Weston ENGINEERING NOTES

VOLUME 1 APRIL 1946 NUMBER 2

In This Issue

John Parker, Editor

Copyright 1946 Weston Electrical Instrument Corp.

WESTON ELECTRICAL INSTRUMENT CORP., 614 Frelinghuysen Avenue, Newark 5, N. J., U. S. A.

CONDUCTION GRID CURRENT MEGOHMMETER

AN interesting application of a vacuum tube connected as a grid current amplifier is that used in the new Weston Model 799 Insulation Tester. Here, small values of current through the unknown resistance are amplified and indicated in terms of megohms on a calibrated microammeter.

The current through the unknown resistance will vary between the limits of 6×10^{-9} ampere up to 1×10^{-4} ampere depending upon the value of resistance under test. This current is injected into the tube as positive grid current and this current plus the resultant plate current deflects the indicating instrument.

Figure 1—Weston Model 799 Insulation Tester complete with Case, Test Leads and Leather Carrying Strap.

I_g—I_p Characteristic

The grid current—plate current characteristic is approximately logarithmic rendering a logarithmic scale distribution covering 5 decades of resistance from one-tenth megohm to 10,000 megohms on the single range. This logarithmic scale distribution is derived from the I_p—I_g characteristic inherent in all tubes operated in the positive grid current region. If a high mu triode is used the range indicates 5 log decades of grid current magnitude. By including the grid return current with the plate return current to operate the indicating instrument, a cathode current limiting resistor may be used without distorting the scale distribution in the low resistance region or near the zero mark on the instrument scale. Characteristic plate and grid current plotted against total cathode current is illustrated in the curves of Figure 2. The tube is considered a three-lead circuit junction wherein I_c equals I_p plus I_g. As the plate current decreases because of lowering plate voltage, the grid current becomes appreciable and maintains the logarithmic characteristic well up to the maximum cathode current.

At very low values of grid current close to the zero cathode current point, ionization of the residual tube gas adds a variable

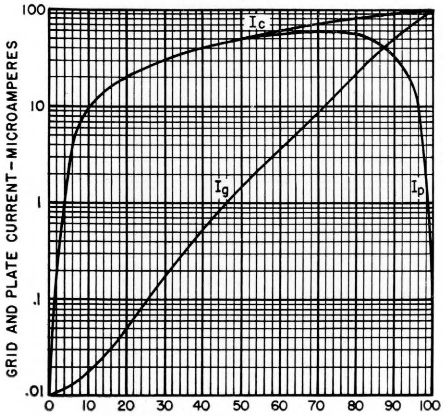


Figure 2—Characteristic Plate and Grid Current plotted against Total Cathode Current

factor that would normally be objectionable. This gas current may be swamped out at a sacrifice of end scale sensitivity by using a high value grid resistor. The use of this resistor only affects the calibration of the 10,000 and 1,000 megohm scale points. Refer to Figure 3 for the diagram, and the location of this resistor, R_4.

The tube is energized by a 67½ volt plate battery of the minimax type, and a 1½ volt unicell for filament energy. The voltage drop through the total cathode resistance R_1 and R_2 is a linear function of the cathode current and, therefore, the tube plate potential is equal to the plate battery voltage less the cathode resistance drop. As the plate battery voltage may be considered constant while measurements are being taken, it follows that the plate potential is an inverse linear function of cathode current. In a high mu tube such as the one used here the grid voltage over the range of operation is low relative to other element voltages. Thus the grid—plate voltage follows the plate—cathode voltage quite closely. From this, the potential applied to the resistance under measurement is approximately inversely proportional to the current through the indicating instrument. This, of course, is quite similar to usual ohmmeter practice, that is, the potential is zero at zero resistance, one-half the plate battery voltage at center scale and full battery voltage at infinite resistance.

With zero applied resistance the plate voltage is practically zero, with the grid voltage still at a low value and thus, current and potential distribution throughout the circuit is equivalent to that obtained by connecting the tube elements together. Conversely at infinite applied resistance the potential distribution is similar to that obtained by tube removal.

Compensation Current Low

Under normal conditions with the megohmmeter binding posts open circuited there is a small residual plate current due to space conduction around the ends of the tube grid structure. This current is compensated out of the instrument by introducing an equal reverse current obtained from the filament battery through the compensating shunt resistor R_3. Actually while the instrument shows a current varying from zero to 100 microamperes, the cathode current varies from about 1.5 to 101.5 microamperes. This compensation current is so low that its normal variation with filament battery voltage would not cause any objectionable variation in readings at the infinite resistance end of the scale.

