the GENERAL RADIO Experimenter

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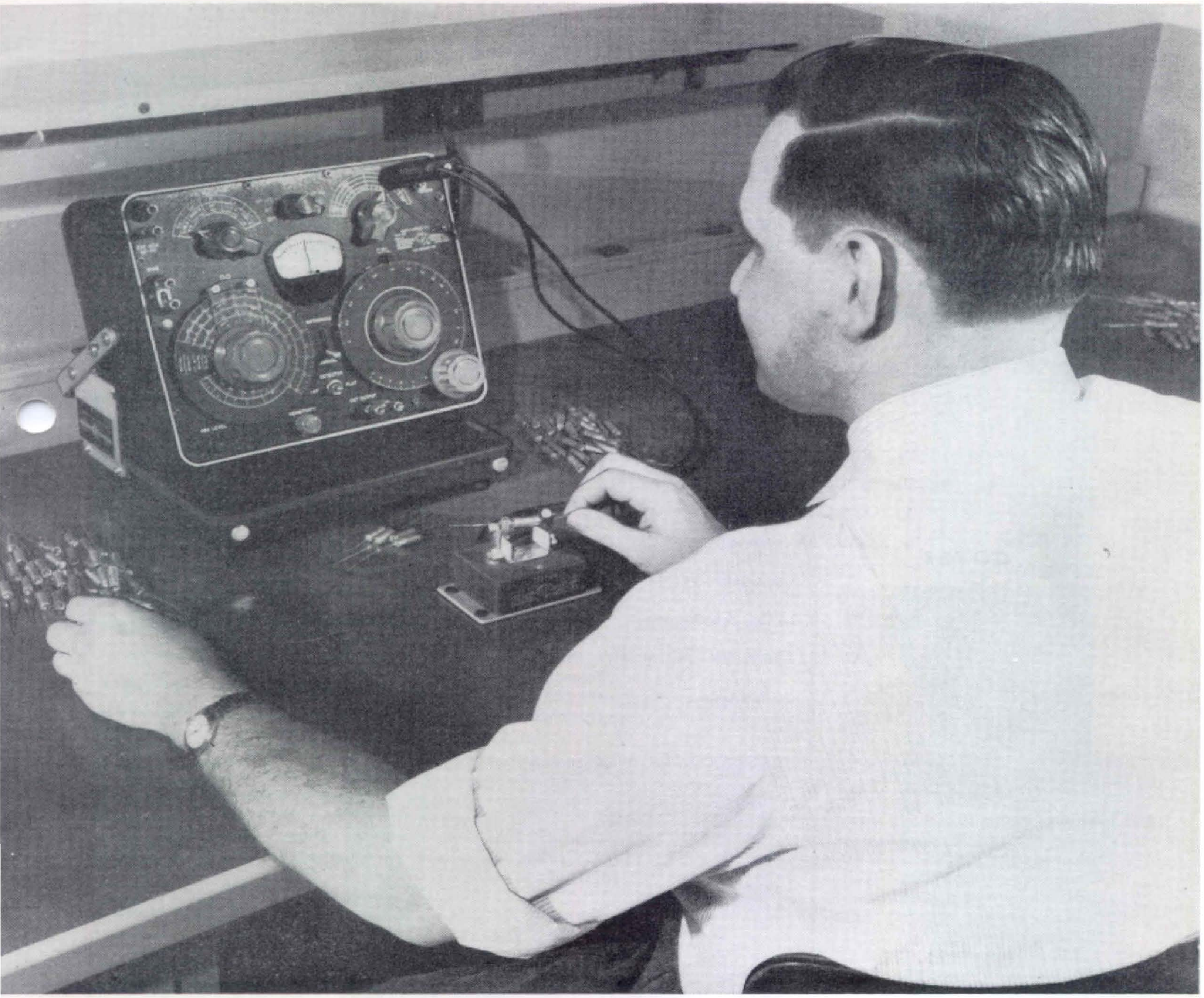

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the GENERAL RADIO Experimenter

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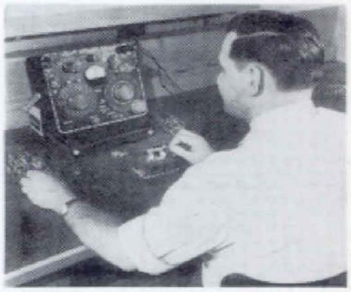

Go-no-go testing is easy with the new Type 1650-A Impedance Bridge and its accessory Test Jig. This photo shows the bridge set up for the rapid testing of capacitors.

The patented *Orthonull* feature of this bridge, which eliminates sliding balances when high-loss capacitors or inductors are measured, is discussed in this issue.

A MILITARIZED, THREE-PHASE, LINE-VOLTAGE REGULATOR

The TYPE 1570-AS25 Line-Voltage Regulator is a completely militarized servo-controlled three-phase regulator. The inherent advantages of no distortion, large power rating, and high efficiency of this type of regulator, combined with its high accuracy and excellent transient response, make it especially attractive for many applications. In addition to the military environmental requirements of shock, vibration, temperature, humidity, and so forth, the unit is designed with particular emphasis on flexibility, ease of maintenance, reliability, and long life.

This regulator is similar in construction to the single phase TYPE 1570-AS15 Line-Voltage Regulator.[1] For adaptability and ease of maintenance, it is built in two units (Figure 1). The control unit contains all the electronic circuitry and is identical with the control unit of the single-phase model. The regulator unit consists of a three-gang W5 Variac, a servomotor, and three "buck or boost" transformers.

Because all three phases are controlled together in response to the variations on one control phase, only a single servo is required, and considerable space and price savings are possible over the use of three separate regulators. While the performance of this type of regulator is independent of load or load balance, any input voltage unbalance that results cannot be corrected, since each phase is not controlled independently. Thus, for accurate regulation, a balanced input voltage is necessary.

Ease of maintenance was a prime consideration in the original design of the regulator. If service of the electronic circuitry is required, only the small control unit need be removed. The larger unit with all its power wiring can stay in service supplying uninterrupted (but unregulated) power while the control unit is being replaced or repaired. Manual control of output voltage is possible during these intervals by means of the Variac® dial on the front panel.

