TEGAM INC.

MODEL RT-60B
RATIOTRAN

Instruction Manual
PN# RT-60B-901-01
Publication Date: June 2011
REV. B

NOTE: This user's manual was as current as possible when this product was manufactured. However, products are constantly being updated and improved. Because of this, some differences may occur between the description in this manual and the product received.

TABLE OF CONTENTS

SECTION PAGE

I General Description..1-1
II Operating Instructions..2-1
III Theory of Operation..3-1
IV Maintenance...4-1
V Calibration..5-1
Ratio Tran Engineering Bulletins..................................A-1

LIST OF TABLES

TABLE PAGE

1-1 Specifications..1-2
5-1 List of Test Equipment..5-2
5-2 Calibration Tolerances..5-3

LIST OF ILLUSTRATIONS

FIGURE PAGE

1-1 Model RT-60B Ratio Tran..1-1
1-2 Dimensions..1-2
2-1 Typical Application...2-1
2-2 Cascade Output Connections..2-2
3-1 Typical Schematic..3-1
5-1 Impedance Test Setup..5-1
5-2 Ratio Accuracy Test...5-2

SECTION I
GENERAL DESCRIPTION

1-1. PURPOSE

1-2. The Ratiotran is an inductive voltage divider providing an output voltage which is in a precise ratio to an input voltage. The Ratiotran can be used to generate an output ratio, to measure the output voltage of a unit under test, or to duplicate the voltage ratio output required of a unit under test.

1-3. DESCRIPTION

1-4. The units are completely self-contained test units which only require connection to an input voltage for operation. The units are designed as bench models, and are easily adapted to standard half-rack mounting, for which brackets are supplied.

1-5. Controls and a set of binding posts are mounted on the front panel. A parallel set of connection points are mounted on the rear panel.

1-6. The ratio accuracy of the unit is based upon the use of a toroidal autotransformer which is not affected by age or environmental conditions. Accuracy is traceable to National Bureau of Standards.

1-7. PREPARATION FOR USE.

1-8. No special precautions for unpacking are required other than that reasonable care must be taken when removing the unit from the shipping container. Installation consists only of mounting the unit in a rack.

Figure 1-1. Model RT-60B RatioTran

TABLE 1-1. SPECIFICATIONS

RT-60B

Accuracy of indicated ratio	50-3000 Hz $\pm\left(.001\% + \frac{.0001\%}{\text{Ratio}}\right)$ 3000-10,000 Hz $\pm\left(.01\% + \frac{.001\%}{\text{Ratio}}\right)$
Resolution	.001% steps
Ratio range	0 to 1.1111
Maximum effective series impedance	Rs - 2.5 ohms Ls - 75 μh
Input impedance	400,000 ohms, min., at 20 V and 400 Hz
Maximum input voltage	.35f (f in Hz) or 350 volts, whichever is less
Terminal linearity	.001%
Weight	approx. 5.5 lbs.