Referring to the diagram, Figure 3, R_1 is a series rheostat to take care of battery voltage variation. It is available on the panel covered by a cap nut marked "Zero Adj.", note Figure 1. With the "Line" and "Ground" terminals shorted, this rheostat is adjusted to set the pointer to the "Zero" position. As filament and plate batteries age, the individual errors tend to compensate up to the point where it is no longer possible to set the pointer to the zero position. Design center is 65 volts for the plate battery and 1.4 volts for the filament battery.

Leakage Shield Provided

A leakage shield binding post is provided for use where required. For best leakage shielding, the shield circuit potential should equal the line terminal potential. In this design cathode potential closely follows grid potential, and this point is used for shield terminal connection.

The complete device with test leads and case is shown in Figure 1. Note that a shoulder strap is provided with panel loops so that the instrument can be shoulder supported allowing freedom of both hands for operation and connection of leads. In view of the fact that the scale must indicate over six decades, it is highly impractical to attempt to include the intermediate divisions. To provide means for recording readings that do not fall on any of the cardinal lines, a 50 line uniformly calibrated arc has been added.

The instrument is small and quite practical for all portable uses. The dimensions of the instrument proper are 3¼″ by 5⅜″ by 4⅞″. The weight is approximately three pounds. It is supplied complete with test leads, tube, batteries, leather carrying strap and case for $54.00 list.

E. N.—No. 4 —*O. J. Morelock*

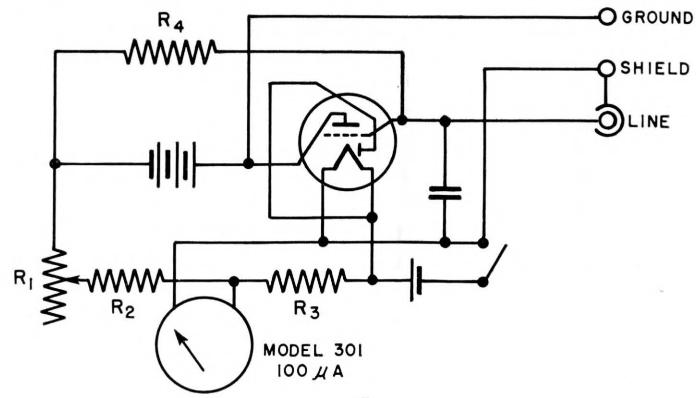


Figure 3—Representative Diagram of a Conduction Grid Current Megohmmeter.

THE SINGLE POINT POTENTIOMETER

THE potentiometer method of measuring or checking a d-c potential usually brings to mind a slide wire, perhaps in the drum type, or a group of dials along with a sensitive galvanometer, a local source of energy and auxiliary apparatus. The laboratory potentiometer in which certain of these items are assembled is typical of the viewpoint.

However, the potentiometer method, as a method, has very broad possibilities and, frequently, relatively simple combinations can secure the high accuracy of the potentiometric system for a specific measurement problem.

The Measuring Circuit Set-Up

Let us assume we wish to maintain a certain voltage to a high degree of precision and to check minor deviations from the prescribed value. Further, assume we are not interested in the value except as it is within 3% of that prescribed. A few simple but accurate resistors, a center zero galvanometer, a standard cell and our measuring circuit is ready for set-up.

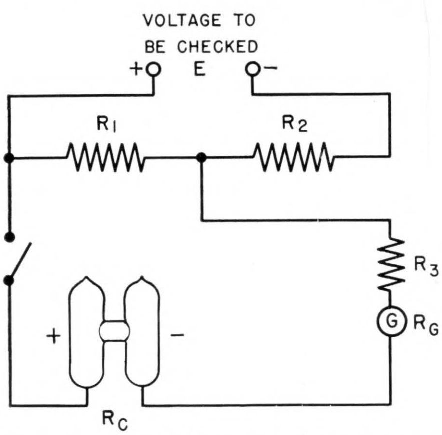


Figure 1—Simplified Diagram of Potentiometer Circuit

Refer to the diagram, Figure 1. Here $R_1 + R_2$ constitute a voltage divider network where the drop across R_1, with the prescribed voltage applied, is equal to the standard cell voltage, nominally 1.0186 volt. In this method we must draw current from the voltage source and can establish 10 ma, for example, as the normal current. R_1 then becomes 101.86 ohms and must be adjusted with an accuracy several times as good as that required over-all. R_2 is the remainder of the divider and, since we have set 10 ma or 0.01 amp as the normal value, $R_1+R_2=E/.01$ or $R_1+R_2=100\ E$. As R_1 has been established, $R_2=(100\ E-101.86)$ *ohms.* On closing the switch, the galvanometer, *G,* will indicate to the right or left of center zero as *E* is above or below the prescribed value.

