USE OF GERTSCH STANDARD RATIO TRANSFORMERS (RatioTran*) FOR LOW IMPEDANCE VOLTMETER CALIBRATION

The RT Series Standard Ratio Transformers are very useful for AC voltmeter calibrations. Basically, the system consists of a standard voltage source driving the RatioTran* which in turn drives the meter to be calibrated.

Several things must be taken into consideration in this system. The source voltage must be known at least as accurately as the calibration to be made. The distortion of the source must be low, particularly in a case where the meter which is monitoring the source measures on a different basis from the meter to be calibrated. For example, the monitoring meter might read RMS voltage and the meter to be calibrated might read average voltage.

The loading effects of the meter to be calibrated on the RatioTran* should be taken into consideration. These loading effects can be easily determined from the ratio of meter impedance to ratio transformer impedance. For all practical purposes the ratio transformer impedance is resistive and forms, with the meter to be calibrated, a voltage divider. Therefore, if the voltmeter is resistive, the voltage appearing across it will be low by an amount equal to the ratio between the RatioTran* resistance and the meter resistance. For example, if the RatioTran* has an internal impedance of 5 ohms and the meter has a resistance of 5,000 ohms, the voltage appearing across the meter will be 5/5000 or .1% lower than it would be if the meter had infinite impedance.

The foregoing analysis can be generalized. The fractional error that will exist with the RatioTran* resistance R and meter resistance M is approximately equal to $\frac{R}{M}$, or stating it a different way, for a maximum error E the meter resistance M must be greater than $\frac{R}{E}$, where R is again the series impedance of the RatioTran*.

The maximum series impedance in any of the ratio transformers for nominal frequencies is less than 5 ohms with the exception of the RT-1 and RT-10 where the maximum is 12 ohms. Consequently, for meter impedance of 5,000 ohms or greater the error introduced by loading effects on the ratio transformers will not be greater than .1% for all ratio transformers except the RT-1 and RT-10, in which case for the same accuracy the meter resistance must not be less than 12,000 ohms.

If greater accuracies are desired or the meter impedance is lower than the values given above, power must be supplied to the meter in a bridge arrangement shown in Figure 1. With this circuit it is possible to adjust the variable series impedance so that all the power supplied to the meter comes from this branch. This, of course, occurs when the bridge is balanced, that is, the ratio of the meter impedance to the total impedance (meter impedance plus variable impedance) is equal to the ratio of the Standard Ratio Transformer. Obviously, when the bridge is balanced there is no current flow through the ratio arm of the transformer and the junction between the series impedance and the meter so there is effectively no load on the ratio transformer.

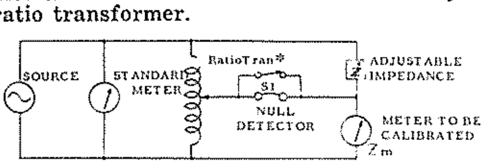

FIG. 1

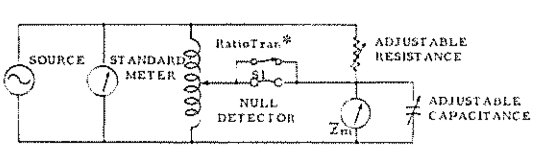

FIG. 1A
Modification of Fig. 1
CONVENIENT WHEN Z_m CONTAINS INDUCTIVE REACTANCE

Since we can make the ratio transformer operate essentially unloaded by this method, meters with impedance as low as desired can be calibrated with no loss in accuracy.

One other restriction must be placed on the variable impedance in series with the meter. It must have the same phase angle as the meter. The total requirement can be stated generally as follows: the ratio of the complex impedances of a meter and series impedance must be real and equal to $\frac{N}{1-N}$ where N is the ratio on the ratio transformer. Here we have assumed that the Ratio Transformer has zero phase shift.

This last statement is merely another way of saying that the bridge formed must be balanced.