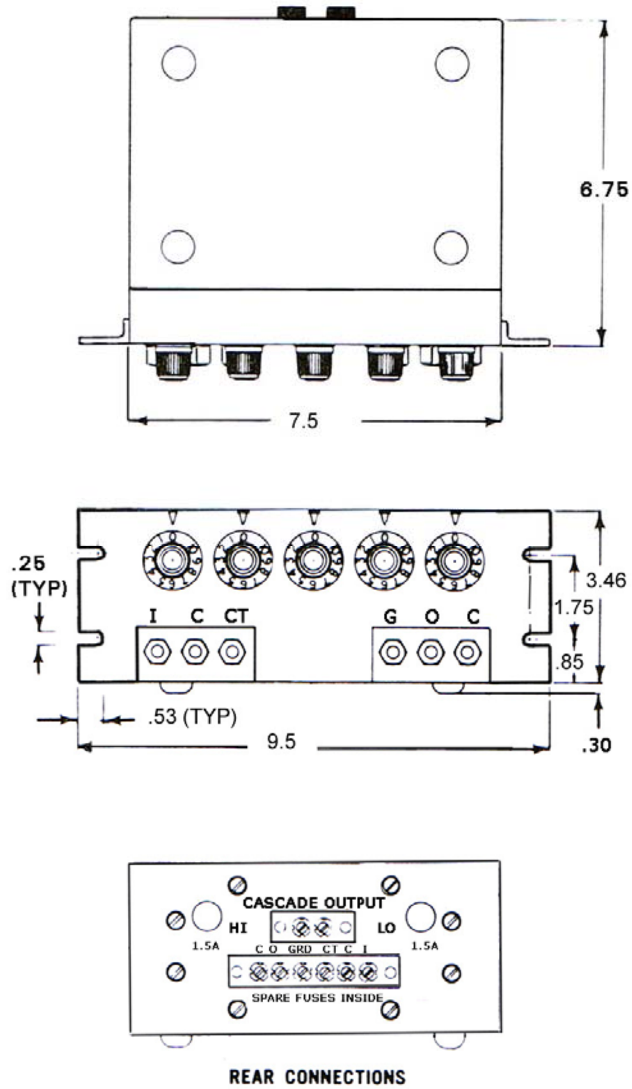


Figure 1-2 Dimensions

SECTION II
OPERATING INSTRUCTIONS

2-1. GENERAL

2-2. A typical application of a RatioTran is shown in figure 2-1. The output of the unit under test using a null indicator or a phase angle voltmeter. When the two outputs are exactly equal, the null indicator or phase angle voltmeter indicates a null. The input-to-output voltage ratio of the unit under test may then be read from the settings of the RatioTran.

2-3. Additional applications are included in the Engineering Bulletins which are appended to this instruction book.

2-4. OPERATION

2-5. To operate the RatioTran. proceed as follows:

a. Connect input or reference voltage source to the I and C terminals. Make certain input voltage is within the input voltage limits listed in the specifications.

b. Make certain that the input voltage does not contain a dc component. DC currents of more than a few microamperes will cause saturation of the input winding. If dc voltage is accidentally applied to the unit, degauss the unit as outlined in the maintenance section.

c. Make necessary connections to the O and C output terminals.

CAUTION

Do no apply voltage across the output terminals.

d. Turn the input voltage source ON.

e. Set the RatioTran controls to the desired ratio or to the setting required to obtain a null.

2-6. CENTER TAP (CT) CONNECTION. The center tap connection (CT) provides the following:

a. A means for applying a balanced input with a center tap ground.

b. A means for measuring + and - ratios from the center tap position.

c. An output voltage which is exactly one half of the voltage applied across the I and C terminals.

2-7. CASCADE OUTPUT. To increase the resolution of the unit, proceed as follows:

a. Connect external voltage divider across CASCADE OUTPUT connections as shown in figure 2-2.

b. Null in the normal manner except use external divider to obtain final null.

c. Multiply ratio setting of divider by .0001.

d. Add number obtained in step c to setting of RatioTran to obtain final ratio reading.

