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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

BRIDGE METHODS FOR MEASUREMENTS AT RADIO FREQUENCIES

IN the development of measuring methods simple circuits involving, so far as possible, only the units under measurement are at first used, and as experience and technique improve, more elaborate but more convenient and flexible methods are developed.

The earliest methods of measuring resistance were the voltmeter-ammeter and later the substitution methods. Bridges, which increased the sensitivity of the substitution method by introducing a differential comparison and extended its range by using ratio arms, naturally developed from the substitution method. Bridges are now universally used for direct-current and audio-frequency measurements.

In the higher frequency ranges, voltmeter-ammeter methods have been extensively used. At radio frequencies (say 100 kc. to 2 Mc.), the tuned-circuit substitution method is generally favored. In this measurement the unknown resistance is replaced in a tuned circuit by a standard which is adjusted to give the same voltage drop at constant current as the unknown. The object of the tuned circuit is to reduce the effect of reactance on the measurement.

Bridge methods have several advantages over voltmeter-ammeter and tuned-circuit substitution methods. They are not limited to narrow frequency ranges, and they grant more latitude in the choice of standards. They involve, however, the introduction of other circuit elements into the measurement and are, therefore, justly viewed with some suspicion when used under conditions where the values of the additional circuit elements are not entirely known.

The essential difficulty with measurements at high frequencies lies in the fact that the circuit elements of inductance, capacitance, and resistance cannot be individually isolated but are present together in all circuit units, and between the units themselves, as well as between units and ground. Most of the technique of alternating-current bridge methods involves the development of circuit units whose characteristics approach lumped constants and means of eliminating the effect of residuals from the measurement.

Leads, also, which are ignored at lower frequencies, may have impedances approaching in magnitude those under measurement. These problems, it should be observed, are present at 1000 cycles, although too frequently ignored. In any bridge method it is necessary to distinguish between a balance of the bridge and a balance between the unknown and standard elements. The effect of residuals is frequently such as to give a false balance involving unknown and extraneous impedances.

Bridges have been used at frequencies well above the audio-frequency range, and there is no question that with proper care bridge measurements can be used at very high frequencies.

The main difference between measurements at audio and radio frequencies is summed up in the one-thousand-fold increase in series inductive reactance and the corresponding decrease in parallel capacitive reactance. This means that distributed inductance and capacitance which were entirely negligible at audio frequencies frequently have controlling influence at frequencies of the order of one megacycle.

The absence of proper standards offers as great an obstacle to high-frequency bridge methods as the difficulties inherent in the bridge circuit itself. Resistance standards usually have some reactance at high frequency, and reactance standards have resistance.

Air condensers have the smallest time constants of any impedance element and their law of variation with capacitance and frequency is known. They may be either fixed or variable. Solid dielectric mica condensers may be made which also have a small time constant varying only with frequency. Fixed straight wire resistors have very small time constants, which can be calculated provided the wire used is non-magnetic. Resistors of the bifilar, Ayrton-Perry, mica-card, and woven-tape forms also have small time constants. Their equivalent series inductances and time constants are independent of frequency over a wide range. They cannot, however, be calculated, but must be compared with the straight wire standards. Variable resistors are inferior to fixed resistors because of the added reactance of the switching mechanism. Inductors make poor radio-frequency standards, since their time constants are large and variable, depending upon skin effect and the characteristics of the iron core if one is used.

Their natural frequencies are low and variable inductors show variation of resistance with setting. They must be compared with standard condensers.

In considering bridge circuits for radio frequencies it is the natural course to select simple circuits and those having similar elements permitting a symmetrical arrangement. The equal-arm bridge should be used, although this limits the usefulness of the bridge method somewhat. It is not too difficult to make similar units having practically identical lumped and distributed constants, but to make dissimilar units in which the lumped and distributed constants bear like ratios is far more difficult. Equal resistances are normally used for the ratio arms, although capacity ratio arms can be used.

An elementary bridge circuit suitable for use at radio frequencies is shown in Fig. 1. It consists simply of the two fixed ratio arms, the shielded input transformer, and terminals for standard and unknown impedances. This diagram is, of course, exactly what would be used at audio or lower frequencies. The modifications necessary for high-frequency use lie entirely in the arrangement of parts and leads and the shielding which is required.