The degree of unbalance which can be tolerated in the bridge circuit can best be expressed in terms of the unbalanced current flowing in the ratio arm of the transformer. Since the product of the unbalanced current times the effective impedance in the ratio arm gives the magnitude of the error voltage, the maximum value of this current can be easily determined. It would be simply E Max. divided by R Max. where E is the maximum allowable error voltage and R is the maximum series impedance in the ratio arm of the transformer.

The unbalanced current itself may be measured directly with a high sensitivity AC current meter, or the bridge may be brought to balance with standard null detector techniques. The null detector should be shorted out with switch, S1, after balance has been reached. This last step is recommended since the voltage at the junction between the series impedance and the meter will always be closer to the true voltage for small errors if the null detector is shorted out.

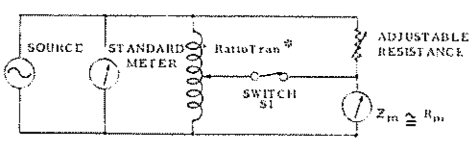

FIG. 2

SUITABLE ONLY WHEN Z_m IS RESISTIVE OR NEARLY RESISTIVE

If the phase angle of the meter is known to be small this series impedance may be resistive and balance of the bridge can be detected with a circuit shown in Figure 2. The switch, S_1, is alternately opened and closed and the series impedance adjusted so that the meter reads the same whether the switch is opened or closed. When this occurs the bridge is balanced provided the phase angle of the meter is small. The phase angle requirement must be met because it is possible, in this test, for the meter to read the same whether the switch is opened or closed and still not have the voltage across it equal to the open circuit voltage of the ratio transformer, when the phase angle of the meter in the series impedance are not equal. The allowable phase angle can be determined from the circuit constants and the accuracy desired, or a direct measurement of the unbalanced current may be made.

For maximum accuracy of calibration the RatioTran* should not be used to divide the standard source too far. The reason for this is, the accuracy of the ratio decreases for small ratios between output and input of the RatioTran.* To guarantee accuracies better than .02% it would be necessary to operate with ratios larger than .01. To extend the system range below .01 a new standard voltage one 100th the original standard voltage could be derived with the RatioTran* and this used to extend the system on down by another factor of 100. In this manner a total range of 10,000 to 1 can be covered with less than .04% error. One method of doing this is to connect two ratio transformers in cascade. The percentage errors of the two transformers can be added in this case.

* *Trademark*

ACCURACY CALCULATIONS FOR GERTSCH STANDARD RATIO TRANSFORMERS (RatioTran*)

1. DEFINITION

The accuracy of Gertsch Standard Ratio Transformers is specified by a formula which gives the maximum error which could be expected in the indicated ratio. This would give the error as a percentage of the output if the input is perfectly known. This accuracy is applicable to a bridge circuit, since the source voltage is common to both branches of the bridge circuit and variations of source voltage cause no error. The accuracy specification is given as a formula similar to $\pm\ (.004\% + \frac{.0001\%}{R})$ where R is the indicated ratio in the decimal fraction form with which the RatioTran* switches are calibrated. This formula gives a more accurate description of the maximum error which could be expected from a Gertsch RatioTran* than would be obtained by the standard definition of terminal linearity. In a potentiometer terminal linearity rating, the error component which is to be expected at the output is quoted as a percentage of the input voltage. A comparison of the specified maximum error in a RatioTran* and a potentiometer of .005% terminal linearity is given in the following table.

ERROR EXPRESSED AS PERCENTAGE OF OUTPUT			
Ratio	Ratio Transformer Units Shipped Prior to 1/1/56 $\pm(.004\% + \frac{.0001\%}{R})$	Ratio Transformer Units Shipped After 1/1/56 $\pm(.001\% + \frac{.0001\%}{R})$	Potentiometer .005% Terminal Linearity
1.0	± .0041%*	± .0011%*	± .005%
.1	± .005%	± .002%	± .05%
.01	± .014%	± .011%*	± .5%
.001	± .104%*	± .101%*	± 5%

*This is the exact solution of the formula. Since "error" is only roughly specified, all digits beyond the first significant figure are meaningless.

