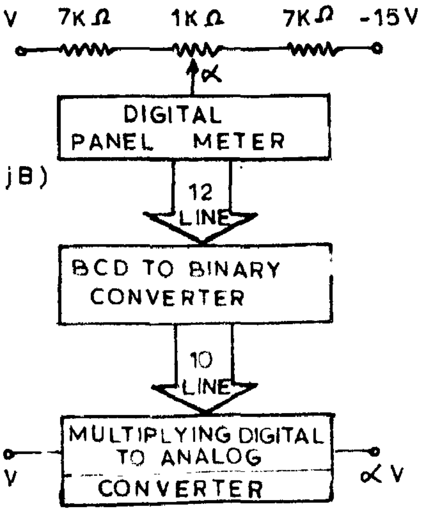


FIG. 9 _ DIGITAL SCALING OF ERROR SIGNAL

2.3.3. Andrew's Method

Andrews Braun has described in his paper [11] a method which can be used for a precision - current transformer having very high primary currents. For very high primary current it is usual practice that the two stage C.T. is used. First the high current is converted to a suitable low value then again it is transformed to standard values (1 or 5A).

In the scheme described the basic principle is same as in Arnold method. Compensated current transformer of very high accuracy has been used instead of standard transformer.

A characterstic feature of the new measuring method is that common circuit resistance R_D is no longer connected in circuit but in the feed back circuit of an electronic operational amplifier located in the common circuit (Fig.7). As the common/effective circuit resistance r_D, this circuit arrangements yields

$$r_D \simeq R_D/\alpha$$

Where α is the open loop gain of ~~an~~ the operational amplifier. In modern amplifiers this gain is $> 10^5$.

The choice of resistence value of R_D depends merely on the desired error range. If for instance $R_D = 10$ K is chosen, $\alpha > 10^5$, yields an effective common circuit resistance $r_D < 0.1\Omega$. At a secondary current value of 5A, a current error of 10^{-6} ($\hat{=}$ 1ppm) leads to a common voltage $U_A = 50$ mV, i.e. with an effective common circuit resistance r_D which is 50 times smaller, the test set is still 2000 times more sensitive than the existing transformer/error measuring devices.

2.3.4. Kahler's Method

Richard L. Kahler has described in his paper [12] a direct reading electronic ratio error set for current transformer callibration. This has the same principle as described in 2.3.2. But in materializing the principle different method is used.

A block diagram of the circuit is shown in Fig.8. The secondary current Is is converted to a proportional voltage. The signal path then splits into two channels direct and quadrature. The direct channel is scaled by a factor of α and the quadrature channel by β. The quadrature channel then receives a 90° phase shift, after which the channels are summed. Finally the voltages are combined and converted to a current.

The special feature of this set is that the scalling is done digitally and the final read out is also digital. It is accomplished through the circuit indicated schematically in Fig.9. Each Channel uses the same circuit so only one is shown. A digital pannel meter is used to generate binary code which is applied to the digital inputs of a multiplying digital to analog converter. The voltage from the previous stage is applied to the analog input of the converter whose output is then the analog voltage scaled by the binary code. The pannel meeter display value, which is the decimal representation of the binary is set by adjusting a 10 turn potentiometer to select the appropriate meter input voltage. In this fashion the scaling of direct and quadrature voltages is controlled by two knobs one for each channel as opposed to one for each digit of the scalling factor and the scaling factor is displayed on the pannel meter. The only critical specifications are the linearity and the gain of the converter,so the scaling accuracy is localized to a single component.

The instrument was constructed using 0.01 percent ratio matching of critical input and feed back resistors where possible. The digital to analog (D/A) converters requires trimming to obtain an accuracy of 0.1 percent, their linearity was found to be better than 0.1 percent by tests on the final instrument. The total uncertainty is estimated to be less than 0.5 percent of the indicated error current.

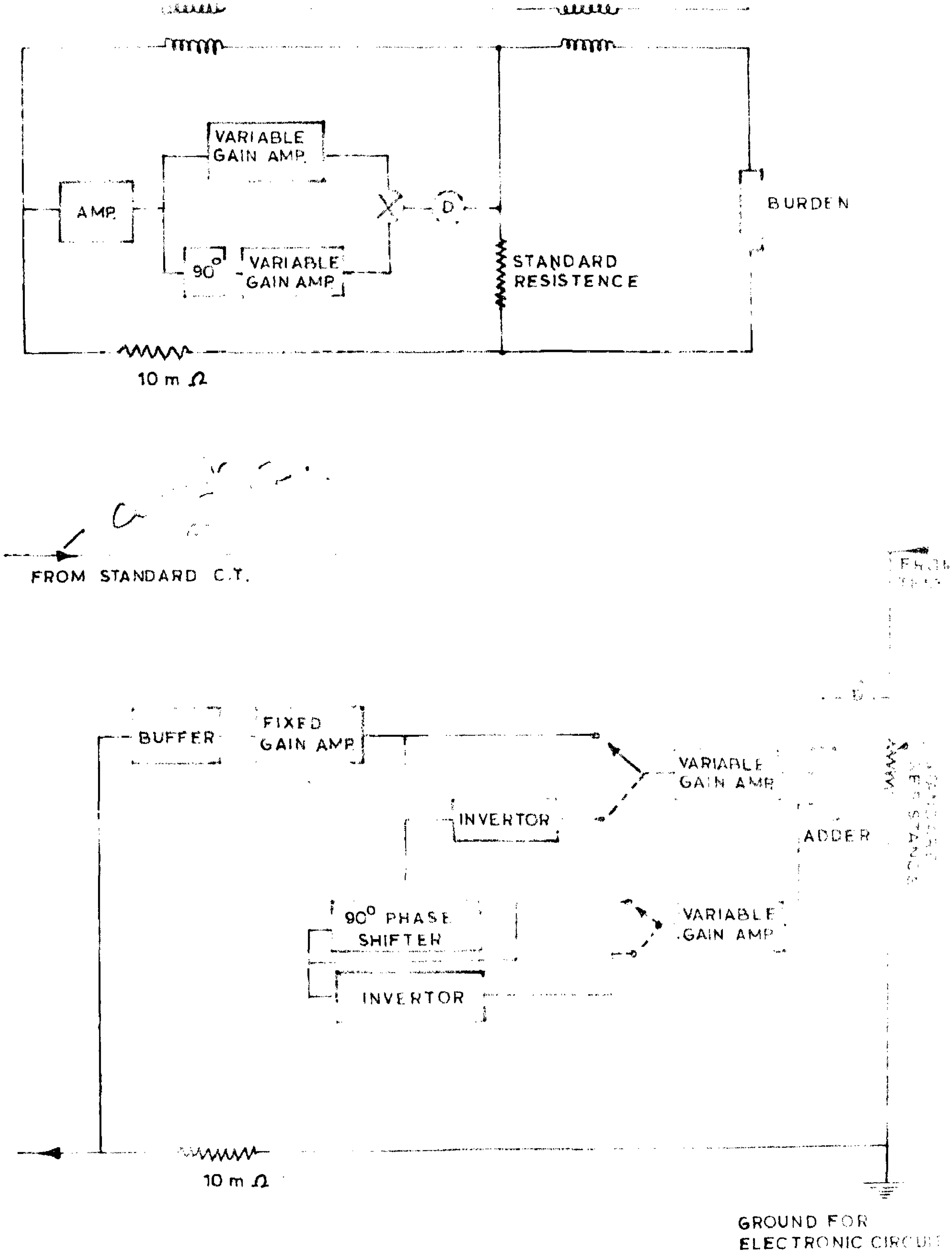


FIG. 11. BLOCK DIAGRAM OF DEVELOPED INSTRUMENT

3. THE DEVELOPED INSTRUMENT

3.1 Principle:

The instrument is based on basic omparision method for C.T. testing. In the Arnold method of C.T. testing we take the standard C.T. current through another C.T. In-phase and quadrature voltages are produced from this current by the help of resistance and mutual inductance. Then addition of these voltage's is given to the common branch and the balance is obtained (Fig.1 in 2.1).

In this instrument these voltages are generated electronically. As Fig.10 shows the voltage is taken by inserting a resistance of 10m in standard C.T. circuit. It is amplified and then splitted in two parts one directly goes to a variable gain amplifier and the other through a 90° phase shifter. Atlast they are again summed up, the voltage obtained is balanced by the voltage in common branch. Thus the gain of the variable gain amplifiers of inphase voltage directly measure of the ratio error and gain of quadrature voltage is a measure of phase angle error. Thus the gain changing elements of the two amplifiers can directly be callibrated in terms of ratio and phase angle errors.

The instrument is a modification over the direct reading electronic ratio error set described in 2.3.2. Comparision of Fig.5 and Fig.10 directly indicates the modification used. In the previous set the current from standard C.T. is taken through a transformer but in instrument developed here it has been taken by inserting a small resistance in the secondary of standard current transformer. By this modification we get a simple and light instrument. The problem of isolation is very easily solved by having a buffer stage of very high input impedance . The second modification is that the phase shifter used here has only one operational amplifier stage instead of two. This phase shifter is well tested and verified and gives a good performance.

The third modification is that a voltage to current converter is not required. It is easy to construct a voltage to current converter for lower currents therefore, this modification does not matter much for lower range. But for higher ranges i.e. higher currents the construction of voltages to current converter requires an additional power stage whereas in the developed instrument no such power stage is required, and the instrument as such can be used for higher ranges.