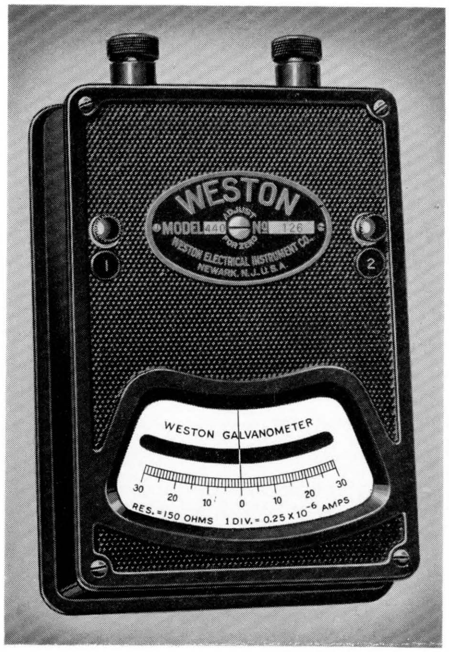


Figure 2—Weston Model 440 Galvanometer

Covering a 3/0/3 Percent Variation

If we wish to have a direct indication of deviation of *E,* we merely have to select a suitable galvanometer and figure the value of R_3 (R_G and the standard cell resistance will be known or selected). Let us assume a 30/0/30 scale as used in several Weston Galvanometers and that we wish to cover a 3/0/3 percent variation. Then, each division represents 0.1% variation from the prescribed value.

First select the Weston Model 440 Galvanometer, Figure 2, which is made standard with a resistance of 150 ohms and a sensitivity of 0.25 microampere per division. Now, we want one division deflection on 1/10% variation, or, in terms of the standard cell voltage, 1018.6 microvolts. This voltage difference will cause the 0.25 microampere to flow through 4074.4 ohms, according to Ohm's law. This resistance must be equal to $R_1+R_3+R_G+R_C$ or

$$R_1+R_3+R_G+R_C=4074.4 \text{ ohms}$$

as $R_1=101.86$ *ohms*
and $R_G=150$ *ohms*
and $R_C=100$ *ohms (approx.)*
then $R_3=4074.4-(101.86+150+100)=3722.5$ *ohms.*

Actually, the 100 ohms value for a Weston Model 4 Standard Cell, Figure 3, is only approximate and it may run 25 ohms higher, but this will give only a negligible error in the calculation of R_3. We can well make R_3 equal to 3700 ohms.

This combination will then indicate directly in terms of percent deviation of the voltage applied from the prescribed value *E,* each scale division being equal to 0.1% variation. If the voltage is not more than 20% in error, not more than 50 microamperes will be taken from the standard cell. If the switch is pressed when there is *no* voltage at the terminals, 250 microamperes will be taken; this

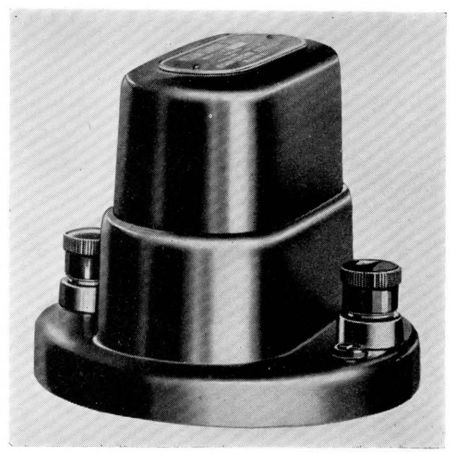


Figure 3—Weston Model 4 Standard Cell

Figure 4—The Single Point Potentiometer

will temporarily pull the cell voltage down a trifle but the cell will recover in a few minutes to within 0.1%.

Similarly, other galvanometers can be used, such as Weston Model 699 Galvanometer, and other degrees of sensitivity can be attained through the use of suitable components. It may be of interest to note that many years ago Weston made a lamp testing potentiometer where the voltage was checked in a manner similar to that shown above.

The Single Point Potentiometer

A wartime requirement for a device to check a double 200 volt circuit resulted in the assembly shown in Figure 4 where a somewhat special Weston Model 301 served as an indicator. The circuit used is essentially that discussed above with two sets of resistors for the two voltage sections and a selector switch. The standard cell is mounted in the case along with the several resistors. An important phase of the use of this assembly is that it is practically immune to vibration and does not need to be levelled; both heavy vibration and the need for levelling preclude the use of direct reading laboratory standards. By using this single point potentiometer, accurate measurements could be made in the field or on shipboard without regard to local conditions.