Tubes can be replaced without the removal of any covers other than tube shields. Removal of a single dust cover exposes all other components. Component wiring is accomplished with an etched circuit to provide a high degree of uniformity between units. Each component is marked with its magnitude and rating and is identified by a com-

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[1] M. C. Holtje, "Militarized Line-Voltage Regulator," *General Radio Experimenter*, 31, 6, November, 1956.

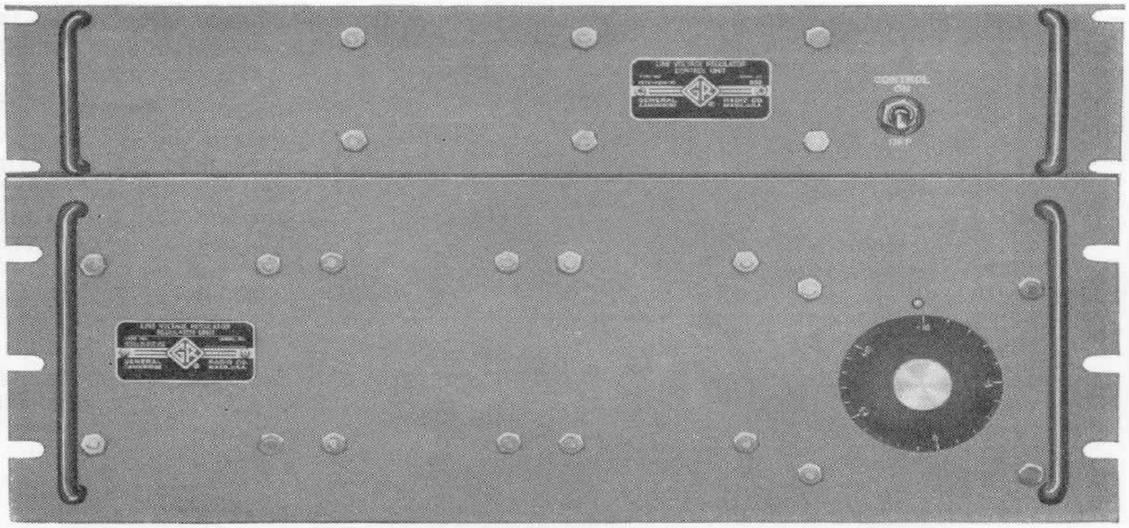


Figure 1. Panel view of the Type 1570-AS25 Three-Phase, Automatic, Line-Voltage Regulator.

ponent number printed on the mounting board. The removal of the bottom cover plate exposes all etched wiring. The complete circuit diagram is silk screened on the inside of this plate. For protection against the effects of moisture and fungus growths, the etched board is sealed with a fungus-resistant varnish.

Reliability and long life have been assured by conservative ratings and the use of the best materials and components in simple circuits that have proved reliable in long field experience.

For maximum versatility, a switch is provided inside the control unit for 50-cycle operation of the regulator. In the 50-cycle switch position, the range of operation is 45 to 55 c; in the 60-cycle position, it is 55 to 65 c. Space is also provided for the installation of a separate output-voltage-sampling transformer to permit control of 400-cycle power, although 50- or 60-cycle power must be available to operate the control unit.

To provide adequate strength for military shock and vibration requirements, the regulator unit is built on a seven-inch, U-shaped, extruded-aluminum channel. The smaller control unit mounts on a 3/8″ aluminum panel. Both units will withstand the standard 1200-ft.-lb. shock test, and they show no significant mechanical resonances up to 55 cycles per second.

The regulator is designed to meet or to exceed the general requirements of MIL-E-4158B and MIL-E-16400B. It will operate at full load over the ambient temperature range from —29°C. to +52°C. (—20° to +125° F.) and for non-operating storage from —54°C. to +85°C. (—65° to +185°F.). With special motor lubricants, operation is possible at far lower temperatures. Operation is possible with relative humidity up to 100 percent, including condensation caused by temperature changes.

While these military specifications are generally more severe than those encountered in most industrial applications, the increased reliability and ease of maintenance may often justify the use of the militarized regulator in critical industrial applications. This is particularly true for applications at high ambient temperatures or for portable installations where mechanical shock or vibration is encountered.

— M. C. Holtje

SPECIFICATIONS

Terminals: Multipoint connector strips.

Frequency: 45-55 cycles or 55-65 cycles, as selected by a switch.

Waveform Distortion: None.

Waveform Error: The average value of the output voltage is held constant, and a loaded dc power supply operated from the output of the regulator will give constant output voltage regardless of the harmonic distortion present in the power line. The rms output voltage will also remain constant, regardless of the harmonic distortion present, as long as the phase and

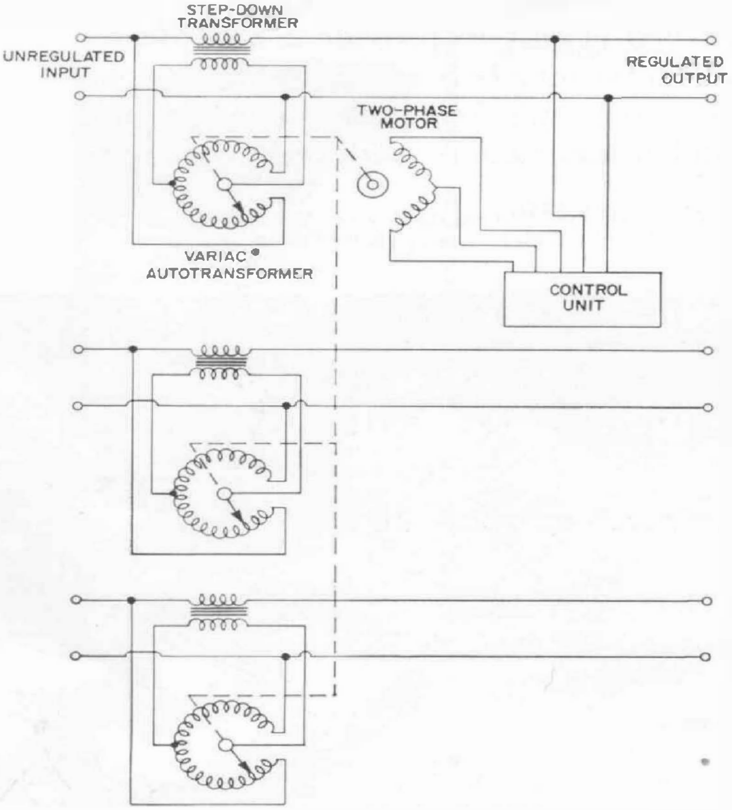


Figure 2. Functional block diagram of the regulator.

amplitude of these harmonics are constant. If the harmonic content changes, the rms value will change by an amount less than $\Delta R/n$, where ΔR is the change in the harmonic amplitude and n is the harmonic number.

