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THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

DELIVERIES

● **OUR MANUFACTURING AND ENGINEERING FACILITIES** are heavily overloaded at present with urgent work, most of it directly connected with the National defense program. Because of this, we are unable to accept most orders for equipment of special design.

We are making every effort to maintain adequate stocks and to make prompt deliveries of standard apparatus, much of which is also necessary for the defense program, but owing to slow deliveries of raw materials and parts, as well as to our own overtaxed facilities, deliveries on some items will necessarily be slow. We ask your indulgence and, on our part, we will do our best to get equipment to you as promptly as possible.

TRANSMITTER MAINTENANCE IN THE MODERN BROADCASTING STATION

By Charles Singer
(*Technical Supervisor, Station WOR**)

● **AS IN MANY OTHER PUBLIC SERVICES,** reliability in broadcasting is achieved only through careful and unceasing plant maintenance operations, which require not only competent personnel but accurate measuring instruments as well. (*Continued on page 2*)

*Bamberger Broadcasting Service, Inc., Carteret, N. J.

ALSO IN THIS ISSUE:

Commercial measuring equipment plays a vital role in the maintenance of transmitters. It makes the testing of transmitting equipment simple and accurate, and it saves many dollars in costly failures. Tubes, condensers, inductances, and all radio equipment can, by proper maintenance, be made to operate more efficiently, thereby achieving many more hours of operating life. In this way the instruments more than pay for themselves.

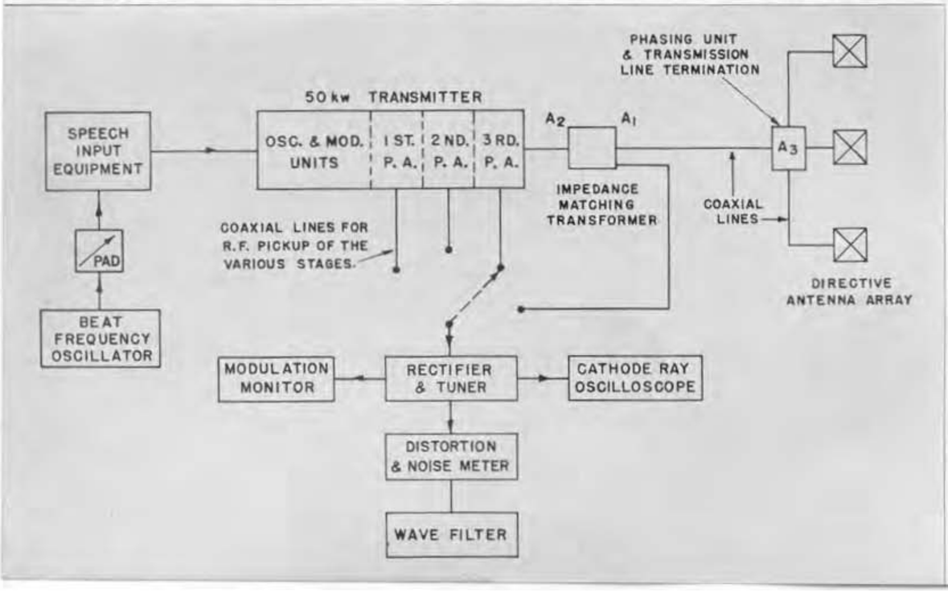
At WOR, the entire transmitting plant is operated and maintained from the instructions given in four operation routine manuals, namely:

1. Operating Routine
2. Night Maintenance
3. Day Maintenance
4. Special Maintenance

In these books, which were developed from WOR's operating experience, there is set forth, each day, a number of items which outline the maintenance to be done. For each individual item there is a detailed maintenance schedule describing the work to be done. Detailed maintenance of this type may seem unnecessarily complicated. It is, however, a vital operation if transmitter failures are to be avoided.