E. N.—No. 5 —*A. G. Smith*

SPECIAL TEST SET FOR RELAYS

In recent years, and particularly during the war, there have been many small requirements for special sensitive relays of the instrument type. These requirements appear to vary enormously as to operating current, voltage, contact duty, and refinements of balancing. None of these special requirements appear to run in any quantity or at least sufficient to justify elaborate individual test facilities so that it appeared necessary to process these special jobs in the Engineering Department.

All-Purpose Test Panel Built

The burden of setting up for all of these different tests finally became so great that it was deemed necessary to build an all-purpose test panel. A description of the device with an indication of some of the several functions may be of some interest.

Figure 1 shows a general view of the device. The panel is 19″ wide x 26″ high, finished in black crackle; the wiring and working parts are easily accessible through doors in the back and top of the cabinet. On the front of the panel the main instruments are located at eye level for easy reading and a row of twelve switches along the bottom of the panel, controlling all functions of the test set, are within easy and comfortable reach of the user.

The device makes use of two adjustable circuits, shown in Figure 2. Up to the selector switch these two circuits are identical, each consisting of a Weston Model 271 Voltmeter with knife edge pointer and mirror scale fed from a potentiometer type rheostat of 1250 ohms resistance. A voltage control switch and a range changing switch for the Model 271 are provided. The output from either potentiometer circuit selected by a double-pole, double-throw switch, feeds through a reversing switch and from there through an adjustable series resistance to the output. By manipulation of the voltage control switches, the voltmeter range switches, and the series resistance, the operator can select any value of voltage from 100 volts down to 200 millivolts or any value of current from approximately 100 milliamperes down to 0.2 microampere and less.

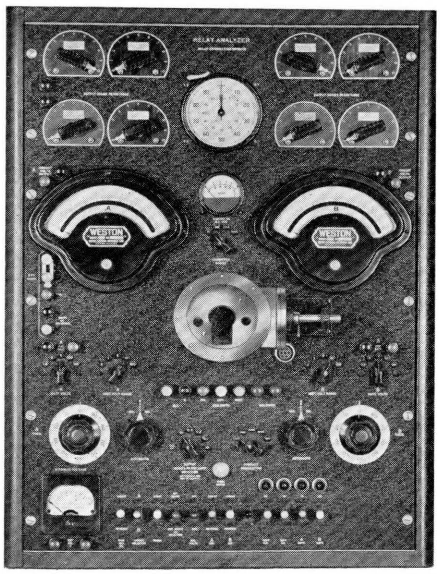


Figure 1—Special Analyzer for Testing Sensitive Relays

The Analyzer Circuit

Assume a sensitive relay of the zero center or galvanometer type that has been adjusted to close contact with 5-0-5 microamperes and must not close contact with 4.9-0-4.9 microamperes. The analyzer circuit may be set up as follows:

The 5 microampere value will be set up in the *A* circuit by selecting a voltage of, let us say, 6 volts. The Model 271 range changing switch is set on the 10 volt range. By means of the potentiometer, adjustment is made to 5 volts. The series resistance is set to 1 megohm minus the resistance of the relay under test. Similarly 4.9 microamperes is set up in the *B* circuit. Now, by setting the *A* and *B* circuit reversing switches on "direct" we can set the main reversing switch on "reverse" and check the left contact of the relay under test first, by setting the circuit selector switch to pick up the 4.9 microamperes from *B* and seeing that the contacts do not close and, second, by selecting *A* and seeing that the contacts do close. We can now throw the main reversing switch to "direct" and check the right contact in the same manner. It is obvious that by the manipulation of the above switches many combinations can be obtained.

Motor Driven Rheostats

The rheostats used in the *A* and *B* circuits can be operated manually or can be made to rotate automatically. Alongside the rheostat control is a knob marked "Automatic". When this is turned counterclockwise a small gear train connected to a 1 rpm motor engages with a large gear fastened to the rheostat shaft, and turns it in a counterclockwise direction. Similarly when the "Automatic" knob is turned clockwise, the rheostat automatically starts turning clockwise. Limit switches prevent overtravel of the rheostat and a neon pilot light shows whether the motors are running or not.

These motor driven rheostats are used in checking relays since they allow for a smooth change in the applied current, and thru an interlocked relay mechanism which stops the rheostat drive when the test relay makes contact, the contacting value is directly indicated on the large Model 271 instruments.

One of the rotary switches located between the rheostat knobs is the contact connection switch. By means of this switch the contacts of the relay under test are connected to various circuits within the analyzer. For instance, when on the ohmmeter position the resistance of the contacts under test appears on the four-range ohmmeter located between the two Model 271's.