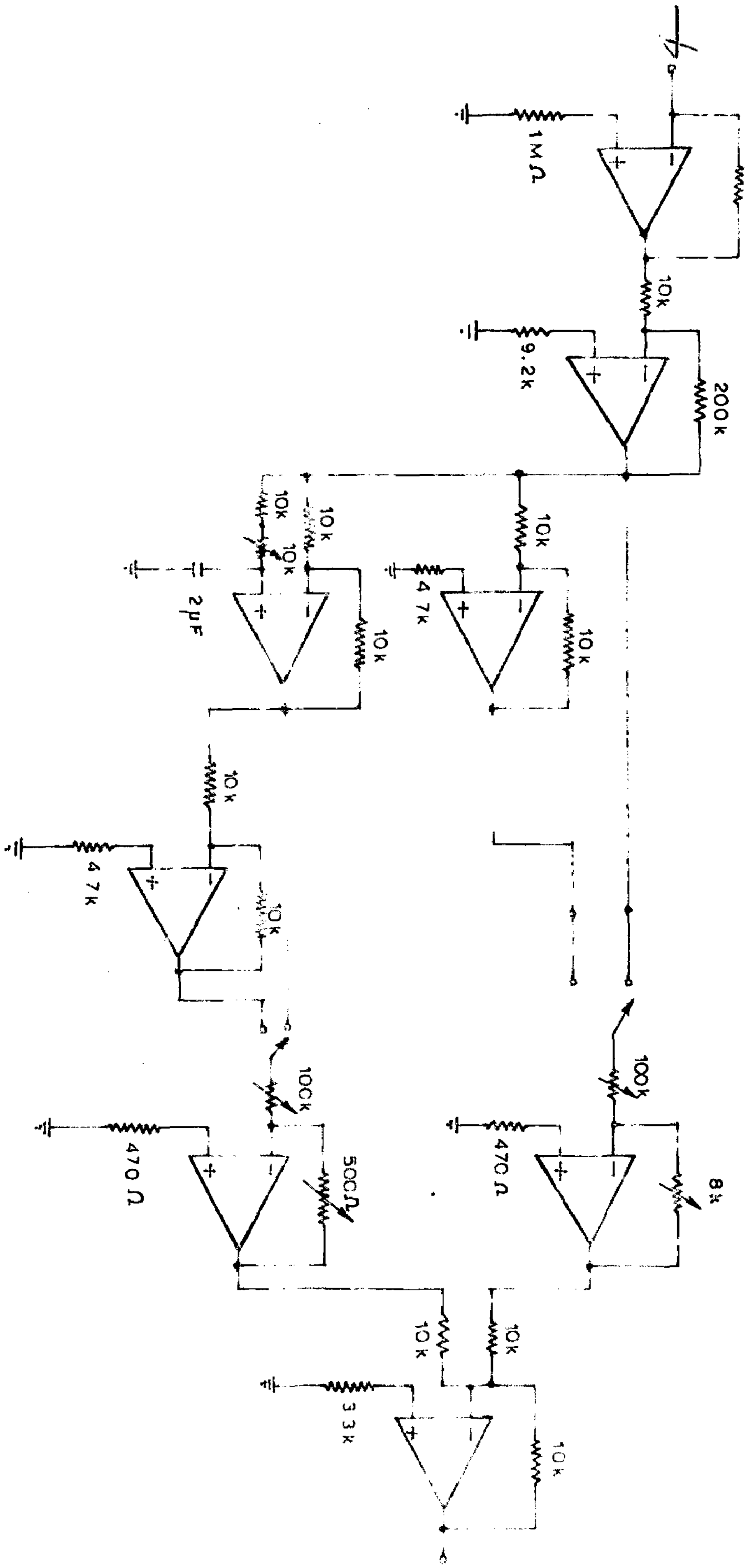
Further-more, the instrument developed is better than other electronic instruments in that they are very complicated and costly items.

An instrument for P.T. testing can also be developed with some modifications in configuration and callibration. For the difference in configuration Fig.4 can be referred. The basic difference is that, here we take the voltage proportional to current in secondary of standard transformer by inserting a resistance but for P.T. Testing the voltage can be taken with the help of another potential transformer. Similarly the voltage proportional to differential current is obtained by using a standard resistance in common branch here whereas this can be obtained in case of P.T. directly by having differential connections of the two P.Ts.

3.2 Block Schematic

The block diagram in Fig.11 shows the basic blocks of the instrument. The voltage across 10mΩ resistance is taken and given to a voltage follower which acts as a buffer and provide a very high input impedance. Then it is given to an amplifier having a fixed gain which amplifies the signal to a suitable voltage level to be processed further with minimum error. This is splitted into two parts one is taken directly and called inphase component, the other is given to a 90° phase shifter, and called quadrature component. Both the inphase and quadrature components are again splitted in two parts each,one through inverters and other directly. The inverted one is for negative ratio and phase angle errors. Then they are given to an adder through a variable gain amplifier and one pole two way switch, as shown in Fig.11. The variable gain amplifiers are basically inverting amplifier modes of operational amplifier acting as an attenuator. The feedback resistances of these amplifiers are variable and therefore we get variable voltages at the output.

These voltages are added up by an adder and given to a detector which is connected to the common branch resistance. In the common branch we have three resistances of 0.01, 0.1 and 1Ωhaving short circuiting plugs so that one of them can be taken in circuit at a time. The voltage drop accorss this resistance due to flowing of differential current ~~is balanced by the output~~ is balanced by the output of the adder by adjusting the resistances of variable gain amplifires. The resistances of the amplifiers in the inphase and quadrature circuit can be directly callibrated in terms of ratio and phase angle errors respectively.



1 MΩ
10 k
9.2 k
200 k
10 k
10 k
10 k
2 μF
10 k
10 k
4 7 k
10 k
10 k
4 7 k
10 k
100 k
500 Ω
470 Ω
100 k
470 Ω
8 k
10 k
10 k
3 3 k
10 k

The detector used for this purpose is also developed. It is basically an amplifier having a tunned frequency of 60 Hz and a gain of twenty thousand. Although at the final stage the voltage has been clamped to 2 volts only because of a log amplifier stage. Log amplifier has been used to give an automatic control of sensitivity. That is more sensitivity atless input voltage and less sensitivity at more input voltage. The detail of detector circuit is given in chapter 4.

3.3 Circuit Details [13]

The circuit diagram showsn in Fig.12 shows detailed circuitary used for the instrument. The stage wise detail and design is given below:

A resistance of 10 m ohm is inserted in the secondary circuit of standard C.T. to have a voltage proportional to the secondary current of standard transformer. This is a piece of constanton wire. Itsxx value is chosen taking three factors into consideration. They are, the burden on standard current transformer, a suitable value of voltage and the availability of the resistance. The value of 10 m ohm is best suited according to these considerations. The exact value of the resistance is not xxxx important as its' constancy with temperature variation etc. is required during the observation and therefore constanton material is suitable.

(i) Voltage Follower Stage:

It is basically a non inverting mode amplifier having a unity gain made with the help of operational amplifier (IC 741). It has an input impedence of 1M Ohm so that no loading and signal drop is there. The circuit is shown in Fig.13 (a).

(ii) Fixed Gain Amplifier

To get a value of voltage which is suitable for further processing such as inversion and phase shifting, we amplify it. This amplifier is basically an inverting mode of operational amplifier (IC 741) having a gain of twenty, so that the voltage now becomes 1 volt. Although it gives inversion but it is not going to effect because accordingly the callibration can be done and positive and negative error points can be decided in the two way switch. Fig.13b shows the amplifier circuit used

taking R_1 = 10K Ohm

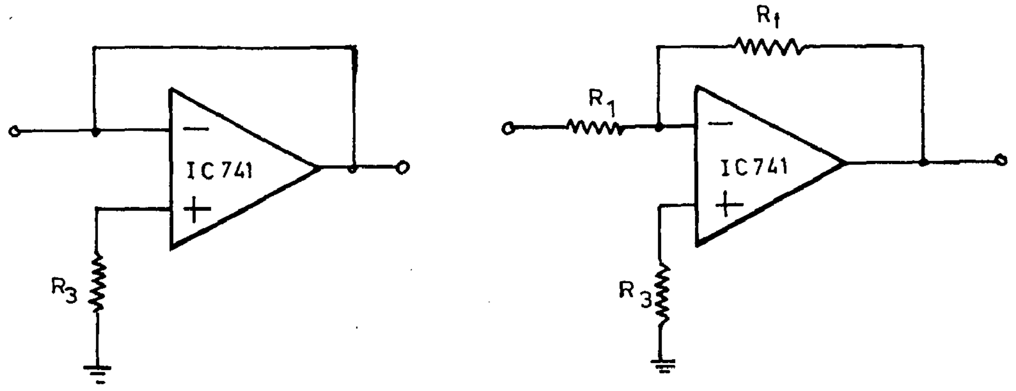
$$\text{Gain} = \frac{R_f}{R_1}$$

$$\therefore R_f = 10 \times 20 = 200 \text{ K Ohms}$$

$$\text{and } R_3 = 200 \| 10$$

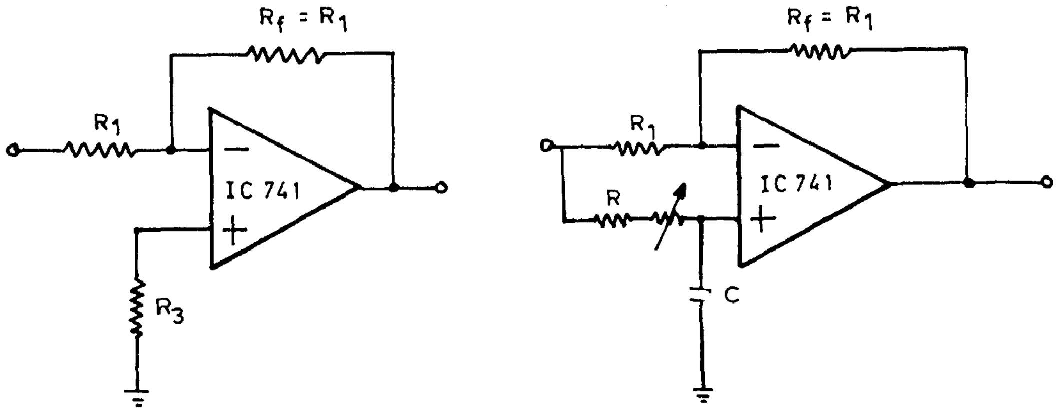
$$= 9.5 \text{ K Ohms}$$

$$\simeq 9.2\text{K Ohms (taking a standard value)}$$



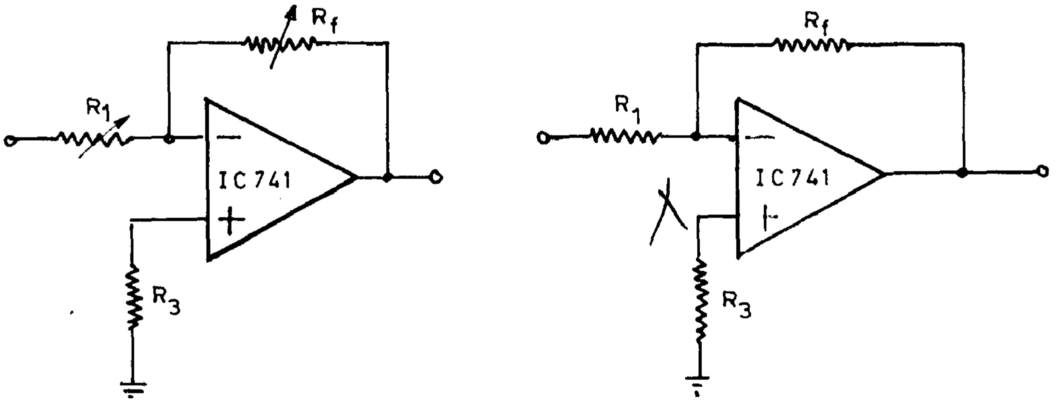
a_ VOLTAGE FOLLOWER

b_ FIXED GAIN AMPLIFIER



c_ INVERTOR

d _ PHASE SHIFTER



e _ VARIABLE GAIN AMPLIFIER

f _ ADDER

FIGURE _ 13

(iii) Invertor

There are two inverters used in the circuit one for inphase voltage component and other for quadrature voltage component. Both the inverters are having the same circuit shown in Fig. 13(C). It is basically an inverting mode amplifier of operational amplifier (IC 741).