Ambient Temperature: Full ratings apply over a temperature range of −29° to +52°C.

Power Consumption: No load, 35 watts. Full load, 140 watts.

Dimensions: Control Unit, panel, 19 x 3½ inches; depth behind panel, 7 inches. Regulator Unit, panel, 19 x 7 inches; depth behind panel, 16¾ inches.

Net Weight: 97 pounds.

Ratings

	1570-ALS25		1570-AHS25	
*Output Voltage per phase	115 ± 10%		230 ± 10%	
**Input Voltage as a percent of Output Voltage	91% to 109%	82% to 118%	91% to 109%	82% to 118%
Output Current per phase	25	12.5	10	5
Approx. KVA (wye***)	8.6	4.3	6.9	3.5
†Accuracy in % of output voltage	0.5	1.0	0.5	1.0
††Speed of response, volts per second	10	20	20	40

***Delta rating is $1/\sqrt{3}$ times wye rating. *Internal adjustment.

**Instruments are shipped connected for ±9% range unless ±18% range is specified on order.

†Applies only to measured phase. Other phases depend on input voltage balance.

††Slightly less for very small voltage corrections.

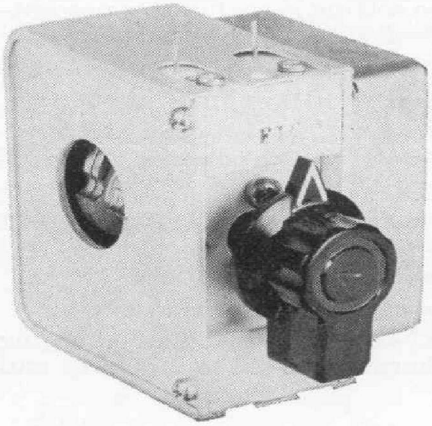
Type		*Code Word*	*Price*
1570-ALS25	**3-phase Regulator, 115 volts**	DICKY	**$865.00**
1570-AHS25	**3-phase Regulator, 230 volts**	DAILY	**885.00**

POLYSTYRENE CAPACITOR DECADE

100 $\mu\mu$f per step

Supplementing the three polystyrene decades previously announced,* a new decade with capacitance steps of 100 $\mu\mu$f is now available. Like its companion units of 0.001, 0.01, and 0.1 μf per step, this new decade is admirably suited for applications that call for high insulation resistance, low dielectric absorption, and constancy of capacitance and dissipation factor as a function of frequency.

Four capacitors are used in the decade, with their magnitudes in the ratio 1-2-2-5. Parallel combinations, as selected by the switch, yield all integral values from 1 to 10. The switch is rigidly constructed and includes a detent mech-



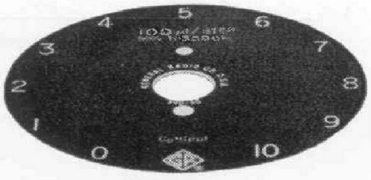


Figure 1. View of the Type 980-D Decade Capacitance Unit.

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*"New Decade Capacitors with Polystrene Dielectric," *General Radio Experimenter*, 31, 2, July, 1956.

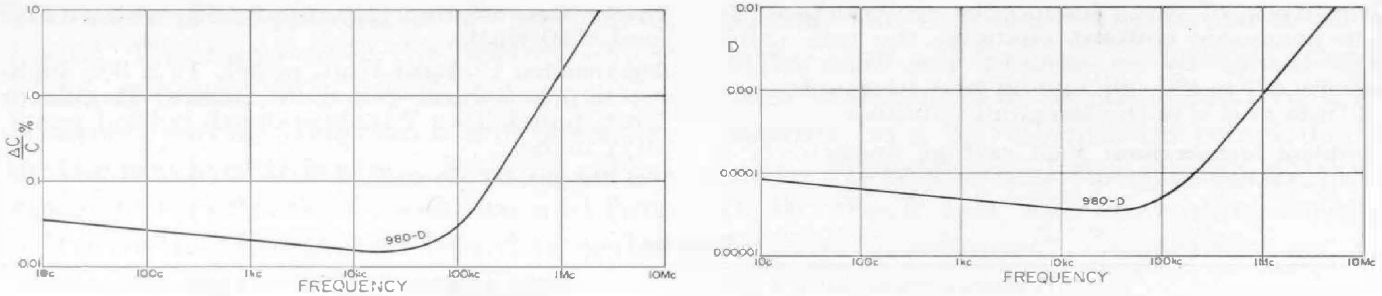


Figure 2 (*left*). Change in capacitance as a function of frequency. Since the capacitors are adjusted to their rated accuracy at 1 kc, the 1-kc value should be used as a reference for an estimate of the frequency error. (*Right*) Typical plot of dissipation factor as a function of frequency.

anism for positive location of position. The switch insulation, including the shaft, is heat-resistant, cross-linked polystyrene. Contact is made by cams bearing on phosphor-bronze springs, and the whole contact structure is heavily silver plated.

The individual capacitor units are wound from continuous interleaved tapes of polystyrene and metal foil. The foils projecting at each end of the roll are soldered together to minimize inductance and series resistance.

The tape used for the dielectric is specially prepared of purified high-molecular-weight polystyrene, having very high insulation resistance and freedom from unwanted polarizations. Hermetic sealing with Teflon feed-through insulators assures high performance, even under adverse humidity conditions. All capacitor units are heat stabilized, so that their long-time stability approaches that of the best silvered-mica capacitors.

