Simple RF Impedance Bridge Checks Amateur Aerials to 432MHz

Here is a further accessory for the author's VHF Powermatch measuring system. If carefully constructed, it is capable of useful measurements on all bands up to and including 432MHz. The author explains in detail how the instrument may be used not only to measure the resistance of an aerial, but also its reactance.

The most rapid and convenient way of checking the impedance matching of an aerial is to measure its SWR, using such instruments as an SWR reflectometer or a slotted line. Instruments of this type can thus be of great value to the radio amateur, and it was for this reason that a reflectometer and a slotted line were included in the VHF Powermatch system. (For those who missed the article, it was in the April issue.)

Unfortunately there are situations where the SWR-reading type of instrument is not of very much help. The most common such situation is where an aerial is known to be mismatched, and the amateur desires to improve matters. Because the SWR only indicates the degree of mismatch, and not the direction in which the impedance error lies, it can only be used to monitor the effect of "cut and try" alterations.

What is really needed in this type of situation is an instrument which can give a reasonably clear picture of the actual impedance of the aerial, ideally in terms of both its resistive and reactive components. Only with this information can the amateur analyse the mismatch and plan to correct it in a "scientific" manner, with a correspondingly higher likelihood of success.

In general, three different methods have been used by radio amateurs to measure aerial impedance. Probably the most popular way is to use an RF impedance bridge, in one of the many forms which have been described. Another method, which is growing in popularity, is to use an instrument known as an "aerial noise bridge". The third method is the so-called "triangulation" approach, where the impedance of the aerial is calculated after comparing either its RF current or voltage drop with that of a (hopefully) pure resistance connected in parallel or series, and with the total current or voltage drop associated with the combination.

All three of these methods are capable of giving much the same information and in the forms generally used by amateurs they are probably capable of giving roughly the same order of accuracy. But each tends to have its own advantages and disadvantages.

The RF impedance bridge has the useful facility that it may be used to cut co-axial cable to accurate electrical quarter-wave and half-wave lengths, at any desired test frequency. This can be very worthwhile when the amateur has to make up baluns and other matching devices. Its disadvantages are that it needs a low-power transmitter or other source of RF to supply drive, is not really suitable for use at VHF and UHF in many of the forms described, and similarly is not usually capable of giving reliable information regarding the reactive component of aerial impedance.

The aerial noise bridge or ANB is a recent variant of the conventional RF bridge which uses a generator of wide band "white" noise in place of the usual low-power transmitter. It also uses the amateur's own receiver in place of the detector and meter combination. The fact that the receiver provides the bridge with a tuneable detector makes the ANB particularly useful and convenient for finding the actual resonant frequency of an aerial.

Like the normal RF bridge, the ANB may also be used to cut cables into accurate electrical quarter-wave and half-wave lengths. However it shares two of the same disadvantages: it is not easily adapted for use at VHF and UHF, and does not easily permit measurement of aerial reactance.

While a little less convenient than the other two methods, the triangulation approach has the advantage that it does permit relatively easy calculation of aerial reactance. In fact this is its main justification. On the debit side, it is if anything even less suitable for VHF and UHF work than either of the other two methods. It does not allow convenient measurement of the resonant frequency of an aerial, nor can it be used readily to cut cables into electrical quarter- and half-wave lengths.

The impedance measuring device to be described in this article, as part of the VHF Powermatch system, is of the standard RF impedance bridge type. This approach was finally selected by the author in preference to the other two, for the following reasons: It seems to offer the best compromise as far as simplicity, low cost and usefulness are concerned, and it also seems to be the approach which lends itself most readily to adaptation for use at VHF and UHF.