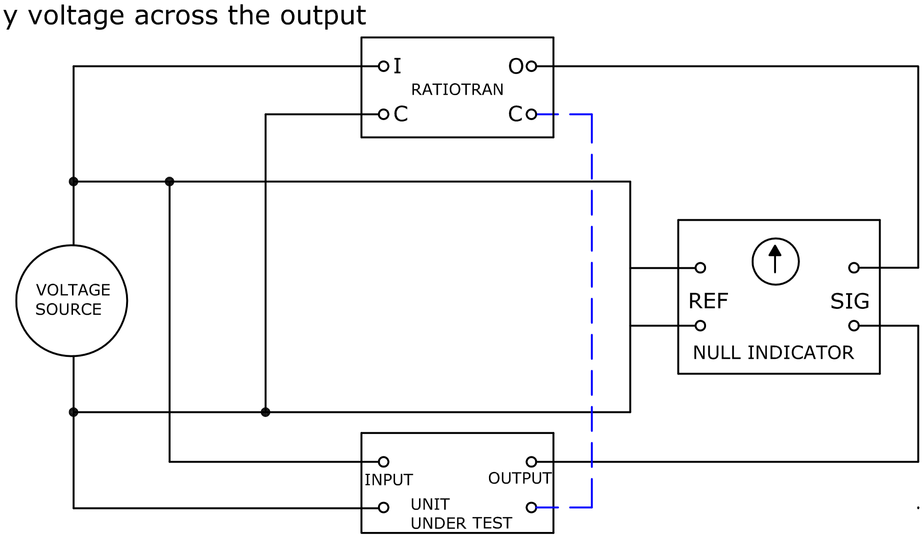


Figure 2-1. Typical Application

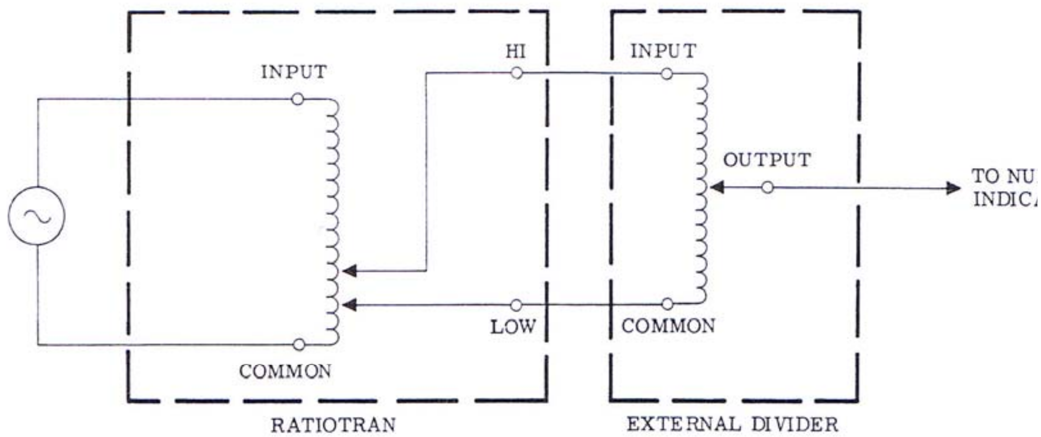


Figure 2-2. Cascade Output Connections

SECTION III
THEORY OF OPERATION

3-1. GENERAL. (See figure 3-1.)

3-2. TheRatioTran consists of five transformer windings and five rotary switches. A portion of the input voltage *is* selected from each winding by the applicable decade switch and these portions are added together to form the output voltage.

3-3. The full input voltage is applied across the first winding which is tapped to provide ten precise voltage divisions. When the first decade switch (X. 1) is turned to a selected position, the lower wiper arm selects a portion of the input voltage. The two wiper arms apply reference points to the second winding which is inductively coupled to the input winding. The lower wiper arm of the X.01 switch selects a 0.01 to 0.1 portion of the input voltage which is added to the voltage selected by the X. 1 switch. The process continues through the unit until the final and smallest portion of the voltage is selected by the .00001 switch.

3-4. The five transformer windings are included in one transformer. Switching transients are virtually eliminated by resistors which maintain continuity between voltage steps while settings are being changed. Both the input and output circuits are fused.

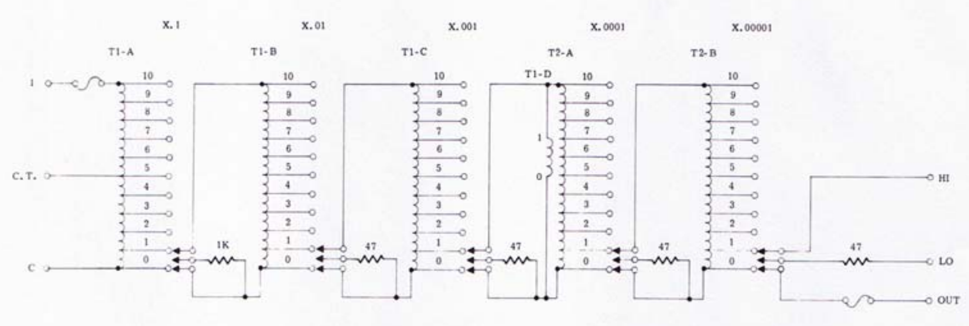


Figure 3-1. Typical Schematic

SECTION IV
MAINTENANCE

4-1. GENERAL.

4-2. Since the RatioTrans are passive devices, a minimum of maintenance is required. With the exception of cleaning switch contacts, no maintenance on a regularly scheduled basis is required. Moving parts are lubricated at the factory and should require no further lubrication.

4-3. SWITCH CONTACTS.

4-4. During calibration intervals, clean switch contacts with a good grade of solvent such as alcohol or acetone. Relubricate switch contacts with a small amount of light Lubricant.

4-5. DEGAUSSING, MODEL RT-60B.

4-6. To degauss the 0.35f units, proceed as follows:

a. Connect a 1K resistor in series with the input connection.

b. By means of a variac or other suitable voltage control, apply a 60 Hz signal between the open end of the 1K resistor and the common terminal.

c. Starting with the voltage control at zero, increase voltage to 40 vrms.

d. Slowly decrease the voltage to zero. The period of time to reduce the voltage from 40 vrms to zero should be between 10 and 15 seconds.

SECTION V
CALIBRATION

5-1. GENERAL.

5-2. The accuracy of the unit should be maintained for a period of not less than three years, provided that the unit is kept in a normal laboratory environment, has clean, low resistance contacts, and does not suffer injury or insulation damage.

5-3. Under the above conditions, the unit should only require a calibration check every three years. Under more severe conditions, the calibration period must be shortened.

5-4. This section includes two tests: an input impedance test and a simplified ratio accuracy test. Refer to Table 5-1 for a list of test equipment required.

5-5. IMPEDANCE CHECK.