2. ACCURACY vs AGE

A careful study of the distribution of resistance and reactance in RatioTrans* leads us to believe that it is extremely improbable that the specified values of error will ever be exceeded. The accuracy of Gertsch RatioTrans* does not change appreciably with age and periodic calibration checks are unnecessary. Any periodic checks should be directed chiefly at detecting malfunctioning switches or potentiometers.

3. ACCURACY UNDER LOAD

Gertsch Standard Ratio Transformers have an internal impedance which can be considered to be in series with the output (see Fig. 1).

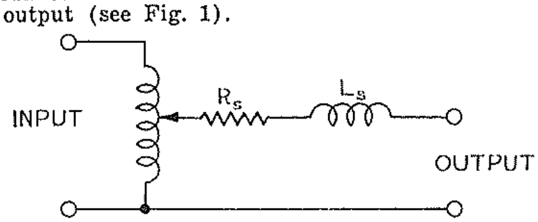

FIG. 1

The value of this impedance varies with ratio in a manner which makes it impractical to define it as a function of ratio. Instead, maximum values of resistance and reactance that can be expected at the worst possible setting of the instrument are given. Voltage drop in the RatioTran* will always be less than the value found by multiplying the load current by the specified maximum series impedance. If the impedance of the load is known, the error introduced by this impedance will always be less than the ratio of the specified maximum impedance to the load. As a numerical example, suppose that a 10,000 ohm resistive load is to be driven from a Model RT-5 operating at 400 cycles. The RT-5 has a maximum effective series inductance of 75 uh. At 400 cycles this is an inductive reactance of .2 ohms, and, for the purposes of this problem, it may be neglected since it is much less than the 3 ohms maximum effective series resistance. The RT-5 may be assumed to have a series impedance of 3 ohms or less resistive. When loaded by 10,000 ohms, the fraction of output voltage dropped across the internal impedance of the RT-5 is given by:

$$\frac{Edrop}{Eout} = \frac{Rseries}{Rload + Rseries} = \frac{3}{10{,}000 + 3} \cong \frac{3}{10{,}000} = .0003 = .03\%$$

In this case the percentage error contributed from this source is .03%. If this error is acceptable, the circuit may be used. Otherwise a bridge circuit must be devised which will drive the required load impedance without loading the Ratio Transformer beyond the acceptable current level. Circuits for this purpose are discussed in another paper distributed by Gertsch Products, Inc. The title of this paper is Engineering Bulletin No. 2 (RatioTran*) "Use of Gertsch Standard Ratio Transformers For Low Impedance Voltmeter Calibration."

* *Trademark*

USE OF RatioTran* IN BRIDGE CIRCUITS

Since any bridge circuit has four terminals, only one of which may be grounded, it is recommended that a shielded bridge transformer such as the Gertsch Model ST100 or ST100A be used to isolate either the generator or detector. Typical circuits are shown below.