With the routine maintenance system of transmitter operations each component part is soon known to have certain measured values. At the completion of a given test, the operator enters his results on a log sheet beside the previous measurement of that component. Should any difference be observed, it is immediately corrected, and, in the majority of cases, a failure can be avoided. For example, each night after sign-off of WOR, the first maintenance operation is to feel all condensers. Two men are on watch; consequently, it takes a relatively short time to do this. Should a condenser have a hot spot on it, it is removed and checked on the radio-frequency bridge. Usually, these hot-spot condensers will show a change in power factor. Failure to remove such a condenser may result in "dead-air." All observations, whether

FIGURE 1. The arrangement of equipment for routine modulation, distortion and noise tests at WOR. Coaxial lines from each power amplifier stage are brought to the measurements room and permit measurements to be made on individual stages. Antenna impedance is measured at A_1, A_2, and A_3.



any change was or was not noted, must be logged.

Another important use of the r-f bridge is in antenna impedance measurements. Such measurements are essential to broadcasting stations using directive arrays, as the replacement of almost any condenser in the phasing units will necessitate a minor adjustment in the impedance matching transformers to obtain the most efficient operation. Replacement may affect critically the impedance match of the individual lines causing a considerable loss of energy, as well as modifying the current balance among the towers, and this cannot be detected unless impedance measurements are made. It is not safe to permit maintenance adjustments in an antenna coupling unit unless an r-f bridge is available, so that, during the inspection, if anything is moved which results in a change in current balance, it may be readily corrected. At WOR the transmission line leading to the phasing unit is measured weekly, and it is assumed that if no change is noted all is normal. However, if a change of 2% in impedance is noted, which cannot be accounted for, a more thorough inspection of the phasing and termination units is undertaken.

The impedance of the individual towers may be measured at A_3 (see Figure 1). The impedance at A_1 in Figure 1 is checked weekly, and is normally of the order of 75 ohms. A_2 is checked monthly, since this transmission line does not undergo radical temperature changes. All measurements are made with the General Radio Type 516-C Radio-Frequency Bridge, and in conjunction with this bridge a Type 605-B Standard-Signal Generator is used as the r-f power source. The frequency calibration of the generator is checked by obtaining a zero beat against the transmitter crystals. The impedance measurement is then carried out with almost any number of observations over a range of plus or minus 20 kc from the carrier frequency.

Distortion measurements also play an important part in the maintenance routine of a broadcast station. Too often stations are run on the theory "It sounds all right to me!" This hit and miss analysis is not adequate today, because instruments are available for measurements to prove the efficiency of the transmitter adjustment. These instruments are easily used and provide an accurate analysis of transmitter performance. The General Radio Type 732-B Distortion and Noise Meter and the General Radio Type 732-P1 Range-Extension Filters are used for both audio and modulated r-f carrier measurements.

The transmitter is measured every

Figure 2. Equipment for measuring modulation and distortion consists of wave analyzer, beat-frequency oscillator, modulation meter, distortion and noise meter, range-extension filter, and cathode-ray oscillograph. These are conveniently mounted on a pair of relay racks as shown here.

Sunday night for distortion and noise. This test is expedited by the explanation in the routine book, and it requires only about fifteen minutes to make a complete set of measurements. The operations are as follows: First, the General Radio Type 713-B Beat-Frequency Oscillator is fed into the speech input equipment, and several levels are selected to provide 15%, 37.5%, 50%, 75%, 85%, and 100% modulation. At each level the distortion meter is used to determine the over-all distortion at a given audio frequency. Figure 1 illustrates this arrangement in block form. The equipment used for the test is shown in Figure 2. The test is repeated for various frequencies, namely, 50, 100, 400, 1000, 5000, and 7500 cycles. A noise measurement is also made, and positive and negative modulation peaks are checked on the Type 731-A Modulation Monitor. At the same time the modulated r-f carrier is observed on a cathode-ray oscilloscope. As was pointed out, this check is made weekly, but whenever a tube is removed in any of the modulated r-f stages, an additional check is made on that stage. This is made possible by coaxial lines which are brought to the measuring room from the 1st, 2nd, and 3rd power amplifiers as well as from a coil coupled to the impedance matching transformer, as illustrated in Figure 1. From previous measurements, each stage is known to perform in a given way, and any changes in its characteristics are immediately detected. Thus, distortion measurements have, in many instances, helped to prevent costly breaks during air shows.