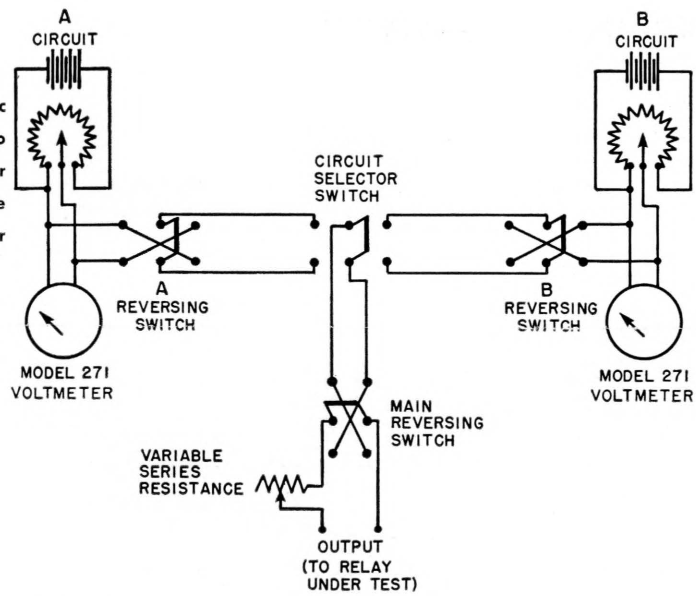
The Timing Circuit

Figure 3 shows the wiring diagram of the timing circuit that is used to check the time required for the relay contacts to close after the proper current has been applied. It consists of a 1/100 second stop clock, two Weston Model 712 Power Relays, and a timing starting switch. The *A* or *B* circuit selector switch also enters into the timing circuit.

The operation is such that the timing check is made from a value set up in one potentiometer circuit to a value set up in the other potentiometer circuit. The relay actuating current is set up in circuit *A*, the *B* circuit is set at zero current. The circuit selection switch is set on *B* which means that the timing shall be from the *B* circuit to the *A* circuit, switched over by power relay *(a)*. Similarly timing can be made from the *A* circuit to the *B* circuit by setting up the proper values and placing the selector switch on *A*.

When the starting switch *(s)* is thrown over, it energizes power relay *(a)* which changes over the output from the *B* circuit to the *A* circuit if the selector switch is on *B*. If the selector switch is on *A* it changes over the output from the *A* circuit to the *B* circuit. Upon closing, this same power relay also starts the 1/100 second timing clock at the same instant that the circuits are changed over. In the case assumed above, before the starting switch is thrown there is no current on the relay under test as it is connected to the *B* circuit. When the starting switch is thrown on, the power relay switches the output to the *A* circuit, the actuating current flows into the moving coil of the relay under test, and at this instant the clock starts. When the contacts of the relay close they cause the power relay *(b)* to operate, opening the clock circuit and giving the exact time required for the relay contacts to close. In the case of a suppressed zero type of relay, the contacting value can be set in one circuit and some other suitable value in the other circuit and the timing between these two values taken as described above.

Figure 2 — Schematic Diagram of the two adjustable Potentiometer Circuits as used in the Weston Relay Analyzer



Binding Posts Provided

Binding posts are provided for the controlled voltage to be taken directly from either potentiometer circuit without going through any resistance or switches. Connections are also provided in each potentiometer circuit for the external connection of batteries or other source of voltage. Extra positions are provided on all switches to facilitate the adding of additional circuits that may later be required.

Support for Relays Has 32 Positions

Mounted at the center of the panel at a convenient height is a device for mechanically holding or supporting most types of Weston Relays. This device, with the relay attached, can be moved into any one of 32 different positions to allow for checking the relay in any odd position that may be required.

Pilot lights are provided on all main circuits and the color coding of all knobs provide easy switching of all circuits.

While this test set is perhaps more elaborate than normally needed, it has given very satistory service because of its versatility in the various tests which can be easily and quickly performed.