Taking R_1 a suitable value of 10K Ohms . For unity gain

$$R_f = R_1$$

$$\therefore \quad R_f = 10 \text{ K Ohms}$$

$$R_3 = 10 \,||\, 10 = 5 \text{ K Ohms.}$$

$$\simeq 4.7 \text{ K Ohms (taking a standard value)}$$

(iv) Phase Shifter

The circuit used for introducing a phase shift of 90° is shown in Fig. 13(d). It is made with the help of an operational amplifier (IC 741). The two equal resistances R_1 are taken of a suitable value of 10K Ohms

If the phase shift is θ , then

$$\tan (\theta/2) = 2\pi f Rc$$

$$f = 50 \text{ hz}$$

$$\text{taking } C = .2 \mu F$$

$$\text{for } \theta = 90^\circ \quad \tan (\theta /2) = 1$$

$$\therefore \quad R = \frac{1}{2 \times 3.14 \times 50 \times .2 \times 10^{-6}}$$

$$\simeq 16 \text{ K Ohms}$$

Therefore a fixed resistance of 10 K Ohms and a preset of 10K Ohms is taken which is trimmed to get exactly 90° phase shift. This can be known with the help of a C.R.O.

(v) Variable Gain Amplifier

This is bascally an inverting mode amplifier made with the help of an operational amplifier (IC 741). Fig.13(e) shows the circuit for the amplifier. The gain of the amplifier will depend upon the range of the instrument.

According to the I.S.I. standards the limit of errors for different class C.T.S. are shown in tables below:

Table 1. Limits of Error For Accuracy Classes 0.1 to 1

Class	Percentage current error at percentage of rated current				Phase displacement in minutes at percentage of rated current.			
	10%	20%	100%	120%	10%	20%	100%	120
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0.1	± 0.25	±0.2	± 0.1	±0.1	±10	±8	± 5	± 5
0.2	± 0.5	±0.35	± 0.2	±0.2	±20	±15	±10	± 10
0.5	± 1.0	±0.75	±0.5	±0.5	±60	±45	±30	±30
1.0	± 2.0	± 1.5	±1.0	±1.0	±120	±90	±60	± 60

TABLE II. Limits Of Error For Accuracy Classes 3 & 5

Class	Percentage Error At percentage of Rated Current	
1	2	3
	50%	120%
3	± 3	± 3
5	± 5	± 5

Note: Limits of phase displacement are not specified for classes 3 & 5.

If we consider that there is no phase angle error then for a current of 5A at the maximum error i.e. 5% will have current = 0.25 A. If we consider the maximum resistance in the common branch i.e. 1 Ohms then the value of unbalanced voltage will be .25V . But if we consider other resistances it can be reduced. Therefore a convenient value of gain = 1/100 is taken so that the maximum value of voltage = 0.1 V. This suits the resistance requirement and the value can cover whole range with a proper accuracy.

For the variable gain amplifier used in quadrature circuit. If we consider equal voltage from both sides then the phase angle will be 45°. For the phase angle error the order is as less as 2° only. For the class 3 & class 5 C.Ts

this is not specified even. Therefore we can certainly say that the voltage obtained from quadrature circuit should be much less than the voltage from inphase circuit. Hence the gain of the amplifier is taken to be 1/1000. This suits to resistance requirement also.
Therefore, resistances choosen for the amplifier in inphase circuit:

$R_1 = 100K$

$R_f = 1K$(Variable).

and for the amplifier in quadrature circuit

$R_1 = 500\ K$

$R_f = 500$ Ohms

Ten turn pots. have been used as variable resistances. The values available were 1K and 500 Ohms and therefore they have been taken. According to the above calculation the fixed resistance in the quadrature circuit amplifier comes out to be 500K but it has been taken as 100 K Ohms to get satisfactory performance of operational amplifier. In fact both the fixed resistances are taken as presets so that proper callibration can be done according to the digit shown by the counter of the ten turn pots.

(vi) <u>Adder</u>

This is an adder circuit which adds the voltages obtained from quadrature and inphase circuits. As this adds the instantaneous values it is a vector adder not scaler.

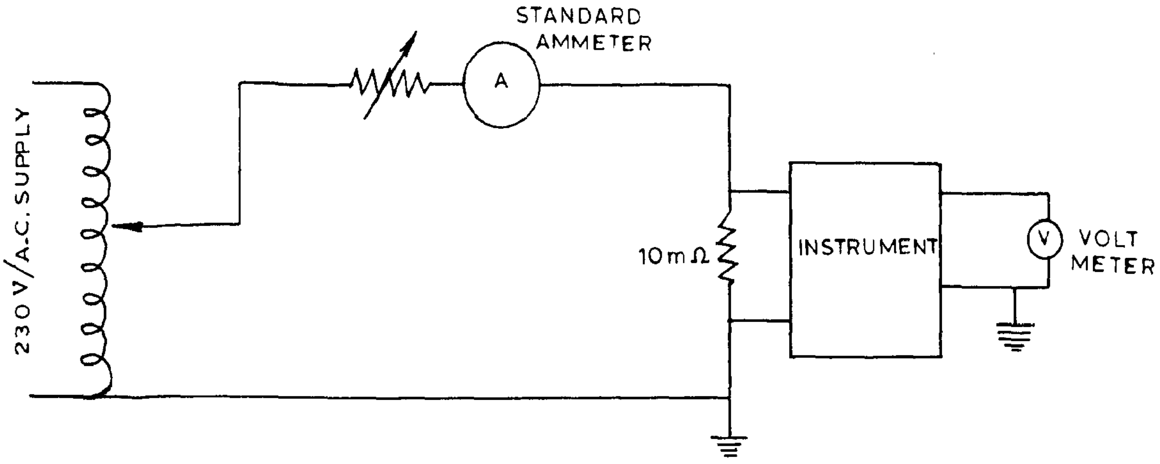


FIG. 13 g _ CIRCUIT FOR CALLIBRATION OF INSTRUMENT

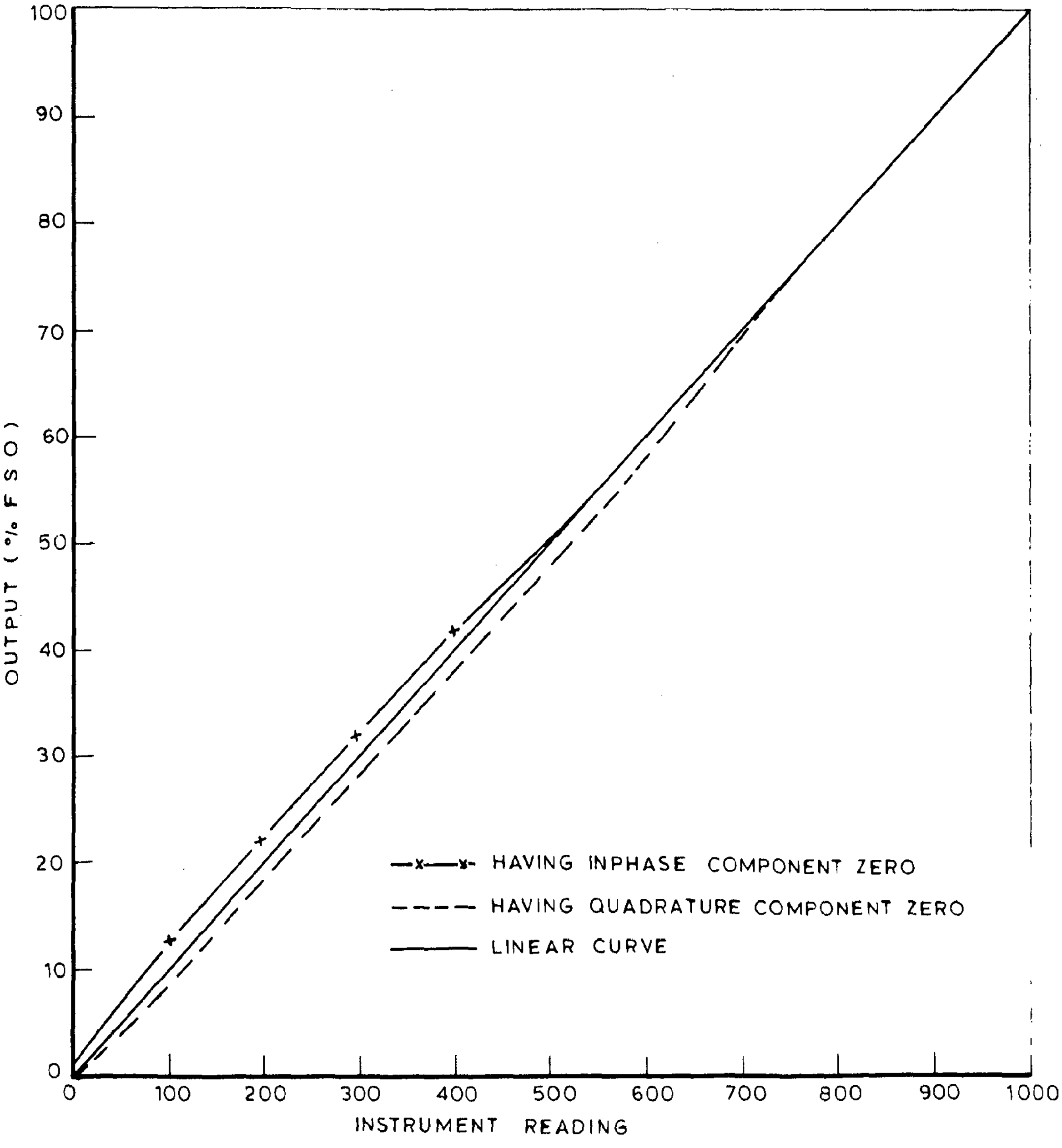


FIG. 13h _ GRAPH SHOWING LINEARITY OF THE INSTRUMENT

The circuit is made with the help of an operational amplifier (IC741) and shown in Fig.13(f) . All the resistances are taken as 10K Ohms a convenient value. If the output is Vo and input voltages are v_1 & v_2

$$\text{Then } V_o = -(v1 + v_2)$$

The resistance at non-inverting terminal of operational amplifier is taken as 3.3 K Ohms , the parallel of the three resistances of 10K Ohms used.