The routine may seem a bit elaborate for a 15-minute test, but it is easily completed within the allotted time after the operations have been repeated a few times. Data sheets are supplied for the measurements, and, since all equipment is housed in one group of racks, all measurements and transmitter adjustments are made from the measuring room. Once each month an over-all check is made from the master control studio in New York, that is, a distortion check is made through the studio equipment to insure low line noise as well as low distortion in the studio equipment itself. Once each year a more comprehensive study is made with the General Radio Wave Analyzer. These checks are important and give the operator a feeling of security because everything is normal.

The routine for the 50 kw transmitter does not tell the entire maintenance story. Other important maintenance operations are carried out on short-wave broadcasting equipment. The many re-

Figure 3. Equipment used on the test bench includes impedance bridges, vacuum-tube voltmeters, standard-signal generators, and other general-purpose test instruments.

ceivers and portable transmitters require careful testing with adequate testing equipment to insure the continuity of short-wave broadcasts. To take care of the necessary maintenance of the short-wave equipment, as well as many other needs which have currently arisen from FM, a measuring bench was made to house these instruments.

Many instruments are capable of being utilized for a wide variety of tests. For example, the TYPE 605-B Standard-Signal Generator is used in almost every activity from alignment of short-wave receivers to field-strength measurements. In field-strength measurements the signal generator is used as a calibration oscillator in the 40-50 Mc band. For short-wave broadcasting it is used as an alignment oscillator for receivers in the high-frequency and ultra-high-frequency bands. It is used for the power source in r-f bridge measurements and for the measurement of all receiver characteristics. It is also used frequency modulated for oscilloscope studies.

The TYPE 650-A Impedance Bridge also has many applications. It is particularly useful in measuring condensers and resistors in the regular nightly maintenance routine on the 50 kw transmitter. For example, overload resistors have very low values, and ohmmeter measurements are unreliable if accuracy is desired. The impedance bridge does an excellent job of checking these component parts at WOR.

The General Radio TYPE 726-A Vacuum-Tube Voltmeter has been used to check r-f voltages on transmission lines; it assists in receiver alignment and is used to measure transmission line voltages in portable high-frequency transmitters.

The high-frequency and ultra-high-frequency transmitters are subject to the same scrutiny as is the standard broadcast transmitter. Distortion measurements, frequency runs, etc., are also made on these transmitters, even when the power radiated is as low as 0.2 watts. A maintenance schedule is necessary for short-wave broadcast equipment, as each transmitter is designed to be used under a number of different conditions. These transmitters are designed and constructed in the laboratory of WOR's Technical Facilities Division, each with different characteristics to meet different conditions. The frequency-response characteristics used with a given transmitter depend upon the background noise conditions. For example, the low frequencies need more attenuation in airplanes than in motor boats and submarines, and this requires that each type of broadcast be given separate consideration.

Many other instruments are used at WOR and, since it would require entirely too much space to explain their specific uses in detail, they are merely listed here. These instruments have an

FIGURE 4. Another view of the test bench showing the TYPE 650-A Impedance Bridge in use.

ever-increasing utility, and, after continual usage, they become almost indispensable.

1. Wave Analyzer
2. Audio Oscillator
3. Q Meter
4. Heterodyne Frequency Meter
5. Frequency-Limit Monitor
6. Standard-Signal Generator
7. A-C Vacuum-Tube Voltmeter
8. Impedance Bridge
9. R-F Bridge
10. Cathode-Ray Oscilloscope
11. Distortion and Noise Meter
12. Range-Extension Filter
13. Modulation Monitor
14. Beat-Frequency Oscillator
15. Capacity Bridge
16. D-C Vacuum-Tube Voltmeter
17. Field-Strength Measuring Set
18. D-C Amplifier and Recorder
19. Square-Wave Generator
20. U-H-F Standard-Signal Generator
21. Portable Cathode-Ray Oscilloscope

A modern broadcast station needs these instruments to attain the best possible conditions for efficient operation as it is felt that only through such a system can broadcasting provide a better public service.