Terminals are provided for both 2-terminal and 3-terminal connections.

SPECIFICATIONS

Capacitance: Total range, 0.001 μf; per step, 0.0001 μf.

Zero Capacitance: 2-terminal connection, approximately 11 μμf; 3-terminal connection, <1μμf.

Accuracy: 2-terminal, ± (1% + 2 μμf); 3-terminal, + 1%, − (2% + 4 μμf). Capacitance increment from zero setting is within this percentage of the indicated value for any setting.

Dissipation Factor: <0.0002.

Insulation Resistance: $>10^{12}$ ohms at 100 v, 25° C., 50% RH.

Temperature Coefficient of Capacitance: Approximately − 140 ppm/°C.

Maximum Operating Voltage: 500 volts, dc or peak, at frequencies up to 10 Mc.

Maximum Operating Temperature: 65° C.

Dielectric Absorption: See Voltage Recovery.

Voltage Recovery: <0.1% of original charging voltage after a charging period of one hour and a 10-second discharge through a resistance equal to one ohm per volt of charging.

Dimensions: See sketch.

Net Weight: 2 pounds, 2 ounces.

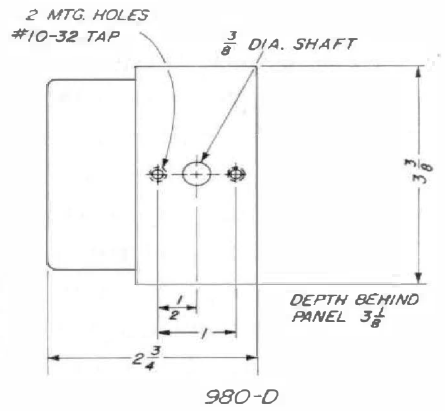


Figure 3. Dimensions of the Type 980-D Decade Capacitance Unit.

Type		*Code Word*	*Price*
980-D	**Decade Capacitor Unit**	ALIEN	**$57.00**

ORTHONULL — A MECHANICAL DEVICE TO IMPROVE BRIDGE BALANCE CONVERGENCE

Impedance bridges can generally be divided into two classes, depending upon the location of the two adjustable components in the bridge circuit. These adjustments may be either in the same bridge arm or in different arms, and their positions determine what the bridge will read and how the balance will converge on the null.

The familiar Maxwell inductance bridge may take either of these two forms as shown in Figure 1. The balance equations are the same for both forms. However, dial reading must, in general, be proportional to only one variable element, so that the quantities indicated on the dials are different for these two circuits as shown.

The bridge that reads L and Q has several important advantages: (1) It reads Q, which is generally a more desired quantity than R because it gives a measure of the purity or quality of the inductor without calculation; (2) because the standard capacitor is fixed, it can more easily be made large to permit higher L and Q values to be measured; and (3) both adjustments are variable resistors, which can be continuously adjustable over a wide range.

The L-Q bridge has one disadvantage, however: when low-Q components are measured, the balancing procedure becomes tedious and often impossible, owing to slow convergence of the balance. This condition, often referred to as a "sliding null," can be remedied by a mechanical unilateral ganging called *Orthonull*, a patented device used for the first time on the GR TYPE 1650-A Impedance Bridge described last month.[1]

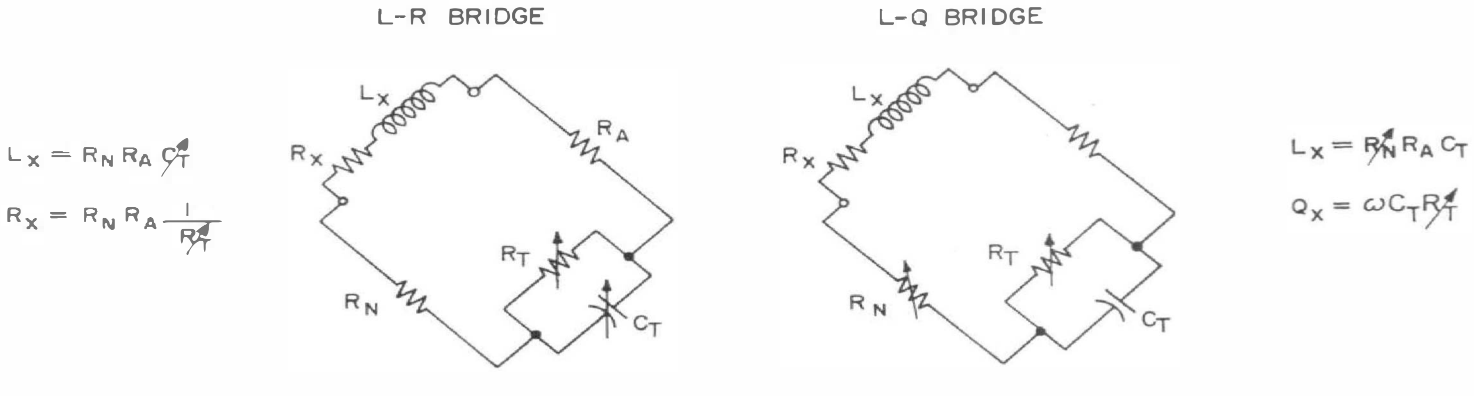
Cause of Sliding Null

The output voltage of an unbalanced Maxwell bridge may be written in the form

$$\frac{E_0}{E_{IN}}=\frac{R_X+j\omega L_X-\left(\frac{R_NR_A}{R_T}+j\omega R_NR_AC_T\right)}{\text{Denominator}} \quad (1)$$

The denominator is a complicated function of the bridge arms and generator and detector impedances, and, for the purposes of this analysis, one can assume that it is constant in the region near the null. The numerator is made up of the difference between the "unknown" impedance and a function of the bridge components, which we will call the "bridge impedance." At null, these two impedances are equal. Off null, the output voltage is proportional to the difference between these two quantities, which is the distance between them on the complex plane. In balancing the bridge, one adjusts the variable components

Figure 1. Two types of Maxwell inductance bridge.



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[1] Hall, H. P., "A New Universal Impedance Bridge," General Radio *Experimenter*, March, 1959, Vol. 33, No. 3, pp. 3-9.

alternately to give a minimum output voltage, repeating the process until a satisfactory balance is reached.