5-6. To check input impedance, proceed as follows:

a. Connect unit into test setup as shown in figure 5-1.

b. Set input frequency to 400 Hz.

c. Adjust voltage source until DVM V1 indicates twice the desired voltage through the unit under test.

d. Adjust decade resistance box until DVM V2 shows equal indications with switch SW-1 in either position A or B.

e. Read input impedance from the decade resistance box. The input impedance shall be 400K or more.

5-7. RATIO ACCURACY TEST.

5-8. To test the ratio accuracy, proceed as follows:

a. Connect unit into test setup as shown in figure 5-2.

b. Set input frequency to 1kHz.

c. Apply input voltage of 20 vac as indicated on DVM V1.

d. Set RT standard controls for an output reading of 0.0000000.

e. Adjust unit under test controls until the null indicator indicates a null.

f. Check the ratio indicated by the unit under test against the ratio indicated by the RT standard unit. The two ratios shall agree within the limits listed in table 5-2.

g. Repeat steps e through f for each switch position of the RT standard unit (0.11111, 0.22222, etc.). The CT connection shall provide a .50000 output with the same accuracy as a .50000 ratio.

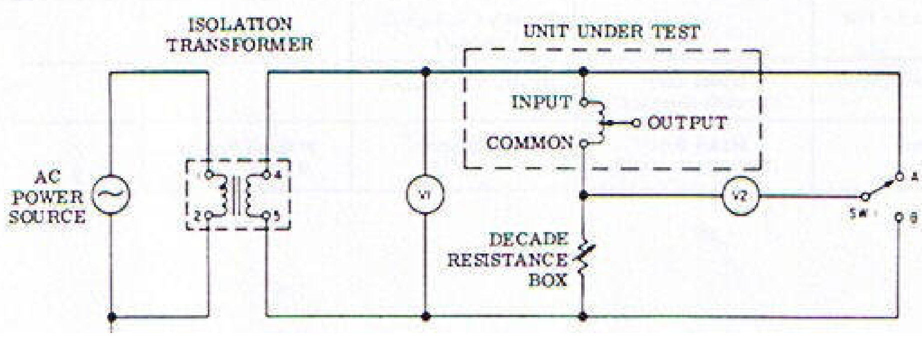


Figure 5-1. Impedance Test Setup

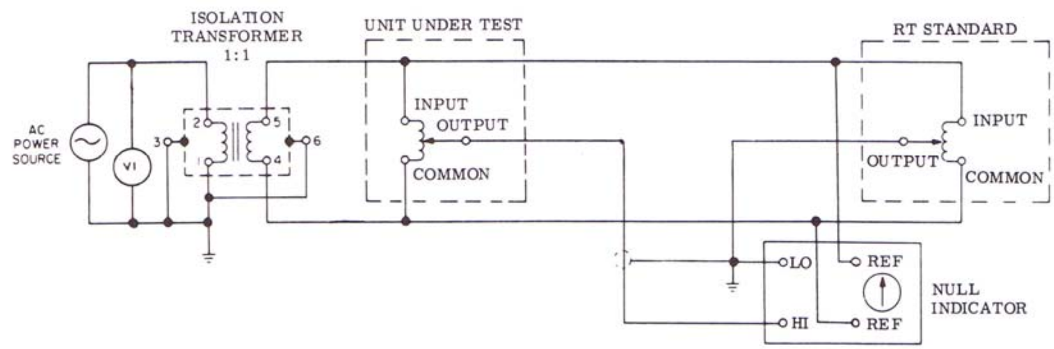


Figure 5-2. Ratio Accuracy Test

TABLE 5-1. LIST OF TEST EQUIPMENT

NOMENCLATURE	PART NUMBER OR MODEL	APPLICATION	RANGE	ACCURACY
AC Ratio Standard	Model 1011 M1011 or DT72	Provides comparison standard for ratio test	1.111111 to -0.111111 ratios	Per National Bureau of Standards Calibration Test
Isolation Transformer	Model ST248	Provides signal isolation	120 vac, 400 Hz (maximum)	
Null Indicator		Provides means of comparing output voltage		
Decade Resistance Box		Provides voltage divider network	1 megohm range	±0.5%
DVM		Measuring voltages		±0.5%
Audio Oscillator		Voltage Source	20 Hz to 20 KHz 0 to 45 vrms	

TABLE 5-2. CALIBRATION TOLERANCES

RATIO SETTING (ALL RATIO SWITCHES)	ACCURACY LIMITS	
	RT-60B	
0	.0000000 .0000100	
1	.1111074 .1111126	
2	.2222162 .2222238	
3	.3333251 .3333349	
4	.4444341 .4444459	
5	.5555429 .5555571	
6	.6666519 .6666681	
7	.7777608 .7777792	
8	.8888697 .8888903	
9	.9999786 1.0000014	

NOTE: All tolerance figures include tolerance of the RT Standard.