CALIBRATING THREE-PHASE POWER-FACTOR METERS WITH THE VARIAC*

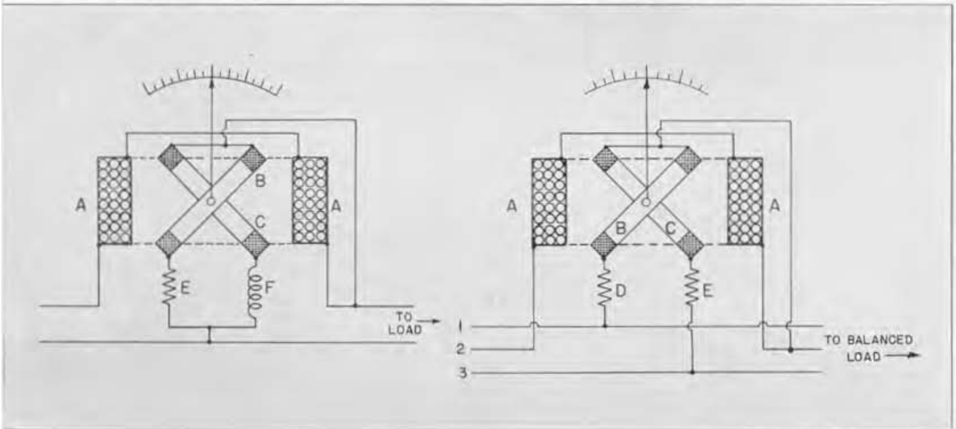
● **IT CAN BE SHOWN** that a single-phase source of controllable voltage plus a voltmeter to read the voltage is all that is necessary to calibrate three-phase electrodynamic power-factor meters, but, because of the usual difficulty of obtaining the variable voltage, it has been customary in the past to use ammeters, voltmeters, and a three-phase wattmeter on a three-phase line with a load to make this calibration. Since the Variac is a convenient device for varying the voltage easily and with negligible phase shift, it becomes an important aid in more easily calibrating these meters.

A description of the power-factor meter itself and its principle of operation will help show the method of using the Variac for calibration. Both single and polyphase power-factor meters have

*We are indebted to Mr. Paul McGahan of the Westinghouse Electric and Manufacturing Company for the original suggestion and details of this application.

FIGURE 1 (*left*). Schematic diagram of the single-phase power-factor meter.

FIGURE 2 (*right*). Schematic diagram of the three-phase power-factor meter.



a stationary series coil, A, and two movable voltage coils, B and C. The two moving coils are fixed with respect to each other, at an angle of 90°, but rotate freely with respect to the fixed coil. No springs or other restoring devices are used, and the only torque produced on the coils is that caused by the action of the electric fields produced when the instrument is connected to the power line. In the single-phase models the voltage is fed to one of the movable coils through a resistance and to the other one through a reactance, as shown in Figure 1. Thus the current through one coil is in phase with the line voltage, while the current is out of phase with the voltage by 90°. With this arrangement there is no torque between the latter coil, C, and the fixed coil at unity power factor, and

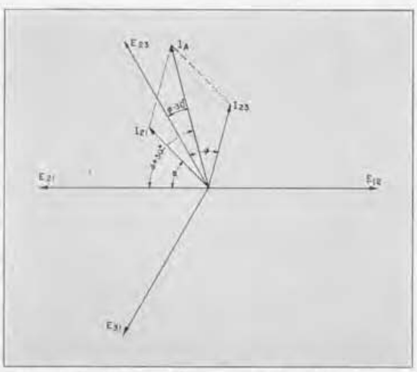


FIGURE 3. Vector diagram of the voltage and current relations in the three-phase power-factor meter. The current through the fixed coil is I_A, and the voltages across coils B and C are E_{21} and E_{23} respectively.

so the movable coil, B, orients itself parallel to the fixed coil. As the power factor decreases, the torque between the fixed and in-phase movable coil, B, decreases, while the torque between coil C and the fixed one increases. Thus, as the power factor decreases, the coils rotate farther and farther from the unity-