In the L-Q bridge, the two adjustable components are R_N and R_T. From the equation above it can be seen that an adjustment of R_T varies only the real part of the bridge impedance and therefore would move this impedance horizontally on the complex plane as shown in Figure 2. Both the real and imaginary parts are proportional to the other adjustment, R_N, so that a variation of this quantity causes the bridge impedance to move radially from the origin. When Q is high, these two adjustments have loci that are almost orthogonal, but when Q approaches zero, the loci become more and more nearly parallel. It is obvious that, at low Q values, a variation in only the imaginary (vertical) direction involves adjustments of both variable quantities. The process of balancing is somewhat analogous to that of tacking with a sailboat that won't point close to the wind.

Examples of two balance loci are given in Figure 3. Many adjustments are needed to obtain a balance, and it can be seen that each adjustment makes so small an improvement in the output voltage that in practice it is often unnoticeable, especially if an aural null indication is used. In this plot, the Q of the unknown is 0.5 which isn't very low. The situation is much worse if the Q is lower.

Orthonull Mechanism

Orthonull[2] makes it possible to get an independent adjustment of the imaginary part of the bridge impedance and hence rapid convergence. To do this, the ratio R_N/R_T in the real part of Equation (1) is kept constant as R_N is varied by a ganging of the two adjustments. However, when R_T is varied, R_N and R_T are not ganged so that only the real part is varied.

The mechanism to obtain the unilateral ganging on the TYPE 1650-A Bridge is shown in Figure 4. The friction clutch which is engaged when *Orthonull* is active has sufficient friction to drive easily the low-friction D-Q resistor (R_T). However, the CRL resistor, R_N, is loaded by a vernier adjustment and by a mechanical justifying mechanism[3] so that its friction is high enough to prevent coupling in the reverse direction.

If the two resistors were always ganged, the ratio R_N/R_T could be made constant

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[2] U. S. Patent No. 2,872,639.

[3] This justifying mechanism is an adjustable cam and cam follower, which varies the position of the potentiometer rotor with respect to the shaft and dial to compensate for variations in the winding.

Figure 2 (*left*). Loci of adjustments on the Z plane.

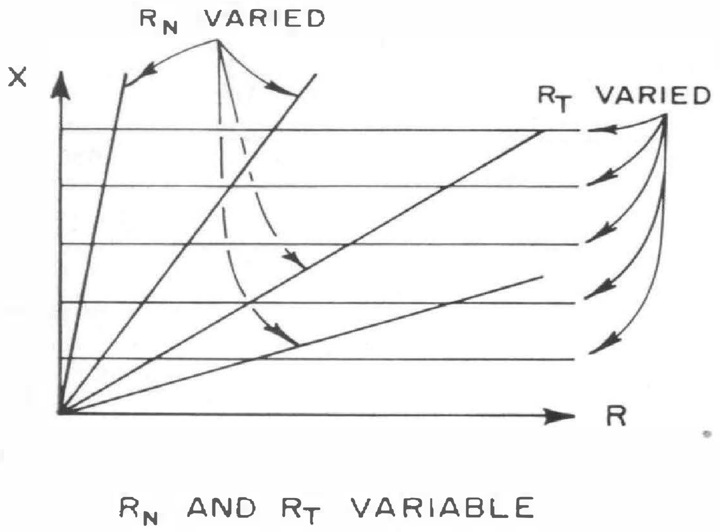
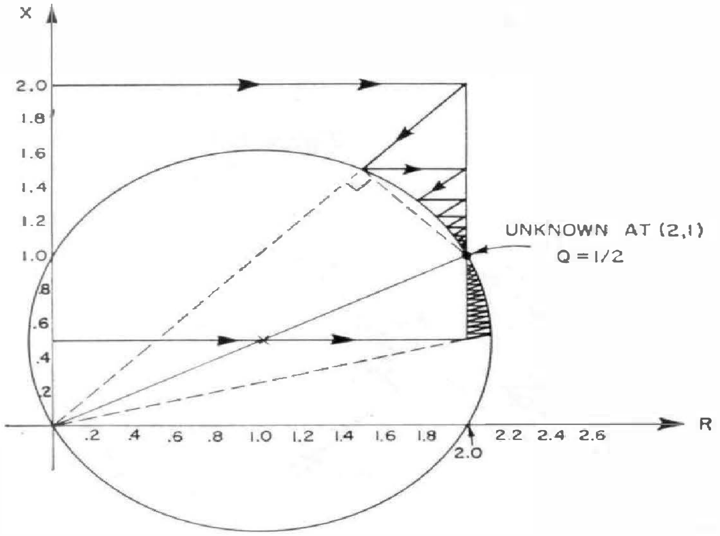


Figure 3 (*right*). Idealized balancing loci; $Q = 1/2$.