While this elementary bridge circuit can be reasonably well balanced at 1000 cycles, at higher frequencies a double balance is necessary in order to eliminate all factors of stray capacitance. Two methods of accomplishing this offer themselves. One is the addition of a Wagner ground circuit by means of which the capacitances to ground are first balanced before obtaining a balance of the main bridge. A second arrangement is the substitution method which is, of course, extensively used in precision measurements at 1000 cycles. In this method, the unknown and standard are placed in parallel in the same side of the bridge and balanced in the other arm by an uncalibrated condenser which must, however, possess reasonably good characteristics. The bridge is balanced once with the unknown disconnected and again with the unknown shunted across the standard. The technique is the same as that used at lower frequencies, except that greater care must be taken and it is particularly important that the arrangement of leads be unchanged for the two balance conditions. The resistance balance is obtained by adding resistance in series or parallel with the capacitance arms. When the added resistance is changed between measurements, correction must be applied for the change in inductance of the resistance unless it can be established that this is negligible. In calculating results from the bridge measurements at high frequencies it is important to use the original bridge equations before eliminations based on orders of magnitude have been made. These equations may be easily derived or are given in most textbooks on bridges. Many of the order-of-magnitude eliminations do not hold at high frequencies.

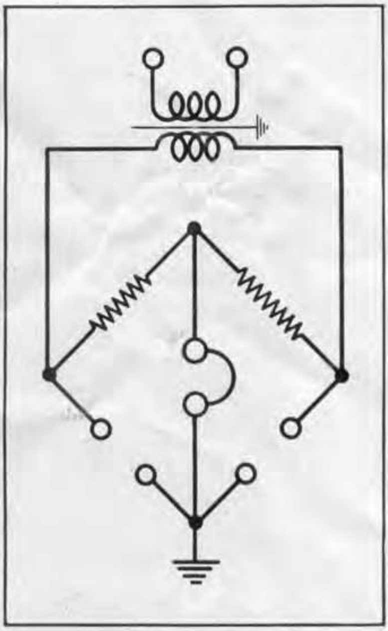


FIGURE 1. Basic bridge circuit commonly used at audio frequencies and suitable for radio-frequency work if precautions are taken

In an endeavor to test out the practicability of bridge methods at radio frequencies, the General Radio Company has developed the TYPE 516-A

FIGURE 2. The new TYPE 516-A Radio-Frequency Bridge, an experimental instrument for the determination of reactance and resistance at high frequencies. Its use is recommended for laboratories having a considerable experience with other methods for measuring impedance

Radio-Frequency Bridge. This is illustrated in Figures 2 and 4 and the wiring diagram is shown in Figure 3.

The entire bridge is enclosed in one shield, while separate internal shields enclose the ratio arms, the balance condenser, the power-factor balance resistor, and the output transformer. The latter also contains a shield between primary and secondary.

The shielded transformer is placed in the output of the bridge, so that at balance it will have no current in it and no external field. It is an air-core transformer with concentrated windings, whose capacitances to each other and to the shield have been minimized. By a suitable choice of the number of turns the band of frequencies between 10 kc. and 5 Mc. may be covered. The ratio arms are 100 ohms each. Low-impedance elements are a requirement of high-frequency measuring circuits. These arms are wound on thin mica cards. Both transformer and ratio arms are mounted on plug-in bases so that they may be transposed or new ones inserted. The balance condenser has a capacitance of 1000 $\mu\mu$f and is provided with a slow-motion friction drive. A small vernier condenser of 15 $\mu\mu$f allows the adjustment of the total capacitance to 0.01 $\mu\mu$f. The variable resistance for power-factor balance has three dials, tens and units decades, and a non-inductive slide wire having a total resistance of one ohm and reading to 0.01 ohm. The zero inductance of this 3-dial resistance unit is only 0.2 microhenrys and the maximum inductance 1.1 microhenry. The leads from the condenser and resistor are brought to a terminal board located in a shielded compartment accessible from the front panel so that they may be connected in series or parallel or used separately.

The measurements are most easily made with a modulated carrier as a power supply and a detector and audio amplifier as a null indicator. An alternative method is to use an unmodulated oscillator, heterodyne to it, and use the rectified audio beat note as a null indication. It is essential that there be no pickup between oscillator and amplifier. Both must, therefore, be well shielded. The shielding of the oscillator must be comparable to that of a good standard-signal generator. Either the TYPE 403-D or TYPE 603-A Standard-Signal Generator is suitable.

Higher powers than are available from the signal generator will add to the sensitivity of the measurements and to the speed with which the balance can be obtained. An oscillator having an output of about 25 milliwatts modulated to 50% is being developed. This instrument will maintain about one volt across the bridge at frequencies between 20 kc. and 20 Mc. It is completely shielded and uses toroidal coils, so that its external field is very small.