The input resistance can be changed if required according to the range and variation in range of both the errors.

3.4 Callibration of the Instrument

The Callibration methods used, require a standard ammeter and a Voltmeter having uncertainty of less than 0.1 percent. Because we did not use a standard resistance in the secondary of standard transformer to pick up the current we require a standard ammeter otherwise with a stable power supply appropriate voltage can be taken. The circuit diagram for the callibration of the instrument is given in Fig.13(g). Current in the secondary of standard transformer is adjusted at 5 A. Then the voltage output is adjusted by trimming the presets in the variable gain amplifier's with full variable feedback resistance in circuit.

For the reasons given above we have taken full scale output of the inphase component as .1V. As the amplifier gain is proportional to the feed back resistance and the pot taken is linear, This will give putput 0 to .1V from 0 to 100% variation of resistance.

For quodrature componant the F.S.O. is tan θ times the F.S.O. of in phase component where θ is the maximum range of the instrument . For the reasons given in design we have taken $\theta = 5^{0}$.

As θ tan θ for small angles the output of the quadrature component will be proportional to the phase displacement.

$\therefore$ For $\theta = 5^{0}$

Tan θ = .08

F.S.O. of quadrature component = 8 m v = .008 volt

Firstly having quadrature component zero the output of inphase component is adjusted to 0.1 volt and then having in phase compnent zero output of quadrature component is adjusted, at 8 m.v.

Full scale output of inphase component is 0.1V which correspondence to error

$$= \frac{6 \times .1}{0.25} = 2\%$$

and the total scale is divided into 1000 division therefore multiplying factor for getting error

$$= \frac{2}{1000} = .002\%$$

This correspondence to common branch resistance 1Ohm. For .1 Ohm and .01 Ohm this will be .02 and .2 respectively.

Similarly full scale output of quadrature component is 0.08 v which corresponds to 5 degrees error, and the scale is again divided into 1000 division therefore multiplying factor $= \frac{5}{1000}$

$$= .005^{\circ}$$

This correspondence to 1 Ohm common branch resistance for 0.1 and .01 Ohm resistances the factor will be $.05^{\circ}$ and $.5^{\circ}$ respectively. Here for testing ammeter and voltmeter of 1% accuracy has been taken.

3.5 Test Results

The instrument has been callibrated using above method and the results are found satisfactory.

The Fig. 13 h and table 3 shows the linearity of the output with the readings. There is some linearity in instrument due to linarity of variable resistance etc. The zero shift is due to Offset of the operational amplifier. Therefore the instrument is not so accurate in voltage range. 0. to 60 m.v. i.e. ratio error range 0. to .1.2%.

Table 3 Output Voltage according to variation in variable resistances in variable gain amplifiers

<u>For In phase component :</u>

Reading of the Pot	Voltage output
1000	100 m v.
900	90 m.v.
800	80 "
700	70 "
600	58 "
500	48 "
400	38 "
300	28 "
200	19 "
100	9 "
0	.25 "

For qudrature component

Reading of the Pot	Voltage output
1000	8 m.v.
900	7.2 "
800	6.4 "
700	5.6 "
600	4.8 "
500	4.0 "
400	3.35 "
300	2.6 "
200	1.8 "
100	1.1 "
0	0.7 "

Current transformers were tested by Arnold set available laboratory and the instrument developed. The errors are found shown in table 4.

The error observed from instrument in reading ratio error d phase angle error is due to following reasons.

Zero slip & nonlinearity as shown in figure 13 h. This may ue to nonlinearity of pots & offset of I.C.741.

For the caliberation of the instrument metres used were t standard. The ammeter error is not so important because percentage taken. The voltmetre error is very much important.

The least and most important reason is the multiplying ctor calculated may have some error because firstly the output

Table - 4

C.T	By Arnold Set		By Instrument	
	Ratio error	Phase angle error	Ratio error	Phase angle error
(1)	.26 o/o	8 min.	212 x .002 = .424 o/o	115 x .005 x 60 = 34.5'
(2)	.1 o/o	3 min.	112 x .002 = .224 o/o	80 x .005 x 60 = 24'

Table 5 - By Instrument of 25 VA

(1) For one C.T.

At 1A		At 2A		At 5A		At 6A	
Ratio o/o error	Phase angle error min.	Ratio o/o error	Phase angle error min.	Ratio o/o error	Phase angle error min.	Ratio o/o error	Phase angle error min.
At 10 VA							
181 x .002 = .362	0	186 x .002 = .372	0	180 x .002 = 0.36	0	187 x .002 = 0.374	0
At 20 VA							
184 x .002 = 0.366	0	186 x .002 = 0.372	0	184 x .002 = 0.368	0	184 x .002 = 0.368	0

Table - 5 (ii) For another C.T. of 5 VA

At 1A		At 2A		At 5A		At 6A	
Ratio error	Phase angle error	Ratio error	Phase angle error	Ratio error	Phase angle error	Ratio error	Phase angle error
At 1VA							
279 x .002	30 x .005x 60	260 x .002 x	22 x .005 x 60	237 x .002	10 x .005 x 60	241 x .002	9 x .005 x 60
= .559 o/o	= 9'	= 0.52 o/o	= 6.6'	= 0.474 o/o	= 3.0'	= 0.482 o/o	= 2.7'
At 5VA							
535 x .002	140 x .005 x 60	5.13 x .002	89 x .005 x 60	473 x .002	52 x .005 x 60	463 x .002	41 x .005 x 60
= 1.070 o/o	= 42'	= 1.026 o/o	= 26.7'	= .946 o/o	= 15.6'	= .926 o/o	= 12.3'

from in phase component is taken to be zero and then output of quadrature component is taken to be zero. This can be modified by testing no. of C.Ts. having different range of errors with the instrument and the standard set. There may be some error due to 1 standard resistance used in the common branch also.

Table - 5 show the error of two C.Ts at different V.A. and different percentage of current. In the case of first C.T. we do not get phase angle error because the voltage is balanced by the zero input voltage of the instrument in quadrature circuit. In the second case is as the error is more we get readings. Therefore, there is some error involved in measuring the phase angle error.

4. DETECTOR

4.1. Principle

It is basically ~~am~~ a high gain tunned amplifier having a gain of twenty thousand, tunned for 50 Hz. Although the output has been clamped to a value approximately two volts. Because last stage is a log amplifier to have an automatic controlled sensitivity. The output of the amplifier can be given to zero centered micro ampère meter with a suitable resistance in series. The basic idea to provide a high gain is to get fairly good sensitivity which is essential for the instrument developed. As at the lower range of errors the voltages to be balanced will be very low and also the accuracy of whole instrument depends upon the sensitivity of the detector so a high gain is required.

The detector developed is simple in construction and cheaper in comparision to other detectors used. Because it is nothing but a simple detector (Galvamometer or Ameter) with higher sensitivity.

4.2 Block Schematic

The block diagram (Fig. 14) shows the different blocks of detector. Firstly a limiting and coupling circuits is used. This provides the operation of the