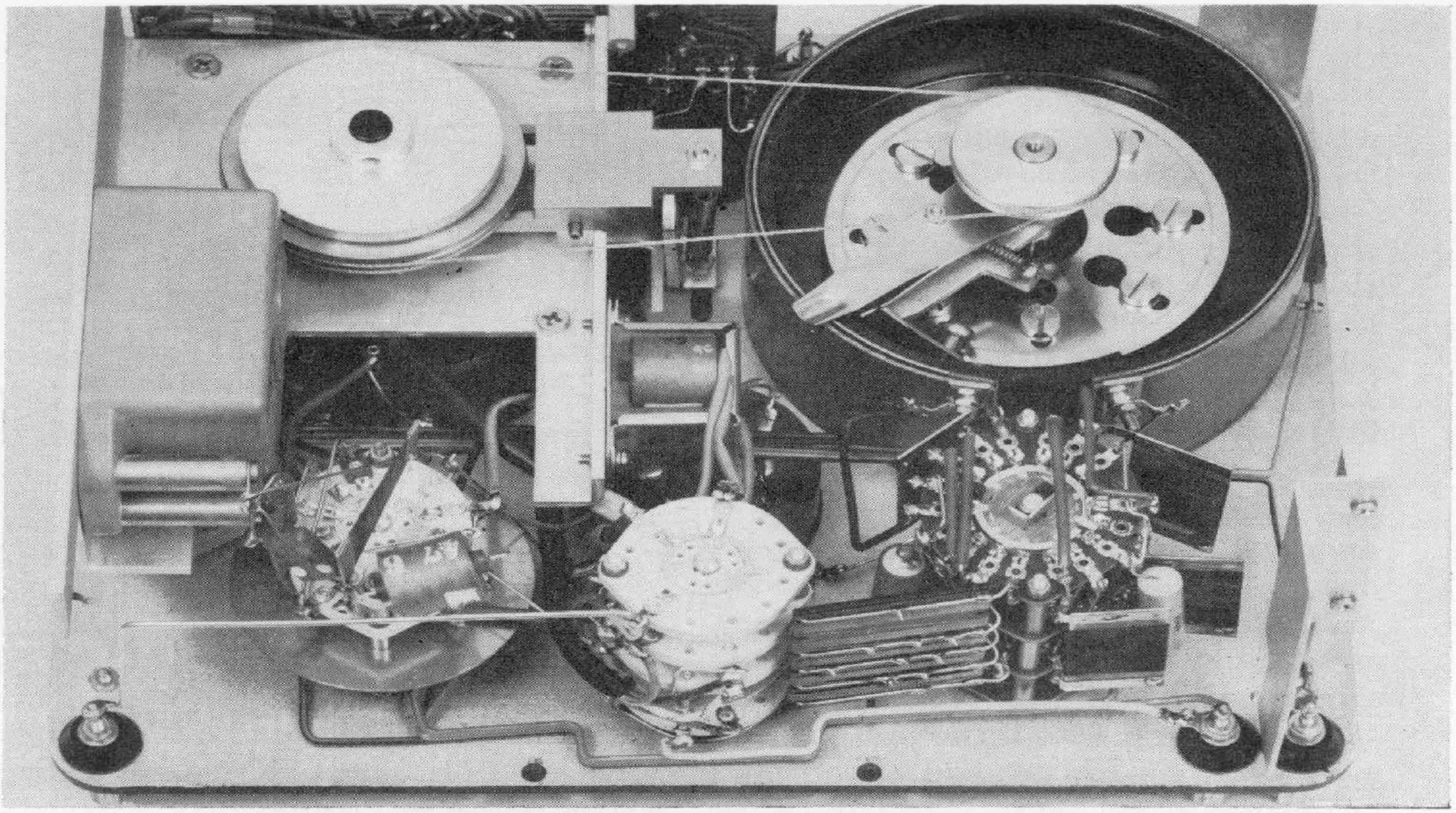
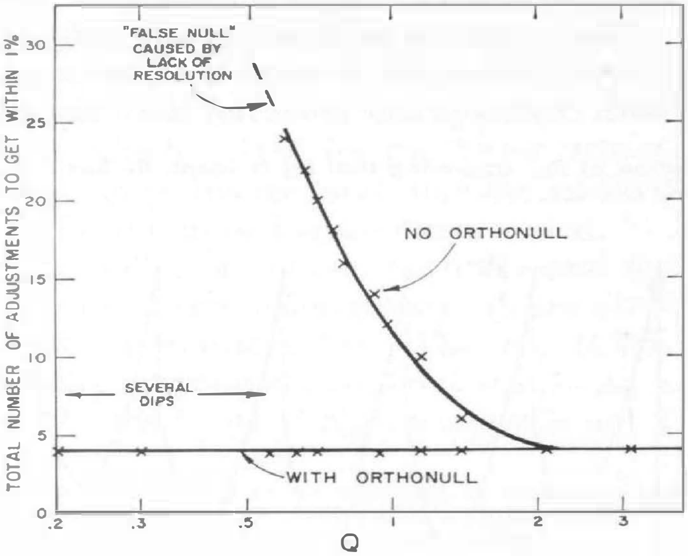


Figure 4. Interior view of the Type 1650-A Impedance Bridge, showing the ganged drive for *Orthonull*. The clutch lever, which is operated from the front panel, is between the two potentiometers; the clutch face is between the two pulleys on the left-hand potentiometer.

by use of resistors of any similar characteristic. However, since R_T must be moved independently of R_X, an exponential R vs. θ characteristic is necessary in order that a given angular change will always produce the same fractional resistance change. Fortunately, resistors with exponential windings have logarithmic dials, which are desirable for constant percentage bridge accuracy. The *D-Q* resistor of the Type 1650-A Impedance Bridge is a 54-db potentiometer and the CRL dial is logarithmic over a 21-db range. The difference in exponential span of the two resistors results in a pulley ratio that is favorable to torque transmission in the direction required. The pulleys are connected by a wire cable with spring take-up to prevent backlash in the adjustments, and two ball bearings are used to reduce drag.

Figure 5. Plot of total number of balances required to achieve 1% final balance, with and without *Orthonull*, as a function of Q.



Advantages

The advantages of *Orthonull* operation can most easily be illustrated by the experimental plot, Figure 5, of Q vs. the number of adjustments necessary to get a 1% balance. At high Q's, four adjustments, two of each potentiometer, are generally required whether *Orthonull* is used or not. Below a Q of 2, however, the curve for "no *Orthonull*" quickly rises while the number of adjustments necessary has not increased for balances with *Orthonull*.

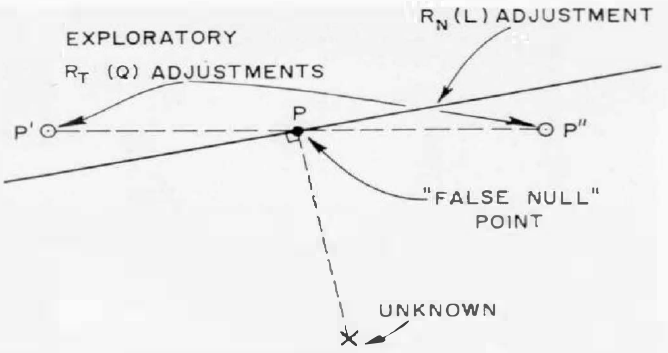


Figure 6. False null. Resolution of $R_T = 0.5\%$; if $Q = 0.2$, the error in L can be as great as 6.25%.