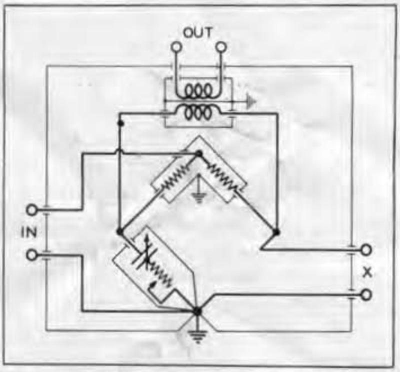


FIGURE 3. Schematic diagram of the TYPE 516-A Radio-Frequency Bridge. The heavy lines represent the bridge elements, the light line the shields

The most available null detector in the broadcast range is a standard receiver of good sensitivity. Commercial superheterodyne receivers having a 10-microvolt sensitivity are entirely satisfactory. Using such a receiver at full sensitivity and merely listening to the loud-speaker, the bridge can be balanced to one part in 100,000 for capacitances of the order of 1000 $\mu\mu$f and to one part in 10,000 for resistances of the order of 100 ohms. These measurements were made in an unshielded room and there was noticeable outside pickup in the receiver.

Measurements have been made with this bridge at a frequency of 1 Mc. by a substitution method, using an external

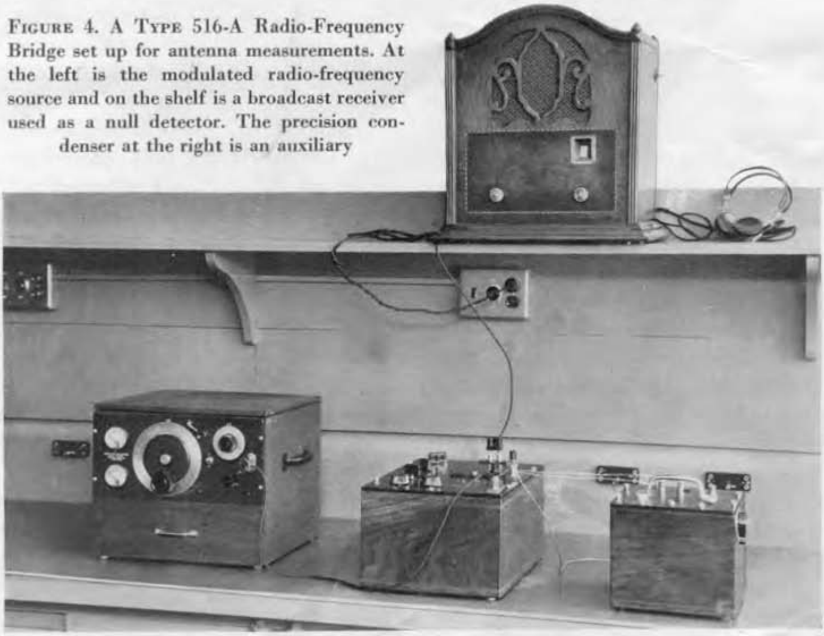
Type 222 Precision Condenser and either the decade resistor in the bridge or a similar external one. The impedances measured have included the capacitance and resistance of air and mica condensers, varying from 100 $\mu\mu$f to 1000 $\mu\mu$f, the resistance and inductance of resistors varying from 1 to 10,000 ohms, and the resistance and reactance of an antenna whose natural frequency was 1.2 Mc. over the broadcast frequency range. The antenna measurements were interesting in showing that the voltages induced in fairly large antennae may approach a volt in magnitude. It is, therefore, desirable that the voltage applied to the bridge be at least of this magnitude and preferably larger, so that measurements may be made at all points.

The Type 516-A Radio-Frequency Bridge has been developed to permit the investigation of the possibilities of bridge circuits at radio frequencies. It will not be regularly carried in our catalog because we feel that an experience in high-frequency measurements which is not possessed by the average experimenter is required in order to obtain satisfactory results with it. It will be available in stock, however, and offers an interesting and useful tool for those possessing wide experience in the technique of high-frequency measurements.

The price of the Type 516-A Radio-Frequency Bridge is $190.00.

— Charles T. Burke

Figure 4. A Type 516-A Radio-Frequency Bridge set up for antenna measurements. At the left is the modulated radio-frequency source and on the shelf is a broadcast receiver used as a null detector. The precision condenser at the right is an auxiliary



MEASURING PENTODES WITH THE MUTUAL-CONDUCTANCE METER

THE Type 443 Mutual-Conductance Meter, developed several years ago for testing triodes, can be used equally well with four-element tubes. After a minor modification (which every unit in our stock now includes) both heater-type and filament type pentodes can be measured.