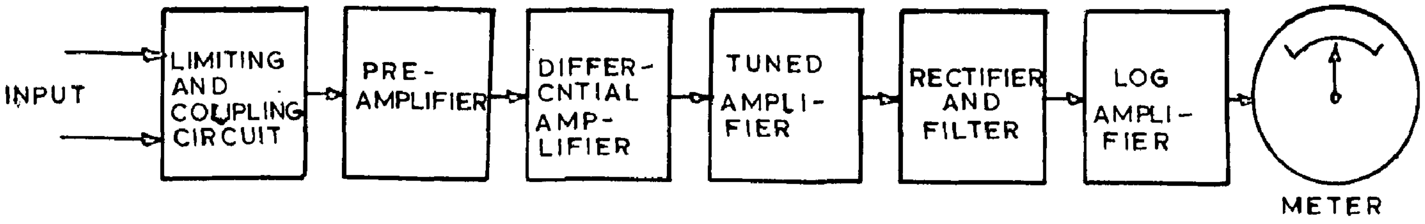


FIG. 14 _ BLOCK DIAGRAM OF ELECTRONIC DETECTOR

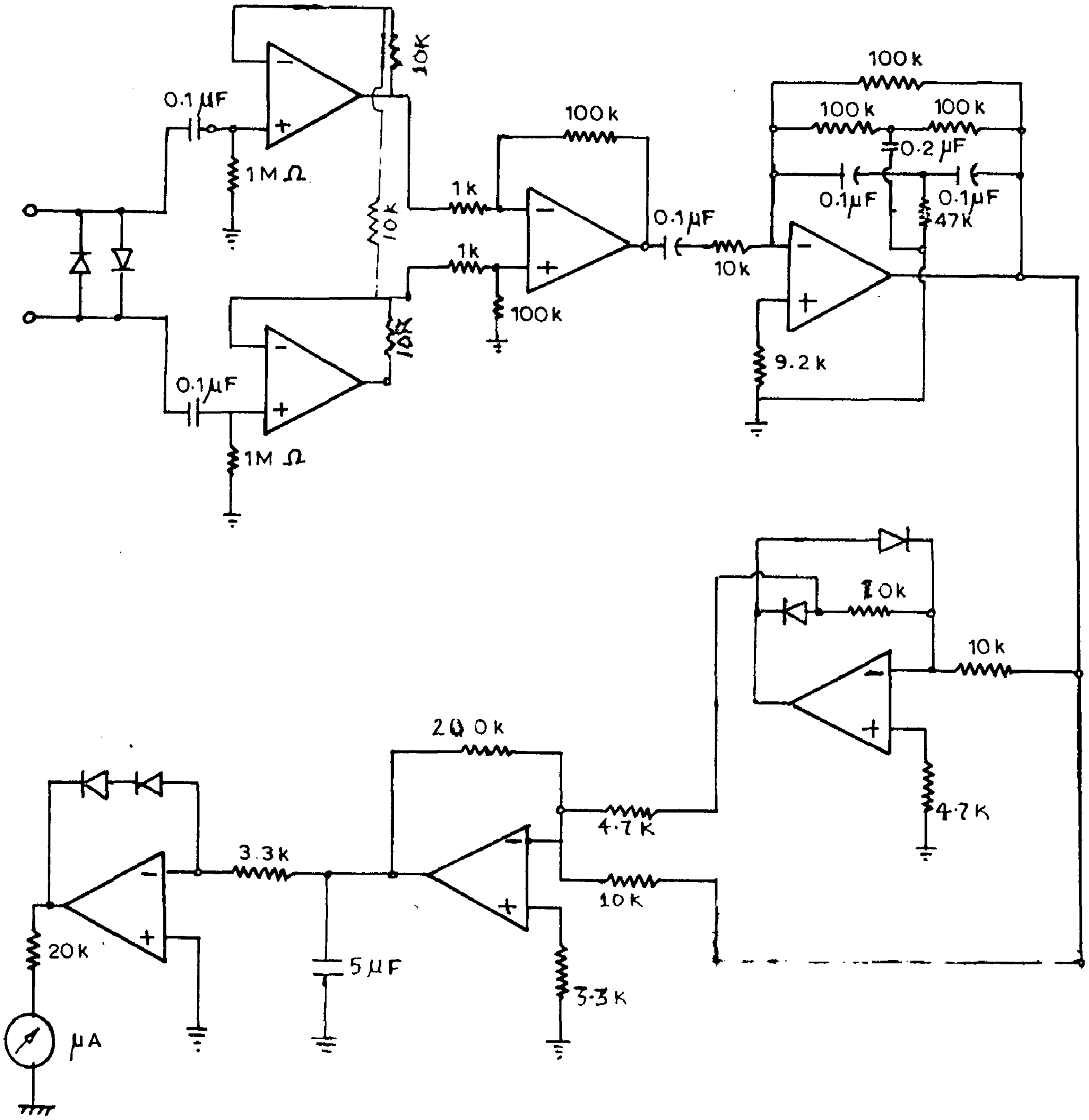


FIG. 15 _ CIRCUIT DETAILS OF DETECTOR

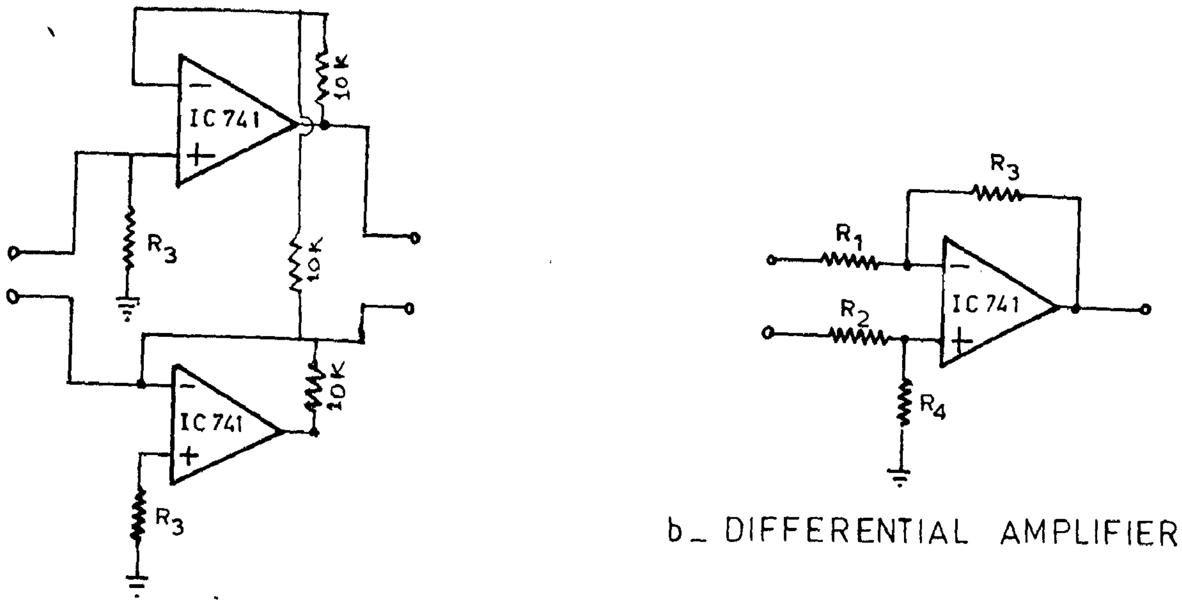
detector within a particular limit of voltage. Therefore, the detector should always be used with a pressing key so that the circuit connected to the detector does not get loaded of the voltage is beyond a particular value which is the forward bias voltage of a germanium diode, that is 0.2 volts. The next stage is a preamplifier to provide a high input impedence. As the detector is having differential input of the preamplifier stage should also be a differential stage. After this a differential amplifier is used to get an amplification of the input. The next stage is a tunned amplifier which is tunned to a frequency of 50 H_z. Then there is a rectifier to get direct voltage suitable for log amplifier. After that we have a lomg amplifier and then the meter. Meter used is a center zero microampere meter with a suitable resistance in series.

4.3 Circuit Details [13]

The circuit diagram (Fig.15) shows the full circuitary used to make the electronic detector. The detail and block wise circuit description and design is given below:

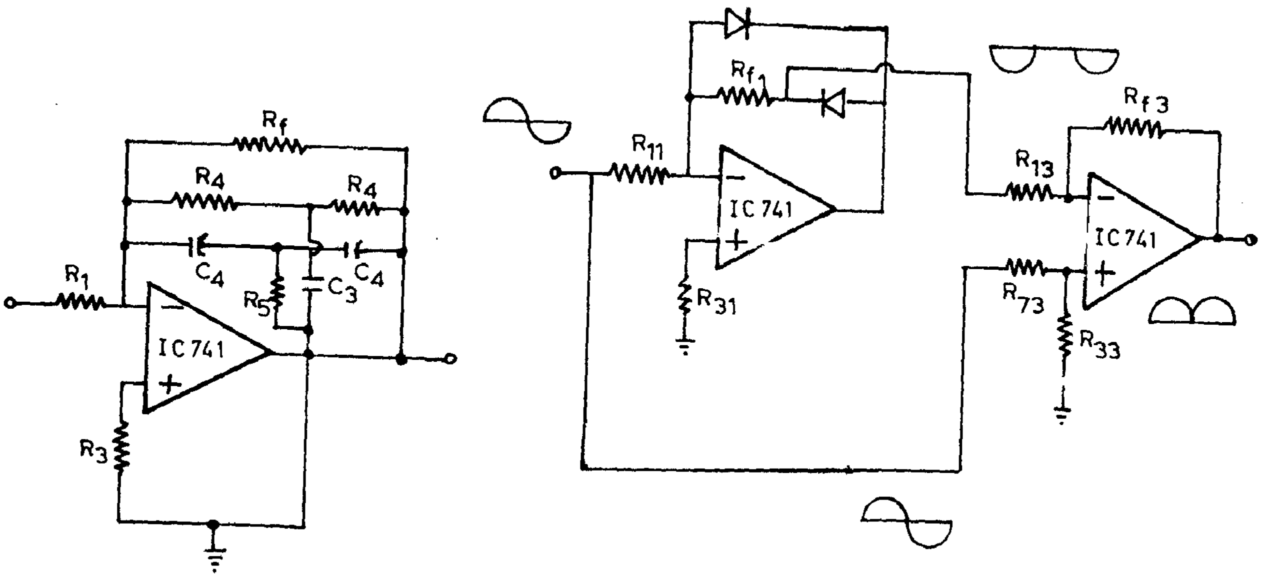
(i) Limiting and Coupling Circuit:

This is made of two germanium diodes (SR204) in parallel across the input, thus giving the maximum voltage 0.2 volt only. The two input are given through 0.1µF



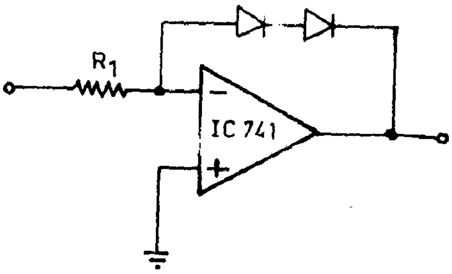
a_ PREAMPLIFIER

b_ DIFFERENTIAL AMPLIFIER



c_ TUNNED AMPLIFIER

d_ R'ECTFIER



e_ LOG AMPLIFIER

FIGURE _ 16

capacitors , which act as coupling circuit. This is used to blockany d.c. component , if present in the input.

(ii) Pre-amplifier

This is a differential preamplifier circuit made by two operational amplifiers (IC 741) both as voltage followers. For each input separate voltage follower circuit is used as shown in the Fig.16 (a). One mega Ohms resistance is connected to noninverting terminal ~~practice~~. which is the usual practice.

(iii) Differential Amplifier

The differential output of preamplifier is given to a differential input single ended output amplifier. The circuit of which is shown in Fig.16(b). The conditions for proper amplification and a defined gain are R_1 should be equal to R_2 and R_3 should be equal to R_4. Then the gain comes out to be

$$\frac{R_3}{R_1} = \frac{R_4}{R_2}$$

The gain of 20000 has been divided in three stages. For differential amplifier 100, then for tunned amplifier 10 , and for rectified 20. Thus the gain of differential amplifier is 100. Therefore, resistances are chosen as

$R_1 = R_2 = 1$ K Ohms

$R_3 = R_4 = 100$ K Ohms

(iv) Tunned Amplifier

Before tunned amplifier for a.c. coupling i.e to filter the d.c. component a capacitance is used. Values of the capacitance can be calculated by

$$\frac{1}{2\pi fc} = R_i$$

where R_i is the input resistance of next stage and C is the capacitor. The next stage has R_i = 10K Ohms

$$\therefore \quad \frac{1}{2\pi fc} = 10000$$

$$C = \frac{1}{10000 \times 2\pi \times f}$$

f = 50 Hz

$$\therefore \quad C = \frac{1}{1\pi} \times 10^{-6} \quad = .3 \times 10^{-6}$$

$$= .3 \mu F$$

This value corresnondence to 3 dB loss . For less loss of singal capacitance value should be more A convenient value of 0.1 μF has been taken.