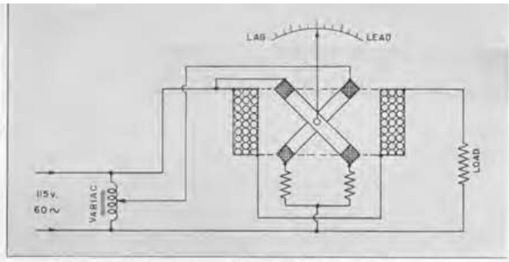


FIGURE 4. Diagram showing how the Variac is connected to the power-factor meter. With connections as shown, one-half the scale can be calibrated. By shifting the Variac to the other movable coil, the other half of the scale can be covered.

power-factor position before equilibrium is reached, until finally, at zero power factor, there is no torque between the inphase coil, B, and the fixed coil, and coil C aligns itself parallel to the fixed one.

In the three-phase power-factor meter, use is made of the different phase voltages instead of using a reactance to shift the phase between the two movable coils. Because of this arrangement, and the fact that only one line current is applied to the instrument, the three-phase instrument operates satisfactorily on the assumption of balanced load conditions only. Figure 2 shows the method of connection to the line and load. The equations for the torque produced between the various coils are:

Torque between A and B =

$$I_A \times E_{21} \times \cos(\theta + 30°) \times \sin AB$$

and torque between A and C =

$$I_A \times E_{23} \times \cos(\theta - 30°) \times \sin AC$$

where I_A is current through the fixed coil and E_{21} and E_{23} are the respective phase voltages. The phase angle of the load is θ, and the cosine terms represent the electrical angle between I_A and E_{21} or E_{23}, as shown in the vector diagram of Figure 3. The sine terms represent the mechanical angles between the moving and fixed coils. When the two torques are equal but opposite, the moving coils will come to rest, and their angles with respect to A can be determined from the two equations by equating them thus:

$$I_A \times E_{21} \times \cos(\theta + 30°) \times \sin AB = I_A \times E_{23} \times \cos(\theta - 30°) \times \sin AC$$

$$\text{or} \quad \frac{E_{21}}{E_{23}} \times \frac{\cos(\theta + 30°)}{\cos(\theta - 30°)} = \frac{\sin AC}{\sin AB}$$

Thus it will be seen that only when the load is balanced and E_{21} equals E_{23} can the mechanical angle of the movable coils be calibrated in terms of the phase angle. It will also be seen from the equation that the mechanical angle can be changed, for a given phase angle, by varying E_{21} and E_{23} with respect to each other. This fact points to the new method of calibration — keeping θ fixed and at zero while varying the ratio E_{21}/E_{23}. The diagram of Figure 4 shows how the Variac and power-factor meter are connected for this method.

The ratio E_{21}/E_{23} need only be set equal to the ratio $\frac{\cos(\theta + 30°)}{\cos(\theta - 30°)}$ to make the movable coils rotate to the proper angle for a phase angle θ. Hence, we can make up the table shown below.

The negative values indicate a change in phase of 180°, but, since most power-factor meters are calibrated from 50% lag through 100% to 50% lead, the low power factors are of lesser importance. Below is a connection diagram showing how half the scale would be calibrated. By changing the Variac to the other movable coil the other half of the scale would be covered.

% PF $\cos\theta$	θ	$(\theta + 30°)$	Cos $(\theta + 30°)$	$(\theta - 30°)$	Cos $(\theta - 30°)$	$\frac{\cos(\theta+30°)}{\cos(\theta-30°)}$	E_{21} % of Normal	E_{23} % of Normal
0 lead	−90°	−60°	.500	−120°	−.500	−1.	100	−100
30 lead	−72°32′	−42°32′	.740	−102°32′	−.213	−3.47	100	−28.8
50 lead	−60°	−30°	.866	−90°	0	0	100	0
70 lead	−45°34′	−15°34′	.964	−75°34′	.253	3.80	100	26.3
100	0°	30°	.866	−30°	.866	1.	100	100
70 lag	45°34′	75°34′	.253	15°34′	.964	.263	26.3	100
50 lag	60°	90°	0	30°	.866	0	0	100
30 lag	72°32′	102°32′	−.213	42°32′	.740	−.288	−28.8	100
0 lag	90°	120°	−.500	60°	.500	−1.00	−100	100

— Martin A. Gilman

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