One of the modified mutual-conductance meters with the batteries connected for measuring a filament-type pentode is shown in Figure 1 and the corresponding circuit in Figure 2. The connecting links to the new binding posts, engraved "+" and "—", marked Pentode Screen, have been installed in the left side of the panel. The cathode circuit has been broken and its two ends connected to the new posts. The screen grid of a filament-type pentode is connected to the prong corresponding to the cathode of heater-type tubes. Tests in our laboratory have shown the necessity for a source of voltage for the screen separate from that for the plate in the filament-type pentode such as the 247. The connections for the screen grid are, therefore,

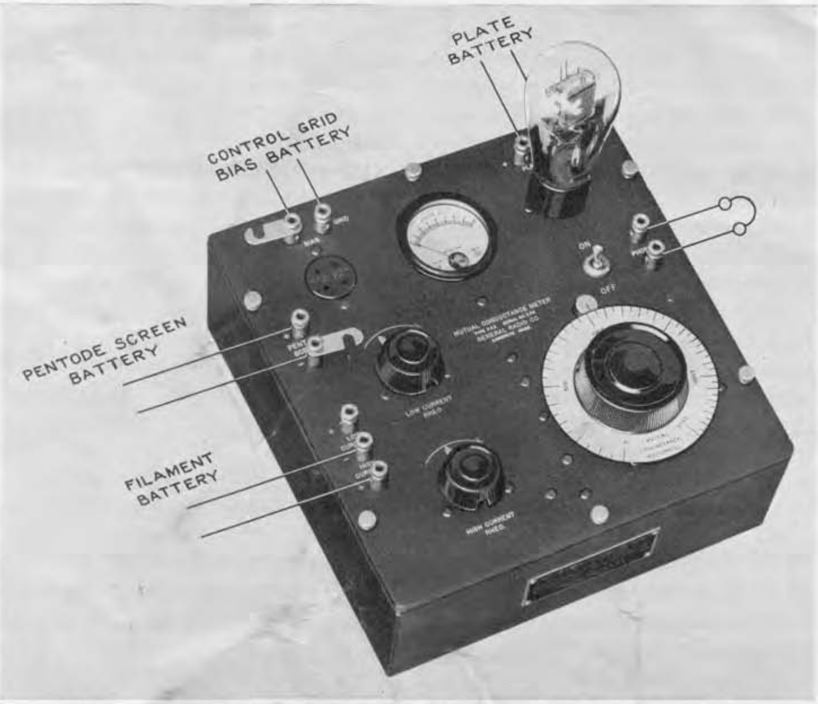


Figure 1. The Type 443 Mutual-Conductance Meter modified for checking filament-type pentodes. Connections for heater-type pentodes are the same as for screen-grid tubes; the pentode-screen terminals are closed by the link

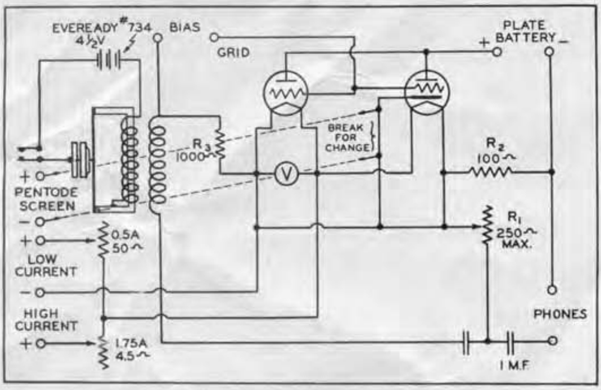


FIGURE 2. The dotted lines in this diagram show the change in wiring necessary to make the TYPE 443 Mutual Conductance Meter suitable for measuring pentodes

made to the two new binding posts.

For the measurement of the heater-type pentode tubes the connecting link is left in place and battery connections are made as if a screen-grid tube were being measured. Detailed instructions concerning this are found in the instruction book accompanying the instrument or in the General Radio *Experimenter* for July-August, 1930.

The charge for the modification is \$3.20 net, and it would require about a week before return shipment could be made. If a mutual conductance meter is to be returned for this change, we suggest that it be packed very well in a wooden case to prevent damage in transit and shipment made by express prepaid.

There are still available in our stock a few of the TYPE 443 Mutual Conductance Meters that have been modified for the measurement of pentode tubes. The price is \$27.00 each and immediate shipment can be made upon the receipt of an order.

— H. H. DAWES

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THE GENERAL RADIO COMPANY mails the Experimenter, without charge, each month to engineers, scientists, and others interested in communication-frequency measurement and control problems. Please send requests for subscriptions and address-change notices to the

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