The circuit of tunned amplifier is shown in Fig.16(c). This is made with the help of an operational amplifier (IC741) in inverting amplifier mode. With a twin T tunned at 50Hz in feed back. This twin T provides infinite impedence at 50 Hz and therefore the parallel resistance Rf only comes into picture. But for other frequencies this provides a very low impedence therefore, the amplifier gives low gain at frequencies other than 50 Hz. The tunning frequency of twin T is given by

$$f = \frac{1}{2C_4 \; R_4}$$

Provided $C_3 = 2C_4$

$\& \; R_5 \; \frac{R_4}{2}$

taking C_4 of a convenient value 0.1 μF

$$C3 = .2 \mu F$$

And for 50 Hz.

$$50 = \frac{1}{2 \times .1 \times 10^{-6} \times R_4}$$

$$R4 = \frac{1}{100 \times .1 \times 10^{-6}}$$

$$= 100 \text{ K}$$

$$R_5 = \frac{100}{2} = 50 \text{ K Ohms}$$

$\simeq$ 47 K (taking a standard value)

Gain of amplifier at 50 Hz $= \frac{R_f}{R_1} = 10$

taking $R_1 = 10$ K

$$R_f = 10 \times 10\text{K} = 100 \text{ K}$$

Resistance at non inventing terminal to compensate the bias current can be calculated

as $R_3 = 10 \parallel 100$

$= 9.2$ K

(v) Rectifier

The rectifier circuit used is not only a rectifier but it is a rectifier with gain and called a precision rectifier. The full wave rectification by this circuit is done with the help of a circuit shown in Fig.16(d) using two operational amplifiers (IC 741). The input is given to a half wave rectifier using diodes in feed back circuit of an inverting mode amplifier as shown in Fig.16(d). The same input and the output of half wave rectifier are added with the help of an adder made by an operational amplifier(IC 741).

The basic principle of the circuit is first the half wave rectification is done & then it is added to the original wave. Because the half wave rectifier is a inverting mode amplifier it gives negative half cycles in place of positive half cycles. When this is added to the original wave it will give only negative cycles. But if the gain with which the rectified wave is added is double than that of original it will give a full wave rectified wave form. Therefore the resistance with rectified wave should be double than that with original wave & the overall gain is decided by ratio of feed back resistance & the resistance with original wave.

Thus the resistances used in the circuit are chosen as

$R_{11} = 10\ K$

$R_{f1} = 10\ K$

$R_{31} = 10 \quad 10$

$= 5K$

4.7K(taking a standard value)

For the adder:

$R_{13} = 10\ K$

$R'_{13} = R_{13}/2$

$= 5K$

4.7K(taking a standard value)

The gain of adder = 20

$\therefore R_{f3} = 10 \times 20$

$= 200K$

$R_{33} = 200 \quad 4.7 \quad 10$

$= 3.3K$

The value of feed back resistance 200K can be obtained by taking two resistances of 100 K in series. Because if we take, a nearest standard value, there will be error in the gain which is not desirable. Matched resistances should be used in this circuit to get an exact wave shape i.e. R_{11} should be exactly equal to R_{12} , R_{f1} and R_{f1}' should be a equal.

At the output of rectifier a capaciter in parallel has been used to get a smooth direct voltage. For the value of capacitence the time constant.

$$R_{1} C > \frac{1}{2 \pi f}$$

where R i is input impedence of next stage which is a log amplifier and = 3.3K

$$3.3 \times C \times 1000 > \frac{1}{2 \times 50 \times 3.14}$$

$$C > \frac{1}{2 \times 50 \times 10^3 \times 3.14 \times 3.3}$$

$$> \frac{1}{.33 \times 3.14} \times 10^{-6}$$

$$> .1 \mu F$$

$\therefore$ C = .5 μF (taking a suitable value)

(vi) <u>Log amplifier:</u> The Fig.16 (e) shows the circuit used for log amplifier. Output of the amplifier stage e_0 can be given by

$$e_0 = - \left(-\log I_0 + \log \frac{e_1}{R_1}\right) K$$

where e_1 in put voltage

I_0 = Saturation ~~forward~~ current of the diode and K is a constant

$$\therefore e_o = -(K' + \log e_1)$$

Thus it gives a log amplification. That is this provides less gain at high input and high gain at lower inputs. Thus this current provides an automatic control of sensitivity which we generally do with the help of a variable resistance in series of meter by varying the resistance from maximum to minimum.

The basic requirement for this circuit to work as a log amplifier is that the diode should be in the region of partial conduction. Because after full conduction it gives a constant voltage across it. Therefore, R_1 is calculated as

$$R_1 > \frac{\text{maximum voltage at the input}}{\text{minimum current for full conduction of the diode.}}$$

The maximum voltage will be depend upon the supply voltage. As we have used batteries of ± 12 volts the maximum d.c. voltage will be 12 volts.

The diode taken is 1N 66 which has minimum forward current = 5mA

$$\therefore R > \frac{12}{5} = 2.4\ K$$

$$R = 3.3K$$

176977

The diodes used are 1N 66 which gives a forward voltage of 1 volt. Therefore maximum output will be 2 volts. Because two diodes are used in series.

The center zero microampare meter used has maximum scale deflection of 100 μA & therefore resistance used in series with the meter

$$R = \frac{2V}{100\,\mu A}$$

$$= \frac{2 \times 10^6}{100} = 20\text{ K Ohms}$$

<u>Test Results:</u> The detector has been tested with a function generator with an alternator. Because by attenuator we can easily get & measure also the voltage for input of the order of 0.1mv. The resistance for attenuator has been taken as 100 & a variable resistance of 1 to 10 . Low resistances have been taken to minimize the noise. And for the same reason shielded wire has been used to give input. The result has been found satisfactory & given in tables below:

Input before attenator of 2/102	Output before log stage V	Output after log stage V
0	0.3	0.05
5	1.8	0.24
10	3.0	0.30
15	5.2	0.37
20	6.0	0.45
25	7.2	0.50
30	8.4	0.53
40	10.5	0.6
100	10.6	0.6
200	10.8	0.6

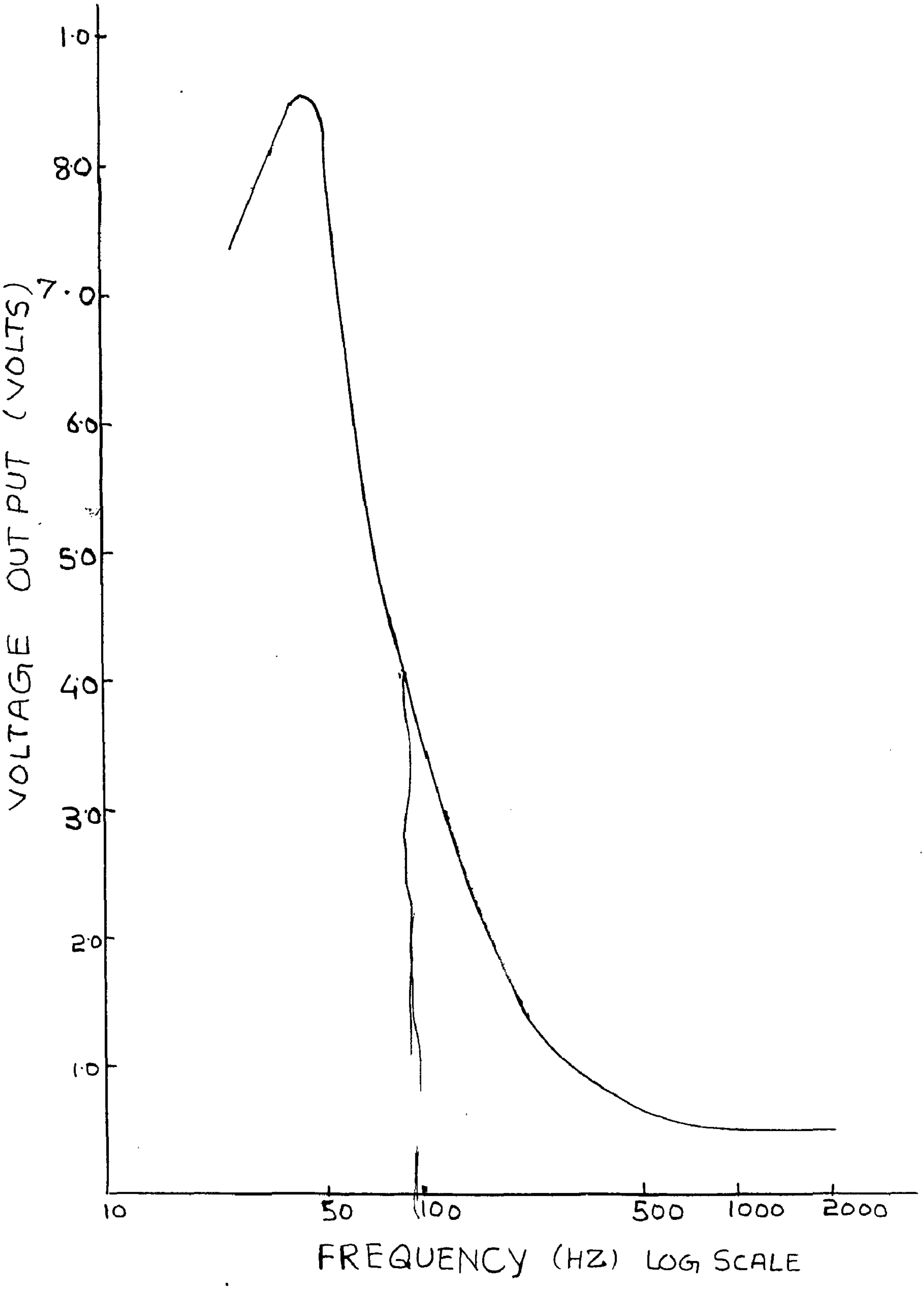

VOLTAGE OUT PUT (VOLTS)
1·0
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
10
50
100
500
1000
2000
FREQUENCY (HZ) LOG SCALE