E. N.—No. 6 —*E. R. Kebbon*

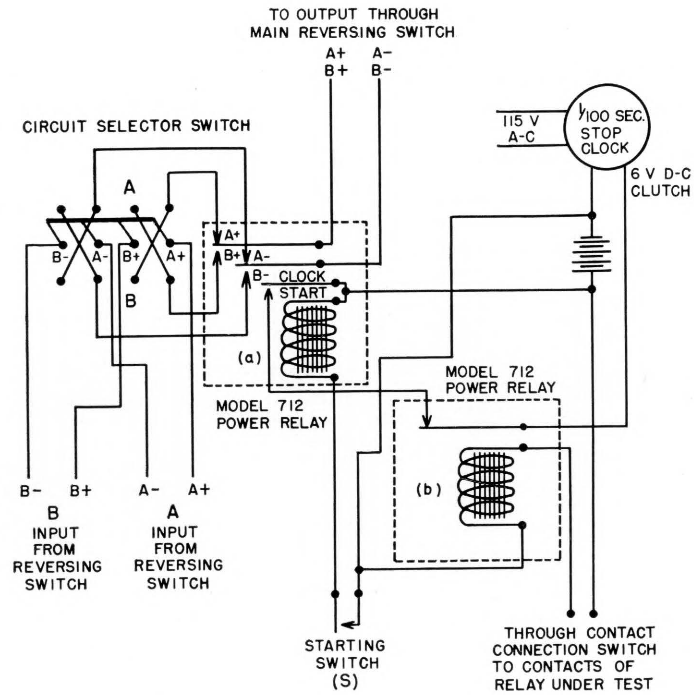
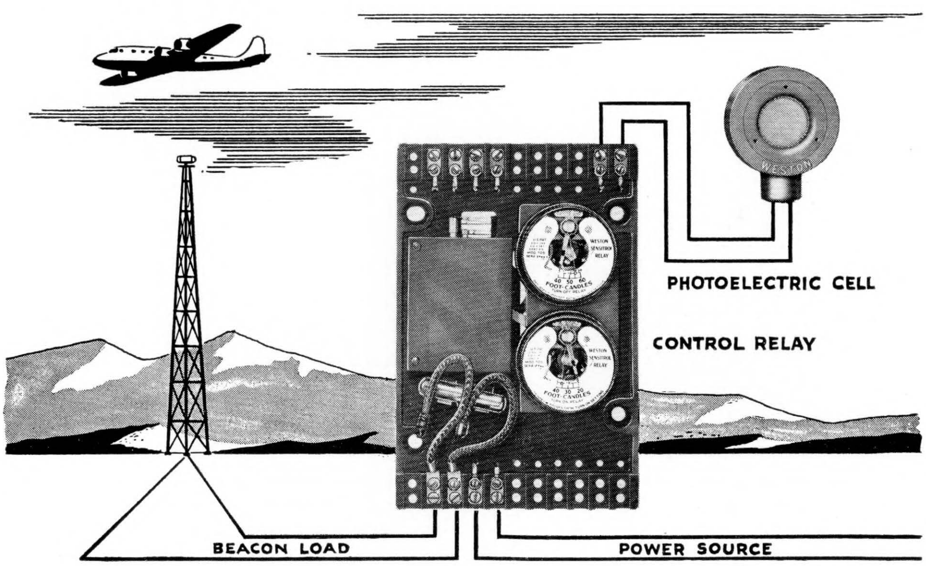


Figure 3—Wiring Diagram of the Timing Circuit used when checking Relay Contact Closing Time

WESTON AIRWAY HAZARD MARKER ILLUMINATION CONTROL RELAY

WESTON Model 709 Type BA 224 sounds unassuming but it is a pioneer among airway safety developments. Many of us have already forgotten the difficulties encountered a mere fifteen years ago by the night flying pilot when few lights were available to mark his path across a foreboding sky and between ominous mountain peaks.



Airway Beacon controlled by the Weston Model 709 Relay and Photoelectric Cell

Long before the days, or more important the nights, when the pilot was equipped with the automatic pilot, blind landing equipment, directional beams, radio marker beacons, and other generally accepted safety means, Weston engineers were working with the Bureau of Aeronautics in arriving at safe requirements as regards the values of ground illumination at which beacon and hazard marker lights should turn on and off to afford the greatest safety and assistance to the pilot and his craft.

Finally after a series of developments and later experiments conducted during 1932-1933 at an emergency landing field at Bowie, Md., and at Newark Airport, the Government airway engineers using the then newly developed Weston Photoelectric Cell and Photoelectric Lightmeter arrived at the required safe illumination values which were ultimately written into Bureau of Aeronautics Specification #BA 224. The Weston Model 709 Type BA 224, Beacon Light Control was then produced to meet the requirements of this specification and after passing the government tests was approved for use along all airways.

The Weston device was the first one to pass the required tests and to this day still stands unchallenged as an important and reliable aid to air navigation.