False Null

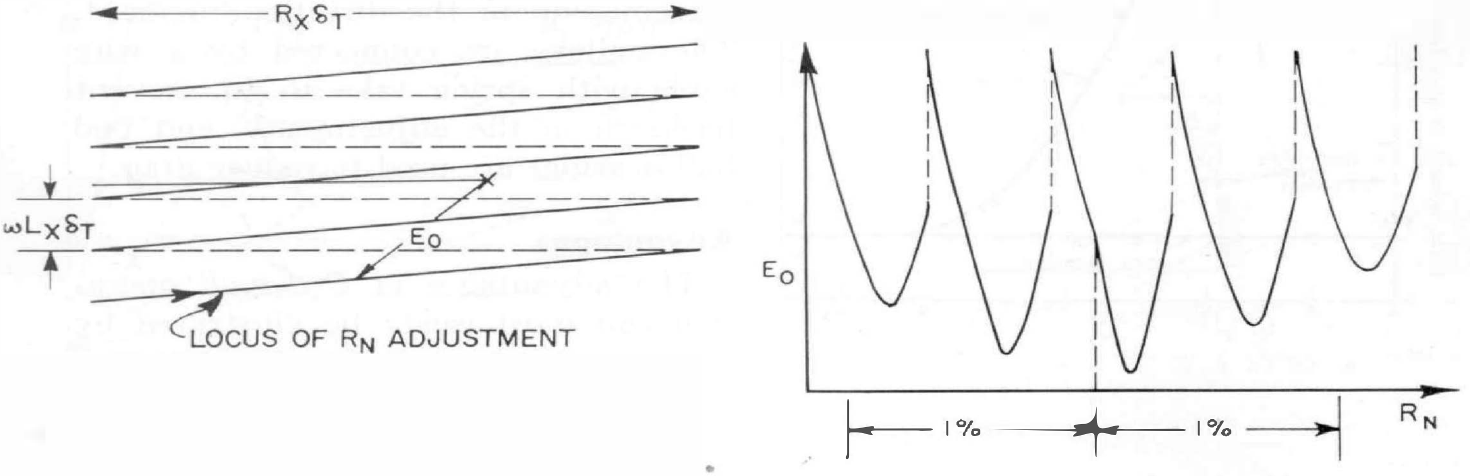
Without *Orthonull* it is impossible to obtain a 1% balance down to Q values of about ½ if the usual balancing procedure is used. Under these conditions, a false null is reached where an adjustment of either variable element only causes a larger bridge unbalance. The phenomenon is due to the finite resolution of the R_T resistor and may be explained with the aid of Figure 6. Let us assume that the R_N adjustment is varied, moving the locus of the bridge impedance along the radial line as shown. The best minimum output voltage occurs at point P, which is the closest point on the line to the unknown. The operator would then make a horizontal, R_T, adjustment, but since the resolution R_T is finite, the locus must jump to either P' or P'', both of which are further from the unknown than P. Therefore, an adjustment of either variable increases the bridge output voltage, and the operator would assume this point to be the best null. It can be shown that this balance can result in an error of as much as $\frac{\delta_T}{2Q_X^2}$ where δ_T is the percent resolution of R_T. For the 1650-A, $\delta_T \approx 0.5\%$, so that the error would be 1% when $Q = ½$ and 25% when $Q = 0.1$.

It should be noted that the "false null" error described above can be avoided by a trial-and-error method. In this procedure one starts with various R_N values and makes successive balances, each of which will be a "false null." The best balance may eventually be obtained in a logical manner if the detector indication is used as a guide in the choice of the succeeding initial R_N value. Needless to say, this is a time-consuming procedure.

Multiple Dips

The finite resolution of the R_T resistor also has an effect on balances made with *Orthonull*, but does not limit the ac-

Figure 7. Effect on output voltage, E_O, of limited resolution of R_T, assuming that R_N is ideal, R_T has 0.5% resolution, and $Q = 0.1$.



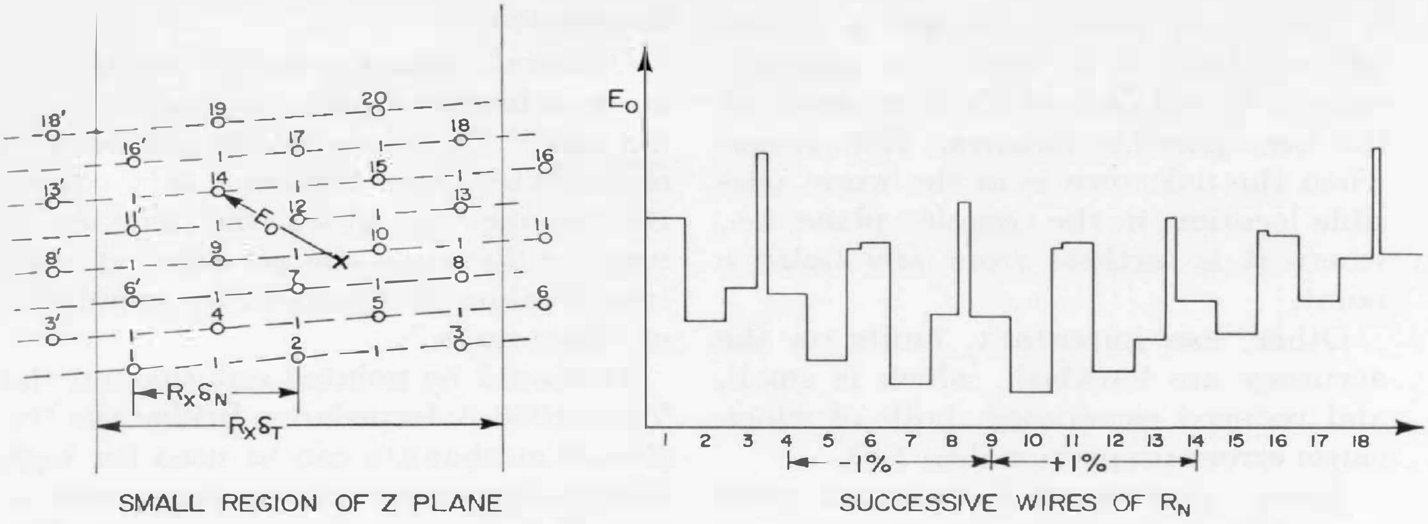


Figure 8. Effect on output voltage, E_O, of limited resolution of R_N and R_T, assuming $\delta_N = 0.2\%$, $\delta_T = 0.5\%$, and $Q = 0.1$.