INDEX TO RatioTran ENGINEERING BULLETINS

The following Engineering Bulletins cover the theory and applications of RatioTran.

BULLETIN NO.	SUBJECT
1	Theoretical Analysis of Accuracy of Ratio Transformers
2	Use of Standard Ratio Transformers for Low Impedance Voltmeter Calibration
3	Accuracy Calculations for Standard Ratio Transformers
4	Use of RatioTran in Bridge Circuits
5	Measuring Small Phase Angles

THEORETICAL ANALYSIS OF ACCURACY OF RATIO TRANSFORMERS
(RatioTran)

Theoretical analysis of a perfect autotransformer used for stepdown purposes shows that if leakage inductance and winding resistance are uniformly distributed and the turns can be accurately tapped, the accuracy as a voltage divider for no load is perfect.

Consider first the effects of leakage inductance. The most symmetric configuration insofar as flux is concerned is the uniformly wound toroid. By suitably interleaving the windings and carefully maintaining uniformity, the total leakage inductance can be kept to under 10% of the air core inductance. Since the air core inductance is approximately 1/u times the inductance with iron core, where u is the permeability of the core material, the total leakage inductance to coupled inductance ratio is 1/10u. The core material used in the transformers is supermalloy which has a guaranteed initial permeability of 55,000. The leakage to coupled inductance ratio is therefore approximately .0002%. Since this figure represents the ratio of voltage dropped in the leakage inductance to total voltage, the error in the transformer due to non-distributed leakage inductance will not exceed this, if the leakage inductance per turn does not vary by more than ±100%. This condition can be met with suitable techniques of interleaving the windings.

Non-distributed winding resistance has much the same effect as non-distributed leakage inductance. If the effects of winding capacitance are neglected, the winding resistance is most important at low frequencies since the exciting impedance of the transformer is directly proportional to frequency. Since the exciting impedance is fairly reactive, the voltage dropped in the winding resistance will be almost in quadrature with the input and consequently any non-distributed resistance will cause some phase error as well as magnitude error. The fact that this error voltage is in quadrature makes the magnitude error extremely small and for all practical purposes negligible. Typical figures might be .000001% for small ratios and even less for larger ratios. Phase angles from this cause would be approximately .01 milliradians at low frequencies and small ratios decreasing for larger ratios.

At higher frequencies distributed capacitance becomes important. It causes voltage drops in the leakage inductance and winding resistance which are not uniformly distributed due to the transformer action. Like the effects of winding resistance, the errors caused by the capacitance are mainly in quadrature and so cause phase shift at low ratios. Typical values for this phase shift are:

Less than .05 milliradians for frequencies below 1 KC and ratios above .1 for low voltage - high frequency units.

Less than .05 milliradians for frequencies below 200 cps and ratios above .1 for high voltage low frequency units.

Phase angle due to this cause is almost directly proportional to frequency for any particular ratio down to frequencies where the non-distributed resistance takes over.

Other sources of error are:

1. Voltage drops due to exciting current in the leads to the transformer.
2. Loading effects of the potentiometers.
3. Non-linearity and end effects of the potentiometer.

The first of these effects may be minimized by using heavy connecting leads or treating the transformer as a four terminal impedance. The internal wiring of the transformers contributes to this error. These effects are worse at higher frequencies, above the self-resonant frequencies of the transformers.

The potentiometers cause some loading effects on the transformers due to the internal impedances of the windings and switch contacts.

For units with the 10 turn potentiometer, such as the RT-1 and Model RT-10, the errors due to this cause are approximately .0001% of the input. In the single turn units this error amounts to about .00001%. The single turn potentiometer causes less error than the 10 turn since the voltage across it is .001% of the input in comparison to .1% across the 10 turn potentiometer.

Non-linearity and end effects of the potentiometer may cause an error of approximately .0005% of the input in the case of the units with the 10 turn potentiometers. The single turn potentiometers may cause an error of .00001% of the input.

From the foregoing considerations a reasonable terminal linearity figure of .001% is derived. The usual definition of terminal linearity is the error in the output divided by the total input:

$$\text{Terminal Linearity} = \frac{\triangle E_o}{E_{IN}}$$

where $\triangle E_o$ is the actual error voltage in the output and E_{IN} is the total input voltage.