Hereafter, as you fly along a regular airlane or as you ride thru cities and countryside, and see a rotating or flashing beacon, or tall radio transmitting towers with red flashing lights at the top of the masts, or high illuminating gas storage tanks or tall smoke stacks lighted by spot lights or with red globes, you will know that Weston has supplied thousands of Model 709 Relays to provide this safety for you and others. Remember also that there are only three ways to turn on a light—one is by hand which is not fool proof as a person can forget, be absent, etc., or in the case of remote installations on mountain peaks, in deserts, in the middle of large bodies of water, et cetera, there may be no human being for 100 miles; the second is by a time clock which must be wound electrically or by spring action and which may lose time during blizzards, etc., to the extent that it will turn the lights on during the day which isn't too bad, but what is worse and may prove disastrous it may turn them off at night; third and best is by a photocell which depends on nothing but natural daylight and will turn on the light at the exact value when required day or night, winter or summer, year in and year out.

E. N.—No. 7 —*Anthony H. Lamb*

THERMOCOUPLE AMMETERS FOR VERY HIGH FREQUENCY

WITH the broader use in communications of the very high frequency band from 30 megacycles to 300 megacycles, a great many questions have been asked as to the performance of thermocouple instruments. Particular attention has been directed to the frequency in the vicinity of 100 megacycles in the center of this band because of the allocation of frequency modulation stations as well as television transmitters to this general region.

Skin Effect Factors Account for Total Error

Some nine years ago a research project was prosecuted in the Weston Laboratories in this regard and a rather complete study was made of the errors in thermo-ammeters at 80 megacycles and the results are still valid. Reference is made to the article by the writer entitled "Thermocouple Ammeters for Ultra High Frequencies", on Page 1567 of the December 1936 issue of the Proceedings of the Institute of Radio Engineers, Volume 24, No. 12. Tests were made of the errors in the instruments using a single straight filament lamp as a comparator between the high frequency and d-c, the light indications being compared by a photoelectric cell and a microammeter, the cell being several inches away from the lamp. Tests were run on a number of 5 ampere instruments and the results reported showed the instruments read quite high because skin effect in the heating wire was such as to give considerably more heat than that represented by the low frequency ohmic resistance of the heater. A detailed study of the situation showed that the application of skin effect factors accounted for the total error and that there were no other factors producing errors of any magnitude.

Figure 1 shows a chart reprinted from the above mentioned article which applies to instruments as they were made at that time and still applies to thermo-ammeters using solid heaters of circular cross-section.

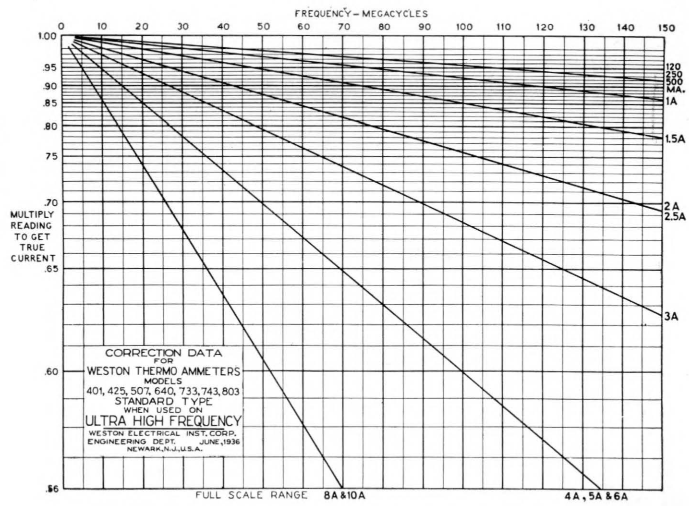


Figure 1—Chart giving Correction Factors for Standard Line of Thermo-Ammeters using Solid Heaters

The data in the chart will not, of course, apply exactly to different designs of instruments but since the designs are rather severely limited by joint Army-Navy specifications as to total allowable loss on the one hand, and enough heat must be generated to get sufficient thermoelectric voltage in the thermocouple to give adequate torque in the instrument mechanism to secure acceptable performance under vibration tests, it is found as a practical matter that the resulting errors are fairly represented by the values in the chart for most all commercial designs.

Tubular Thermocouples

As a result of this work the Weston Corporation shortly thereafter began to produce thermo-ammeters with tubular heaters associated with the thermocouples, the walls of the tubing being just as thin as could be reasonably fabricated. The net result is that the performance of these tubular thermocouple instruments follows the top line in the chart as for the milliammeters and essentially giving an error of 2% at 65 megacycles, 3% at 80 megacycles, 4% at 95 megacycles and 5% at 110 megacycles.

Weston thermo-ammeters are made today following this procedure and, to cover the band to 300 megacycles Figure 2 has been drawn showing the correction factors to be applied to Weston thermo-ammeters over this range and of the type being currently manufactured.