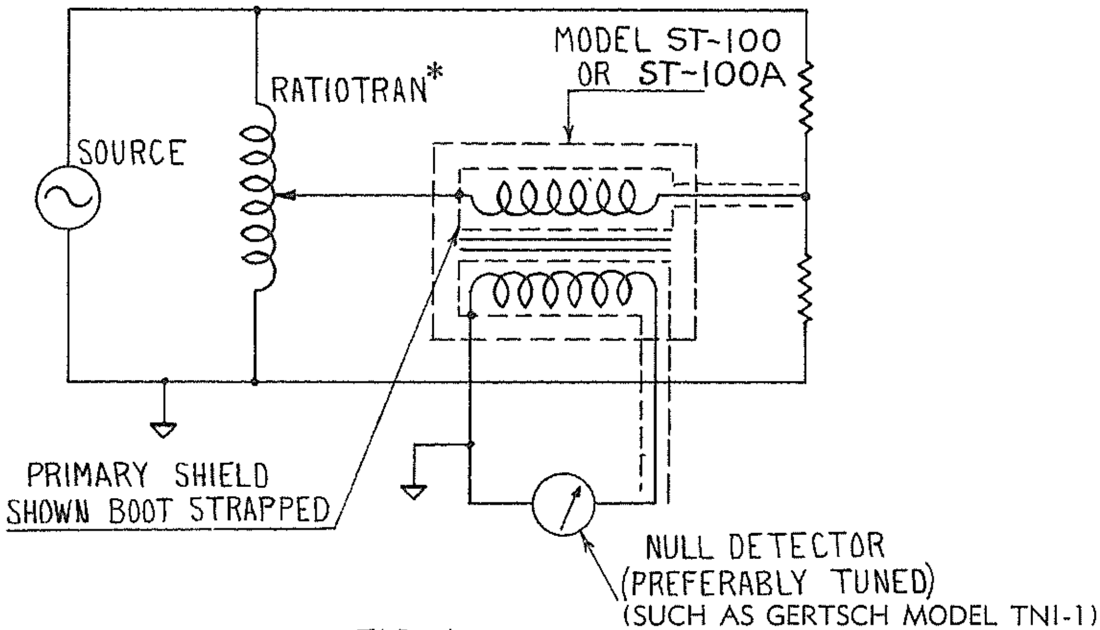

FIG. 1

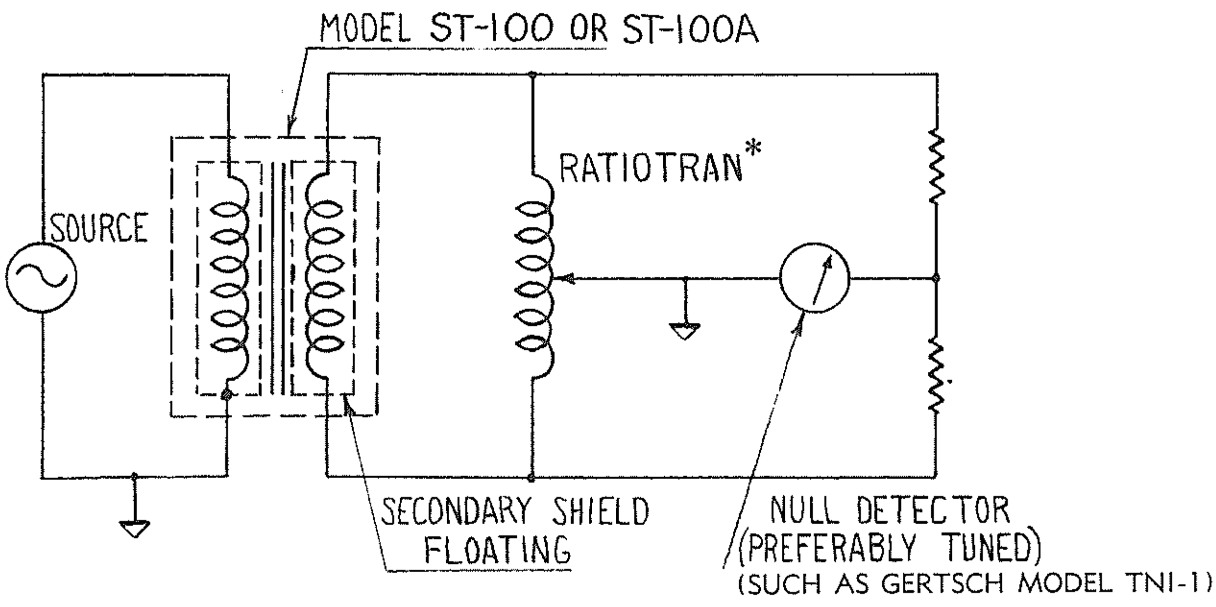

FIG. 2

The degree of shielding of the various bridge elements used depends on impedances and accuracy desired. For a good treatment on AC Bridge technique the reader is referred to "Electronic Measurements" - Terman & Pettit.

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The following article originally appeared in the January 1956 issue of Control Engineering and is reprinted here with the permission of Control Engineering and the author, Mr. Jack Gilbert.