An accuracy figure in terms of the output voltage would be

$$\text{Ratio Accuracy} = \frac{\triangle E_o}{E_o}$$

where $\triangle E_o$ is the actual error voltage in the output and E_o is the total output voltage.

When the ratio gets small, the error caused by pot loading, pot non-linearity, and lead drops become predominant. Since these errors are constant in absolute value, their fractional value in terms of the output is inversly proportional to the ratio of the transformer. Taking this into account a reasonable ratio accuracy for the three decade units with the 10 turn pot is:

$$\text{Ratio Accuracy} \quad \pm \left(.001\% + \frac{.0006\%}{R}\right)$$

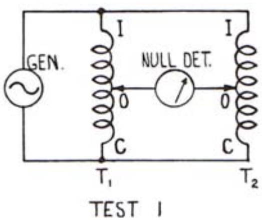
(This applies to Models RT-1 & 10 and for the 5 decade units, with or without the single turn pot:

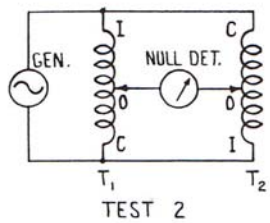
$$\text{Ratio Accuracy} \quad \pm \left(.001\% + \frac{.0001\%}{R}\right)$$

where R is the indicated ratio of the transformer. (This applies to all Models except RT-1 & 10)

Standards suitable for certifying transformers to the accuracy figures quoted are not generally available. It can be seen, however, from the foregoing discussions that the transformers are inherently excellent voltage dividers. They can be considered primary standards of ratio in that one can be constructed by following assembly instructions and requiring no measurements or calibrations other than wiring checks and tests to make certain that the number of turns is correct. A unit so constructed will match any other unit so constructed to well within the specifications quoted above. The units are ageless, requiring no calibration tests and should perform indefinitely with no loss in accuracy barring some switch failure or actual damage to the transformer.

Tests have been performed on a basis of comparison between several units. While it is not possible to get complete absolute data in this manner, certain facts can be deduced. Referring to the diagram T_1 and T_2 represent the two transformers under test.





Let R_1 be indicated ratio of T_1
R_2 be indicated ratio of T_2

Let E_1 be error in indicated Ratio of T_1
E_2 be error in indicated Ratio of T_2

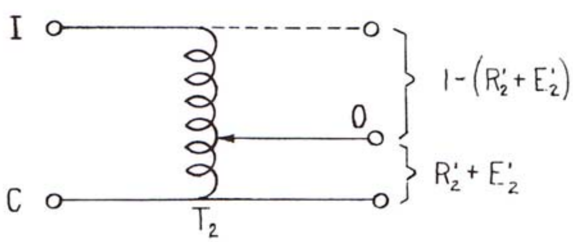
then at balance in Test 1

$R_1 + E_1 = R_2 + E_2$

at Balance in Test 2

$R_1 + E_1 = 1 - (R_2' + E_2')$

where $1 - (R_2' + E_2')$ is the complement of $R_2' + E_2'$ as shown below



Now suppose that in both tests

$R_1 = R_2$
$R_1 = 1 - R_2'$

then $E_1 = E_2$

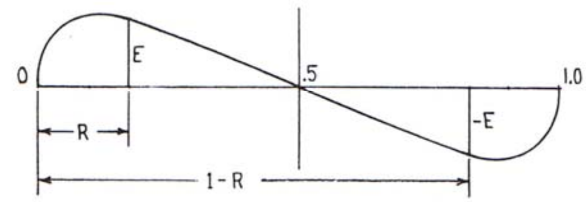
$E_2' = -E_1$

or $E_2' = -E_2$

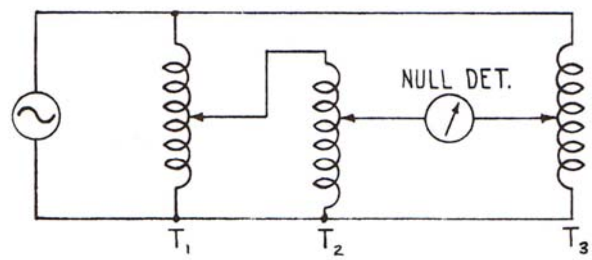
This shows that if at balance in both tests the indicated are exactly equal or complementary there can exist an error of a special nature which cannot be detected.

E at R = -E at (1-R)

E must be zero at R = .5 and show odd symmetry about R = .5



In general, any two transformers so tested will meet the conditions for the tests within 1 or 2 parts in 10^6 so that any components of error which do not show the above symmetry must be at least this small. To obtain some idea of the absolute errors two transformers were cascaded and compared against a third as shown below.