Coordinate System Simplifies Plotting

The form of the chart may be of some interest. W. N. Goodwin, Jr., the inventor of the compensated thermo-ammeter, in studies of effects at very high frequencies, worked out a special set of coordinates where the relation between resistance and frequency became a straight line. Such a coordinate system simplifies plotting since a single point determines each characteristic because the resistance ratio is unity at zero frequency. If the coordinate system is accurate, the straight line allows for good accuracy in the interpretation of results and appears to give a better picture of the resulting effect. The equations from which the data were taken are due originally to Maxwell, although the simplified form by Dr. F. W. Grover of Union College was actually used. Grover's data is given in the Smithsonian Physical Tables.

While the errors in standard Weston thermo-ammeters are given in the chart, it is a rather straightforward procedure to calibrate into the instrument these errors whereby the instrument will read directly in true RF current in the instrument at a specified frequency. This is rather simply done by adjusting an instrument specified for use at 100 megacycles, for example, to read 4.5% low on 60 cycles; when used on 100 megacycles the difference in resistance of the tubular heater will be compensated by the special calibration and the instrument will read correctly.

Of course, in all of this discussion it must be understood that the instrument can only read the current appearing in its heater. If there are standing waves in the system the instrument will read the current intensity at the center point between its stud terminals and so indicate along with the correction factors involved. Care is usually required in the placement of the instrument so that its indications are representative of the requirements.

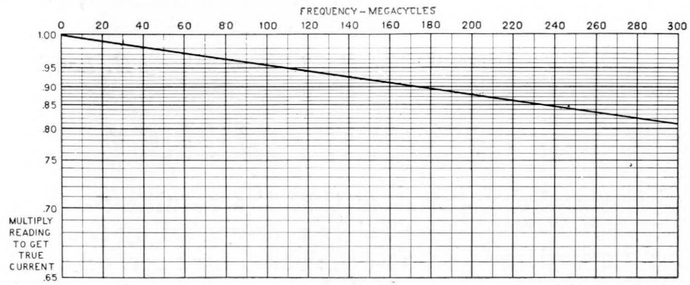


Figure 2—Chart Showing the Correction Factors to be applied to Weston Thermo-Ammeters over a range of 300 megacycles

Monitoring RF Instruments

Many of the transmitters being designed today use monitoring RF instruments which are actually of 1 ampere range and having the instrument itself coupled to the main current system through a short loop amounting effectively to an RF current transformer. Calibration is usually accomplished after the set is assembled and in terms of a high range instrument placed in the circuit where the final current is to be measured. The instrument scale is marked in terms of the total current and the final adjustment is merely that of changing the coupling slightly by moving the associated loops or the loop and the main conductor. The same sort of thing can be worked out with a coaxial line by placing a small loop inside of the outer conductor and bringing out a bit of the RF energy to the 1 ampere thermocouple. A 1 ampere thermocouple is recommended for this application because it represents about the lowest current for which a rugged heater can be made with normal overload capacity and suitable high frequency characteristics. The current is generally in the region which can be adequately handled by a small loop and represents the accumulated experience of a large number of such applications.

 —*John H. Miller*

ERRORS AND MEMORIES

A few days following the mailing of WESTON ENGINEERING NOTES, Volume 1, Number 1, a letter from a reader was received by John H. Miller who authored THE GALVANOMETER AND THE BRIDGE, calling attention to a typographical error in his article.

The numerator in equation (3) on page 2 appeared "I (bc + ad)." It should have read "I (bc − ad)."

This friendly and much appreciated letter brought back a memory . . . it took us back to a Weston advertisement that appeared in the October 26, 1929 issue of Electrical World, entitled "An Apology to Franklin." We then hastened to apologize for a grave error in date having to do with Ben Franklin's kite flying experiment.

In this "apology" reference was made to a letter calling our attention to a mistake with the just criticism that . . . "even a typographical error in a Weston advertisement was inexcusable—and as inexplicable as an inaccuracy in a Weston Instrument!"

While on this subject of errors your attention is called to Figures 2 and 3 which appeared on pages 4 and 5 in the article entitled COPPER OXIDE RECTIFIERS AS USED IN MEASURING INSTRUMENTS. *The small disc was shown as 0.008″. It should have appeared as 0.080″.*

It is significant of our scrupulous regard for truthful statements that we should be unwilling to permit these errors to stand uncorrected. We desire to be as meticulously careful in the inspection of the typography and illustrations appearing in WESTON ENGINEERING NOTES as we are known to be technically thorough in every detail of design and manufacture.

—The Editor

Printed in U.S.A.