FIG. 16

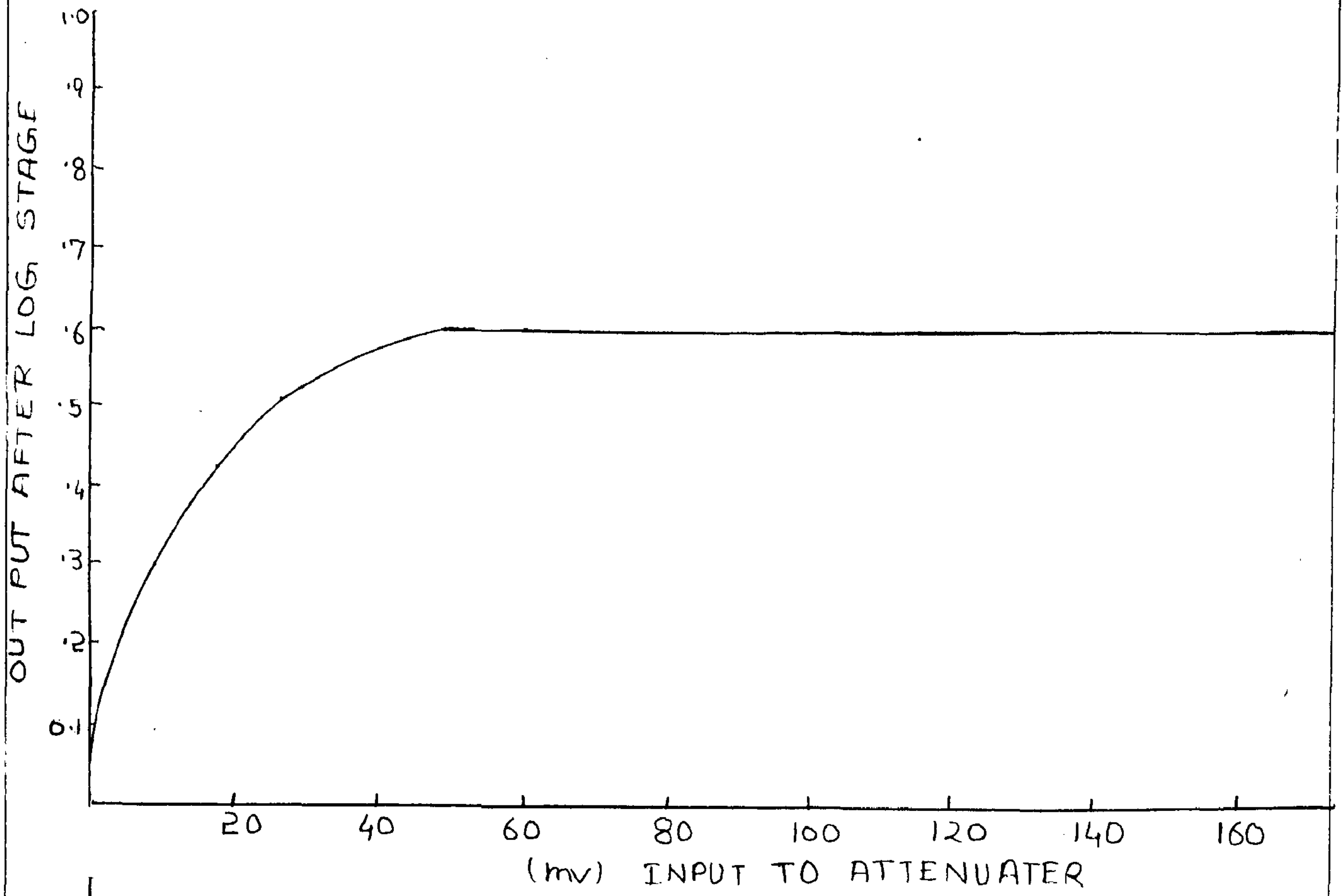


FIG 16 (g)

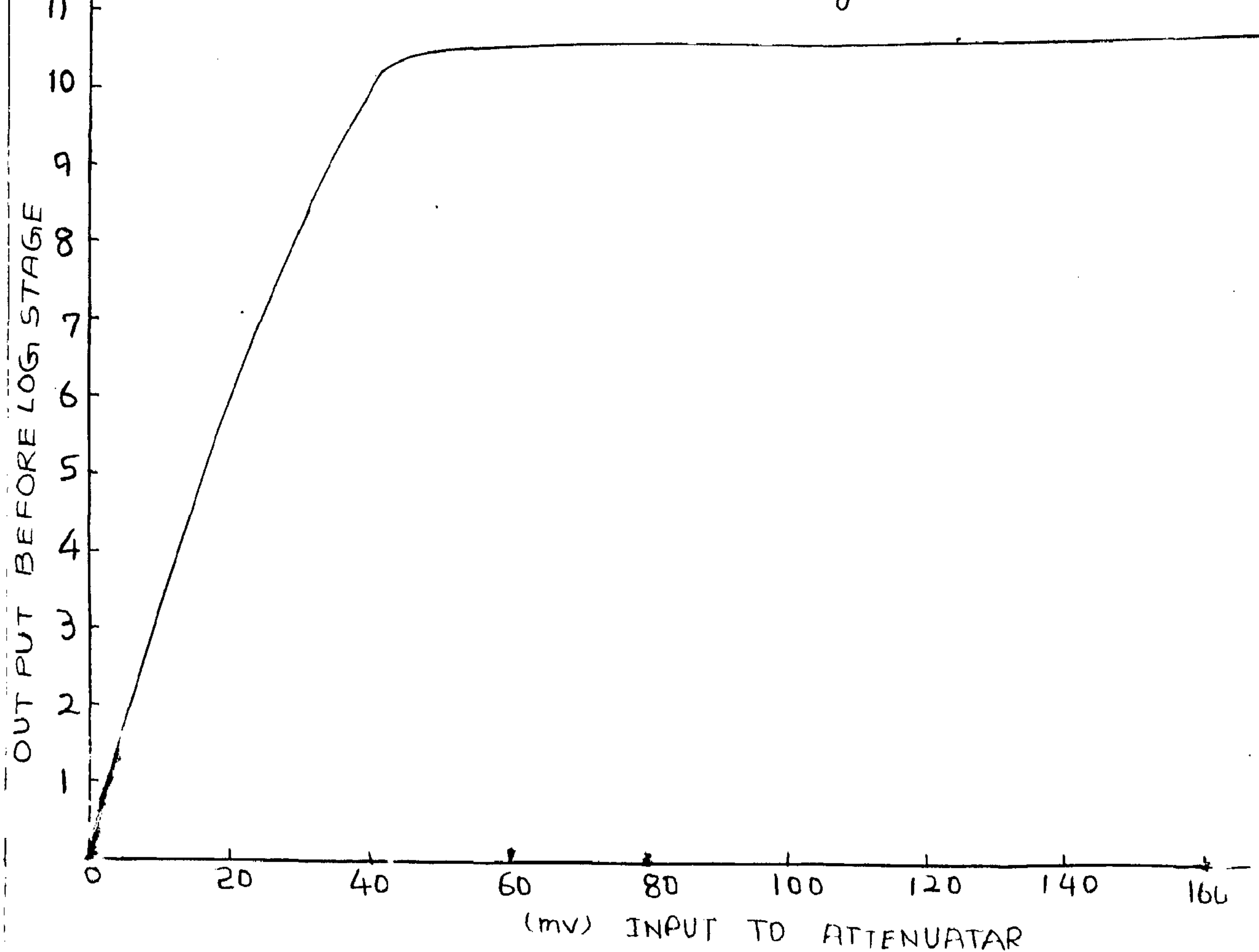


FIG. 16(f)

Frequency Hz	Output at 0.6 mV
25	7.4
30	7.5
40	8.5
50	8.4
60	6.5
70	6.4
90	3.9
150	3.0
200	1.5
400	0.8
500	0.8
1000	0.5
2000	0.5

The fig.16g shows the variation output before log stage with respect to input, the gain comes out to be approximately fifteen thousand.

Fig.16h shows the variation of output after log stage. It is clear that more gain is obtained at lower values.

Fig.16i shows the output vs varying frequency input We see that at 45Hz we get the maximum output. This is because of some error in resistances & capacitances. This can be made tunned to 50Hz having a preset instead of fix resistances. But this gives fairly high output at 50Hz also therefore it is not going to effect the detector performance.

The output at zero input does not come exactly zero because of offset of rectifier & log stage amplifier I.Cs.

5. PROPOSED AUTOMATIC INSTRUMENT

5.1. Principle

In the instrument developed one has to adjust the two variable resistances to get the balance and then the reading obtained on the resistances will give the ratio and phase angle error. But for a direct indication of error we can have following scheme. In 2.3.2 a self balancing scheme is discussed but that scheme is very complicated whereas the scheme proposed here is a simple and equally accurate scheme. The basic principle remaining the same as 2.3.2. Equation no.(10), (11), (13) & (14) from 2.3.2 are

$$6_v \propto \left|\frac{U_x}{Us}\right| \text{Cos}\,\alpha\,.\,100 \text{ in percent} \qquad \ldots\ldots\ldots(1)$$

$$\beta_v \propto \frac{Ux}{Us} \quad \text{Sin}\,\alpha \qquad \ldots\ldots\ldots(2)$$

$$6_c \propto \frac{Ix}{Is} \quad \text{Cos}\,\alpha\,.\,100 \text{ inpercent} \qquad \ldots\ldots\ldots(3)$$

$$\beta_c \propto \frac{Ix}{Is} \quad \text{Sin}\,\alpha \qquad \ldots\ldots\ldots(4)$$

If we multiply two sinusoidal signals say

$A \sin wt$ & $B \text{ Sin } (wt - \alpha)$

Then output $Vo = A \sin Wt . B \sin (Wt. - \alpha)$

$$= \tfrac{1}{2} AB\,(\,\text{Cos}\,(2wt - \alpha) - \text{Cos}\,\alpha)$$

and now with the help of a filter we filter out a.c. component and take only d.c. component then the output will be given by

$$\text{d.c. component} \propto \tfrac{1}{2}\, A.B \ \text{Cos} \qquad \ldots\ldots(5)$$

Now from equation (1)

$$\epsilon_u \propto \frac{|Ux|}{|Us|}\ \text{Cos}\,\alpha$$

$$\propto \frac{|Ux|\,.\,|Us|}{|Us|\cdot|Us|}\ \text{Cos}\,\alpha$$

$$\propto \frac{|U x| \times |Us|}{|Us|^2}\ \text{Cos}$$

$$\propto \frac{U\,x\,max\,.\,Us\,max}{|Us|^2}\ \text{Cos}$$

$$\propto \frac{\text{d.c. component of multiplication of Us \& Ux}}{|Us|^2} \qquad \ldots\ldots(6)$$

(from equation No.5)

It we take A sin (wt. + 90) and B.Sin (Wt+ α) then the d.c. component will be given by

$$\text{d.c. component} \propto \tfrac{1}{2}\ AB\ \sin\alpha \qquad \ldots\ldots.(7)$$