$(R_1 + E_1)\ (R_2 + E_2) = (R_3 + E_3)$ at Balance

if we choose $R_1 = R_2 = .5$

from the foregoing analysis $E_1 = E_2 = 0$

If proper care is taken to compensate for loading effects the magnitude of E_3 can be determined at $R_3 = .25$. This error in general is less than .001%.

This process can be continued by cascading more transformers and measuring the error at points $R = (.5)^N$

It is easy to show that the same analysis applies to quadrature voltage. The same tests can be made and values of θ at points $R = (.5)^N$ determined. The phase angle data given earlier in this article was derived in this manner.

All of the foregoing discussions apply to completely unloaded conditions on the transformers. Effects of loading are discussed in Engineering Bulletin No. 3 entitled "Accuracy Calculations for Gertsch Standard Ratio Transformers."

Accuracy formulas given above apply only to those units shipped after January 1, 1956. Previous units have accuracies of $\pm(.004\% + \frac{.0006\%}{R})$ and

$\pm(.004\% + \frac{.0001\%}{R})$ respectively.

USE OF TEGAM 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.

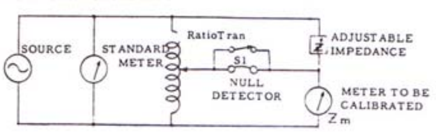


FIG. 1

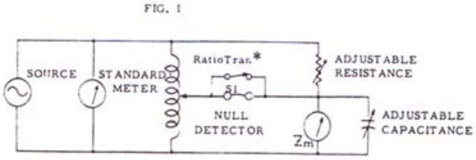


FIG. 1A
Modification of Fig. 1
CONVENIENT WHEN Z_m CONTAINS INDUCTIVE REACTANCE

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.

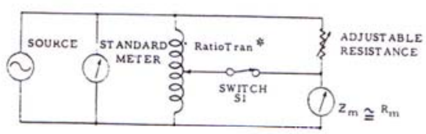


FIG. 2

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.

ACCURACY CALCULATIONS FOR TEGAM STANDARD RATIO TRANSFORMERS (RatioTran)

1. DEFINITION

The accuracy of 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 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 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 RatioTran leads us to believe that it is extremely improbable that the specified values of error will ever be exceeded. The accuracy of RatioTran 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

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

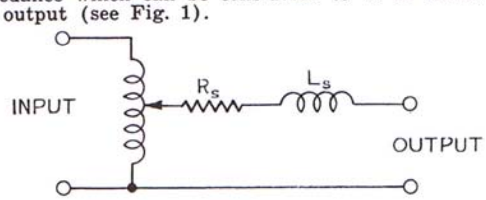


FIG. 1

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:

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

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.

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 Model ST100 or ST100A be used to isolate either the generator or detector. Typical circuits are shown below.