Measuring Small Phase Angles

JACK GILBERT, Norden Laboratories

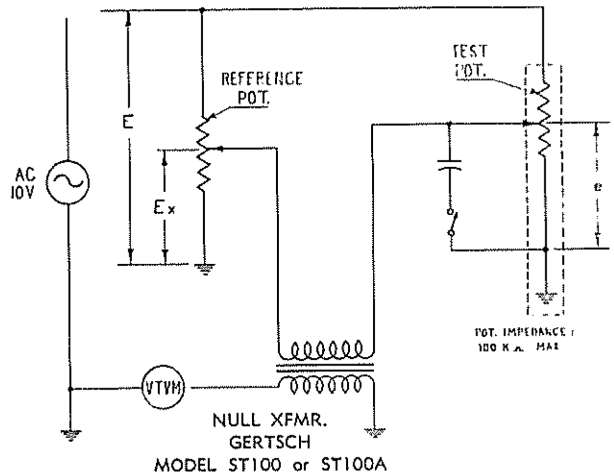

FIG. 1

Phase shift due to potentiometers, precision resistors, computer amplifiers, ac tachometers, and transformer windings can be found by a relatively simple technique that can measure phase angles as small as 0.005 deg and as large as 30 deg. With some loss of accuracy, angles up to 90 deg can also be detected by the method. The detection circuit, with elements of only conventional accuracy, obtains phase shift and quadrature voltage from a reference voltage varying from 50 to 5,000 cps. And the result is accurate to plus or minus 0.01 deg plus or minus 5 per cent at midband (350—1000 cps).

The reference voltage, E, is divided by the reference pot slider until a minimum or null reading is observed on the vacuum tube voltmeter. This voltmeter reading will be the quadrature voltage. The phase shift created by the reference pot is insignificant because of its relatively low impedance and internal construction. Figure 1 illustrates the circuit and Figure 2 its theory of operation.

The voltage ratio X is read directly from the dial of the reference pot, and the null voltage from the meter. An infinite resolution slide-wire type pot is desirable for

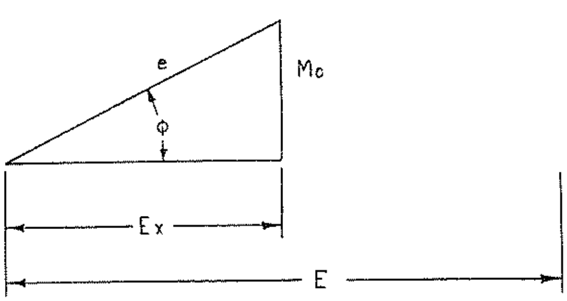

FIG. 2

the reference voltage divider. The phase shift is an angle whose tangent is equal to Mo/EX. For angles less than 6 deg, multiply the ratio Mo/EX by 57.3 deg to calculate a phase angle within the accuracy of the measurement technique. If a constant reference source is used, the dial of the voltmeter can be calibrated in phase shift directly.

It will be noted that as the phase angle becomes smaller, variations in EX produce an increasingly greater role in the variations of Mo. Hence, the accuracy of the technique for small angles is exceeded by its sensitivity. To achieve the indicated accuracy of 5 per cent, the reference pot should be accurate to ¼ per cent for angles less than 1 deg and the meter calibrated within 3 per cent.

For potentiometers, a small capacitor may be switched across the test component to determine the polarity (lead or lag) of the shift. The change in meter reading is then indicative of the polarity of the phase angle. For instance, if the shift is caused by capacitative reactance of the tested part, the condenser will augment them, increasing the negative phase shift and hence the null voltage. Similar techniques may be used for other components.

A plot of the phase shift of an unloaded ten-turn potentiometer can be easily calculated once its time con-

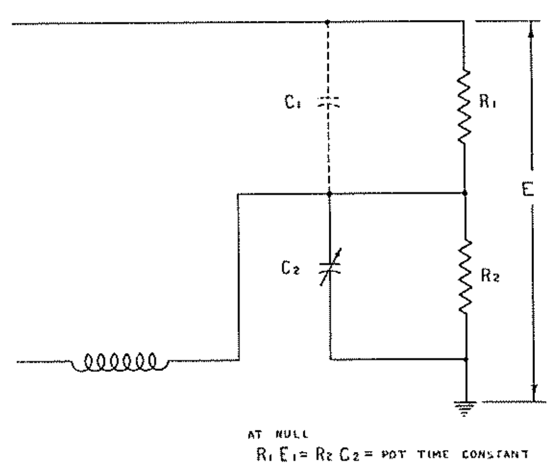

FIG. 3

* *Trademark*

stant is known. The time constant could be found by suitable calculation involving the phase shift measurements (obtainable by the balancing technique), but here is a direct way of finding it.