Now from equation (2) similarly we can obtain that

$$\beta_v \propto \frac{\text{d.c. component of multiplication of Us with with a phase shift of } 90^\circ \text{ and Ux}}{Us^2} \qquad \ldots\ldots.(8)$$

Similarly for C.T. ratio and phase angle errors can be written as

$$\epsilon_c \propto \frac{\text{d.c. component of multiplication of } I_s \,\&\, I_x}{|I_s|^2} \qquad \ldots\ldots(9)$$

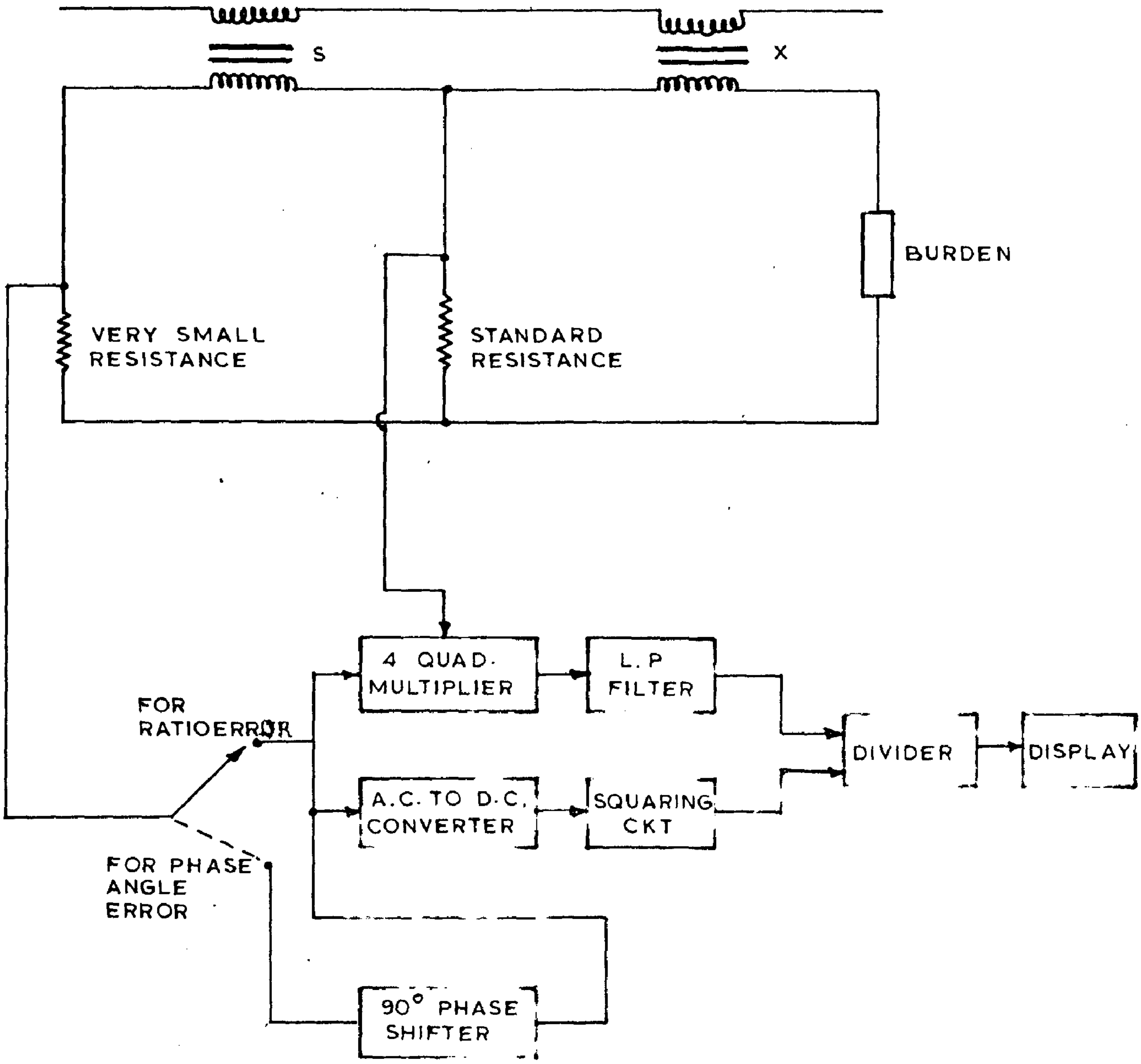


FIG. 17 _ PROPOSED AUTOMATIC INSTRUMENT

$$\beta_c \propto \frac{\text{d.c. component of mulitiplication of } I_s \text{ with a phse shift of } 90^{\circ} \text{ and } I_x}{|I_s|^2} \qquad .....(10)$$

Equations (6), (8), (9) and (10) can very easily be r-ealized.

5.2. Scheme

A scheme for realizing above equations is given below Here the block diagram for realizing the equations for C.T. testing only is given in Fig.17 because the only difference is that in the case of C.T. we take voltages by inserting resistances in the circuit whereas in the case of P.T. voltages can be taken directly. For the exact connection Fig.4 can be referred.

Fig.17 shows the basic block diagram of the circuit. The basic principle is same as comparision method. The voltage taken from secondary of standard current transformer and the common branch is given to a four quodrant multiplier The voltage from secondary of standard current transformer U_s is directly given to multiplier for ratio error and through 90° phase shifter for phase angle error. This can be selected by a one pole two way switch, Out put of multiplier goes to a low pass filter which gives d.c.outout. This direct voltage and square of rectified Us isgiven to a divider,output, of which is given to a meter which can be callibrated in terms of ratio and phase angle errors.

One four quadrant multiplier one d.c. multiplier and one d.c. divider are the main components required for this scheme. All types of multipliers and divideers required are available in integrated circuit chips. To make a divider a multiplier can also be used in feed back of an amplifier.

The meter used should be centre zero so that it can give positive and negative both type of errors. The meter can be callibrated separately for ratio error and phase angle errors. This may have a scale for potential transformer errors if the instrument is designed in such a way that it can be used for P.T. testing also. An A/D converter with a digital display can be used for display of ratio error and phase angle errors. One advantage of this instrument is that having digital output, the human involvement may be reduced and the data can directly be used in computors for data processing.

6. CONCLUSION

6.1. Conclusion drawn from the work done

Although the instrument developed is not so accurate its shows ~~the~~ an accurate pattern and therefore it is sure that an instrument with enough accuracy can be developed with the same scheme using better components and better callibration method. The test result and performance of the developed instruments is given in third ~~the~~ chapter.

The main problem with I.C.741 is its offset. In the case of detector it becomes predominant because the gain is very high and the output is also d.c. It is not at all desired for the detector because it is used for null detection. The test result and performance of the detector is given in fourth chapter,

6.2 Application of Instrument

The instrument has application in both the ends that is at manufacturers end and consumer end. As the procedure is easy to get error this can be used By manufacturers of C.T.S. to get errors easily and in less time. It can be used by consumers also ~~who~~ who require no.of C.T.s. for their work. It is a cheaper device so the consumer can very easily afford to have it.

Accuracy can be increased by having better components and better callibration methods, So it can be used in laboratories also.

With some modification in configuration this can be used for potential transformers testing also. The modification needed is given in the report.

The detector developed can be used for other null balance applications like bridge balance etc. It can be made tunned to other frequencies by having other tunned twinTcircuit and a selector switch.

6.3 Suggestions for Further work

For range selection the fixed resistance used in the variable gain amplifier can also be taken of three values according to the resistance inserted in common branch . This will give equal accuracy linearity and sensitivity for each resistance. One selector switch can be had for selection range.

The resistance used in common branch can be replaced by having an operational amplifier and a resistance of more value in feed back as discussed in 2.3.3. This will reduce the burden on the C.Ts

Better components like I.Cs with no offset error can be used and accuracy can be increased in the case of instrument and detector both. For the detector it is very much important as it is for null detection and output is d.c. with the detector we can have dthe tuned twin Ts and having a selector switch it can be made tunned for different frequencies.

For use for P.T testing different configuration given in Fig.4 can be used. The voltage output ferom the configuration can be calculated and accordingly the components like P.T. in the configuration can be designed to ssuit the instrument. The multiplying factor can also be changed accordingly.

The proposed scheme in Chapter 5 can be constructed and callibrated to have an automatic instrument for instrument transformer testing.

REFERENCES

1. Golding, E.W., Widdis , F.C., 'Electrical Measurements and Measuring Instruments" pp.743-60.

2. Rusters and Moore, The Current Comparator and its application to the absolute Callibration of Current transformers". Trans.A.I.E.E. 1963 pp 94-104.

3. Miejenic, Rusters, Moore, " The development of the Current Comparator, a high accuracy A.C. Ratio Measuring Device, AIEE(Communication and Electronic) Vol.64 Nov.1963. pp 359-363.

4. The Compensated current Comparator, a new reference in Industry", IEE E trans. on Inst. & Meas. Vol.IM-13 pp 107 -114 June,Sept.1967.

5. Kusters, Nerbut, "Current transformers Callibration using Compensated Comparator,LTIM 69 Dec.261-265.

6. S.K.Basu, S.N. Chakraborty, S.Sen Gupta,"Applied Physics Department,Calcutta University," IEE-IERE. Proc.India (GB)Vol.15 No.6 Prec.India IEE p -235-43 Nov.-Dec.1977.

7. T.M. Sounders" A Wider Ranges Current Comparator System for Callibrating Current transformers" IEEE Trans. Power App. & Syst. (U.S.A.) Vol PAS -90 No.1 p-318-24 Jan.-Feb.1971.

8. P.M.Miljanic,N.L.Kusters, WJM. Moore, "The application of current comparators to the Callibration of Curent transformers at ratios upto 36000/5 amps,IEEE Trans. Inst.Meas (U.S.A.) Vol.EM 17 No.3 pp 196 -203 Sept. 1968.

9. ERICH ZINN, "An Electronic self Balacnging Instrument Transformer testing device IEEE Trans.IM -20 No. Nov.1971 pp .291-296.

10. Moore, William J.M. "Direct reading ratio error Sets for Callibrations". TIM -70Aug.161-166.(pp).

11. A Bram," Determination of C.T. errors at primary current upto 100000 A "IEEE trans. on Instru.& Meas. (SA) Vol. IM26.No.3 p 263 -7(Sept.1977).

12. Richard L Kahler." An electronic Ratio error set. For current transformer Callibrations". IEE Trans. On Instrumentation and Meas.Vol. IM.28 No.2 June 1979 pp-162 -4.

13. Coughlin and Discoll.FF Operational amplifiers and Linears Integrated Circuits 1977.