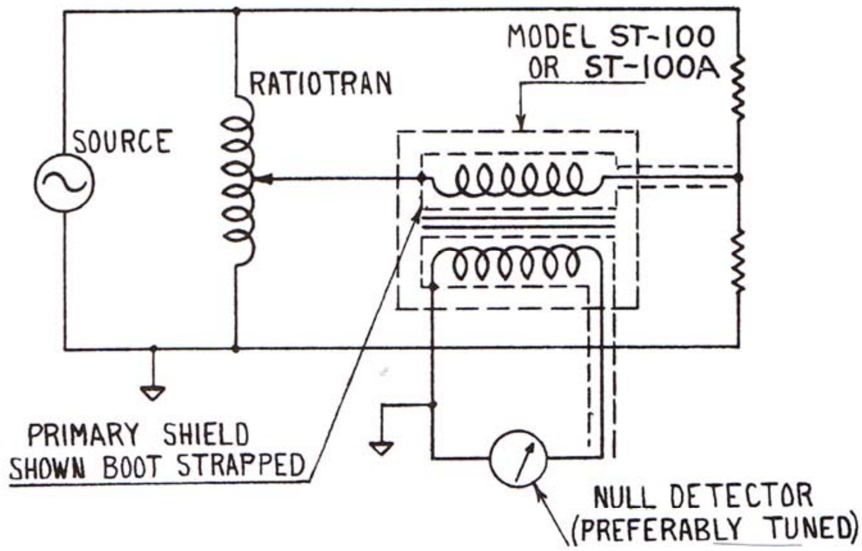


FIG. 1

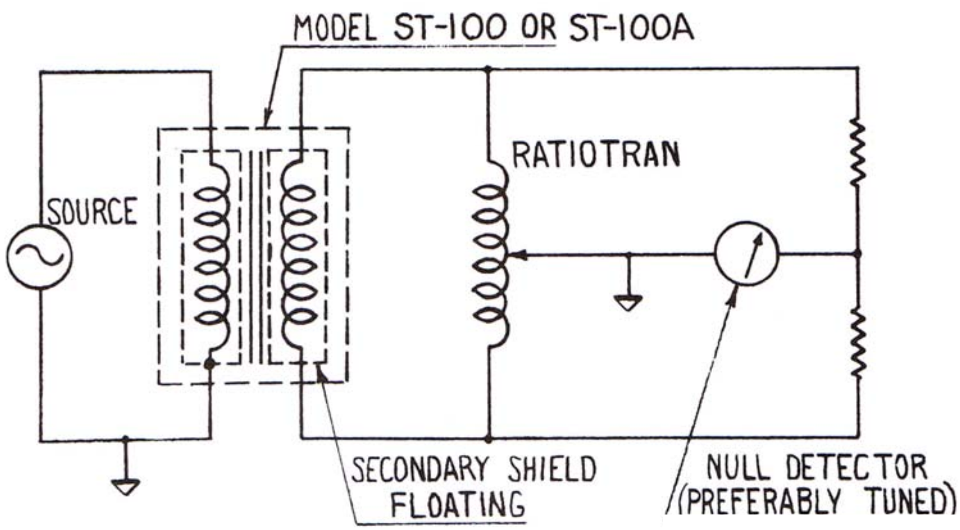


FIG. 2

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.

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

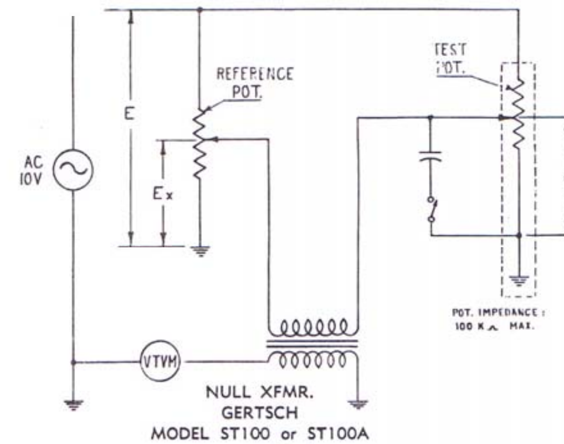


FIG. 1

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

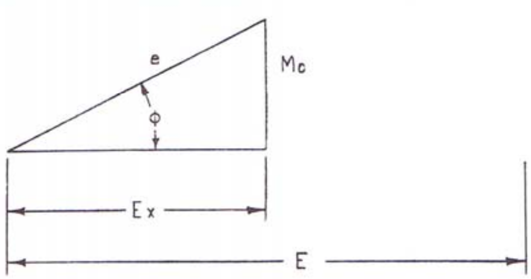


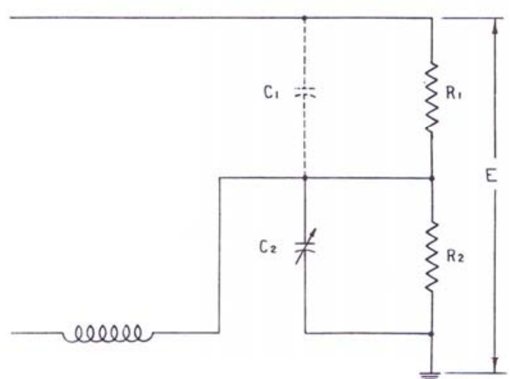
FIG. 2

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-



AT NULL
$R_1 E_1 = R_2 C_2$ = POT TIME CONSTANT
FIG. 3

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 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.

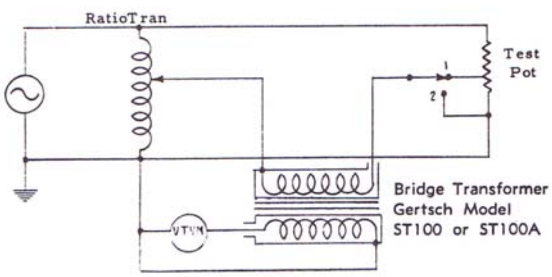


FIG. A

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.

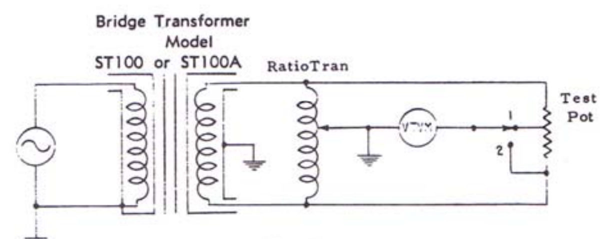


FIG. B

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