Figure 3 shows the setup R_1 is the entire ten-turn pot. R_1C_1 is the time constant produced by the distributed capacity of the pot. C_2 is a variable capacitor, and R_2 a small fixed resistor of approximately the same resistance as the pot. The phase shift through this resistor is too small to be significant. Only when the adjustable capacitor, C_2 is such that R_2C_2 equals R_1C_1 is the output voltage in phase with the input voltage. With the reference pot set near its halfway point, the in-phase component of the voltage will equal the voltage EX, but will be out of phase with EX depending on the time constant of R_1C_1.

This time constant can now be used in the following equation to find the quadrature voltage of any of the ten-turn pot's shaft settings.

$Mo = EwRC\ (1-2S)\ (1-S)\ (S)$

E = input voltage
w = radian frequency
R = potentiometer overall resistance
C = equivalent lumped capacity measured across end terminals
S = shaft position, in per cent of maximum rotation.

Similarly, one can calculate phase shift (in radians) by

$\varnothing = wRC\ (1-2S)\ (1-S)$

Since similar expressions can be derived for other pot types, one reading provides all the information needed to plot a pot's phase shift characteristics.

Rather than a slide-wire pot, an ideal standard voltage divider is a Gertsch Ratio Standard, Model RT-5. Resolution better than 0.0001 per cent is available together with a voltage ratio accurate to within 0.004 per cent. The advantage of this item is accurate output with very low internal impedance and extremely low phase shift.

The following additional information is supplied by the Engineering Department of Gertsch Products, Inc.

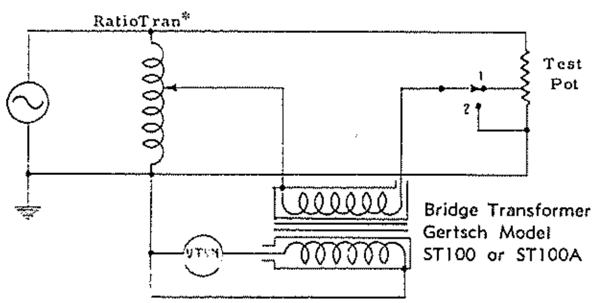

FIG. A

The circuit shown in Fig. A is a variation on the method described in the preceding article. Leads may be changed instead of using a switch.

In operation, the RatioTran* is adjusted to the best null with the switch in position 1. The RatioTran* then reads the inphase component of voltage ratio. The VTVM is read and the switch thrown to position 2. The RatioTran* is then adjusted to bring the VTVM back to the same reading. The RatioTran* then reads the quadrature component of the unknown ratio. This method has the advantage of eliminating errors from the null transformer voltage ratio. Also, the source voltage need not be accurately known.

A possible source of error when measuring phase angles by this method is the loading on the bridge caused by the null transformer and null detector. The method depends on measuring the remaining voltage at the best null. This voltage will be reduced because of current through the primary of the null transformer. Unless the impedance of the device under test is low compared to the impedance of the null transformer primary, the error will be serious. The circuit of Fig. B can be used to reduce this effect since a high impedance VTVM may be used directly as a null detector.

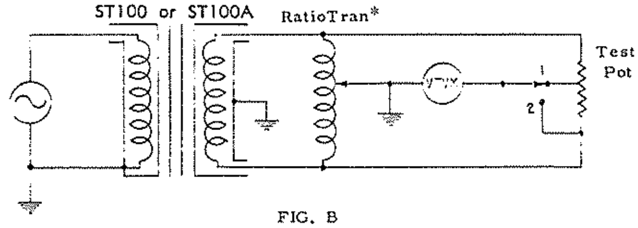

FIG. B

The bridge transformer may be omitted in this circuit if the source is capable of satisfactory operation as a floating source.

* *Trademark*