curacy. Instead, the limited resolution causes the output voltage to make repeated dips as R_N is varied, and the best dip can be chosen to give a more accurate reading. If both resistors were perfectly continuous, a variation in R_N would move the locus of the bridge impedance vertically on the complex plane, due to *Orthonull* action. However, if R_T has finite resolution, an adjustment of R_N results in a zigzag locus, as shown in Figure 7a, where each line corresponds to the variation of R_N for one particular wire of R_T. Since the output voltage is the distance between the unknown, Z_X, and the zigzag line, this voltage will go through a series of dips as R_N is varied, as shown in Figure 7b. If the best null is chosen, the error is always less than $\delta_T/2$, which is ¼% for the TYPE 1650-A Impedance Bridge, and thus the error of the false null of Figure 6 is avoided.

Actually, of course, both R_T and R_N have finite resolution since both are wire-wound potentiometers. The R_N (CRL resistor) resolution is about 0.2%. As a result, the locus of R_N variation is not a series of curves as indicated in Figure 7, but a step from one wire to another as shown in Figure 8. This latter figure is idealized in that the ratio of resolutions of the two potentiometers, $\frac{\delta_N}{\delta_T}$, is assumed to be exactly 2/5, which results in an even pattern of possible balance points. As R_N is varied, the output jumps in discrete steps, with large jumps coming as the setting of the coarser potentiometer, R_T, changes from wire to wire.

The most important limit on accuracy

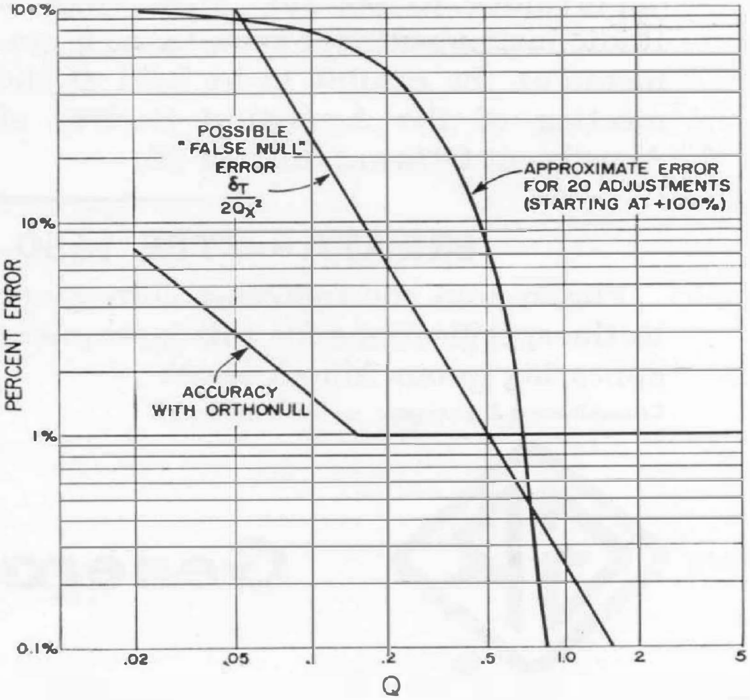


Figure 9. Accuracy to be expected in measurement as a function of Q, with and without *Orthonull*. "False null" error is also shown.

is that it is possible to get a bridge balance that is in error by approximately $\delta_N/4Q$ but which is as good as the best possible balance. This occurs when the unknown is in the worst possible location, in the complex plane, *i.e.*, where it is farthest from any balance point.

Other, less important, limits on the accuracy are backlash, which is small, and reduced sensitivity, both of which cause errors proportional to $1/Q$.

Many experimental balances were made to see what sort of accuracy could be expected, and it would seem that, with reasonable care, one should be able to get balance of 1% or $0.15/Q\%$, whichever is larger. This is plotted in Figure 9. Also on this plot is the possible error occurring as a result of the "false null" when conventional balancing technique is used as described above. A more practical limit for operation without *Orthonull* is the line which shows the approximate accuracy possible with 20 balance adjustments starting with a +100% unbalance in inductance.

Conclusion

Orthonull makes possible rapid balances at low Q values, avoiding the "sliding null." The basic bridge accuracy is not affected since *Orthonull* only affects the manner in which the balance is made. Effectively the accuracy at very low Q values is improved by avoidance of "false nulls."

It should be pointed out that on the Type 1650-A Impedance Bridge the *Orthonull* mechanism can be used for high D capacitance measurements as well as low Q inductance measurements. The device can be disengaged so that high Q (low D) balances can be made in the usual manner.

Acknowledgments

The idea for *Orthonull* was prompted by a suggestion from Dr. D. B. Sinclair for making an orthogonal L-R bridge (Figure 1) give a Q reading by appropriate adjustment of logarithmic scales. The mechanical design of the mechanism was worked out by G. A. Clemow.

— H. P. Hall

GENERAL RADIO EXHIBITS IN CANADA

Our Canadian friends will have an opportunity to see the latest General Radio instruments for acoustic measurements at the exhibit to be held at the meeting of the Acoustical Society of America at Ottawa, May 14-16.

A General Radio traveling display will be in Ontario and Quebec from May 11 to May 28. It will be at the Seaway Hotel in Toronto on May 16 and at the Capri Hotel in Montreal on May 24, from 12 to 6 P.M.

ERRATA—TYPE 1650-A IMPEDANCE BRIDGE

Please note the following corrections to the specifications for this instrument appearing in our March issue:

Capacitance Accuracy: ± 1% ± 1 μμf.

Frequency Range for R: 20 c to 5 kc.

On page 7, under **Iron-Core Inductors,** the last line of the first paragraph should read "at initial permeability."

General Radio Company

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