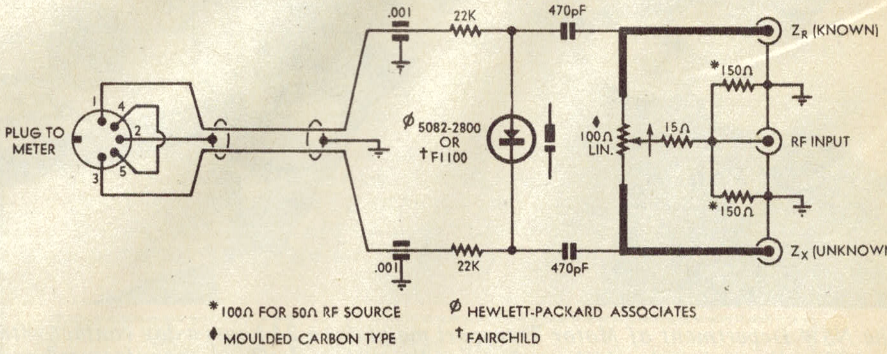
Much of the inspiration for the design of the unit has been provided by a unit described in the VHF-UHF Manual, published by the RSGB. The RSGB design is for a fixed ratio bridge which employs a very carefully planned and highly symmetrical physical layout to ensure reliable balancing of stray reactances. It is claimed to be capable of making useful measurements up to 432MHz, and there is no reason to believe otherwise. However, the fact that its bridge ratio is inherently fixed would seem likely to limit its usefulness.

In developing the present design, what the author has done is to use the same basic idea of a carefully designed and highly symmetrical bridge, but adapt it to produce a more flexible variable-ratio instrument. At the same time the physical construction has been considerably simplified, and the size reduced. The author has also developed a relatively simple way of using this type of bridge to measure aerial reactance – but more about this aspect later.

As may be seen from the circuit, the unit is electrically quite simple, using a mere handful of components. It is basically nothing more than the familiar Wheatstone, whose arms are formed by the two sections of the 100-ohm pot, the known impedance Zr, and the unknown impedance Zx. The known impedance Zr may be nothing more than the 75-ohm or 50-ohm dummy load in the basic VHF Powermatch.

It is the particular bridge configuration used, and the components, which distinguish the unit from others and make it suitable for use at VHF and UHF.

Note that the configuration of the bridge is such that the "earthy" sides of the known impedance Zr, the unknown impedance Zx (ie, the aerial), and the RF input to the bridge are all commoned, and connected to the case



RF IMPEDANCE BRIDGE

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The circuit of the bridge, which uses only a handful of components. If carefully constructed according to the instructions given in the article, it is capable of making reliable measurements to beyond 432MHz.

by JAMIESON ROWE

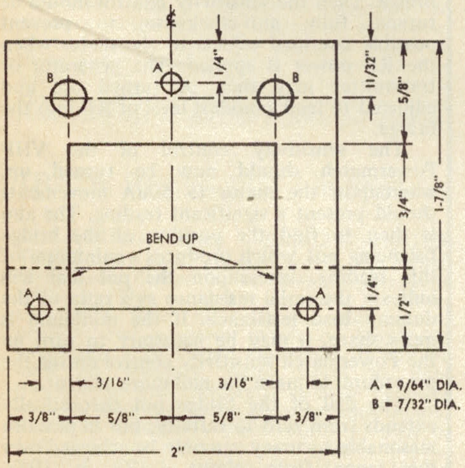
of the unit. The common "earthy" point forms the "bottom" of the bridge. This arrangement is ideal for an RF bridge because it allows co-axial cables to be used to connect both known and unknown impedances to the bridge, and also to connect the bridge to the source of RF. It also allows relatively easy balancing of the stray bridge reactances.

The RF input to the bridge is terminated, to ensure that the feed cable is relatively free from standing waves – a high SWR on the feed cable could upset measurements by disturbing earth potentials. Two 150-ohm resistors are used in parallel where the RF source has an impedance of 75 ohms, or alternatively two 100-ohm resistors where the source impedance is 50-ohms. From the termination the RF is then fed to the moving arm of the 100-ohm bridge pot via a 15-ohm isolating resistor.

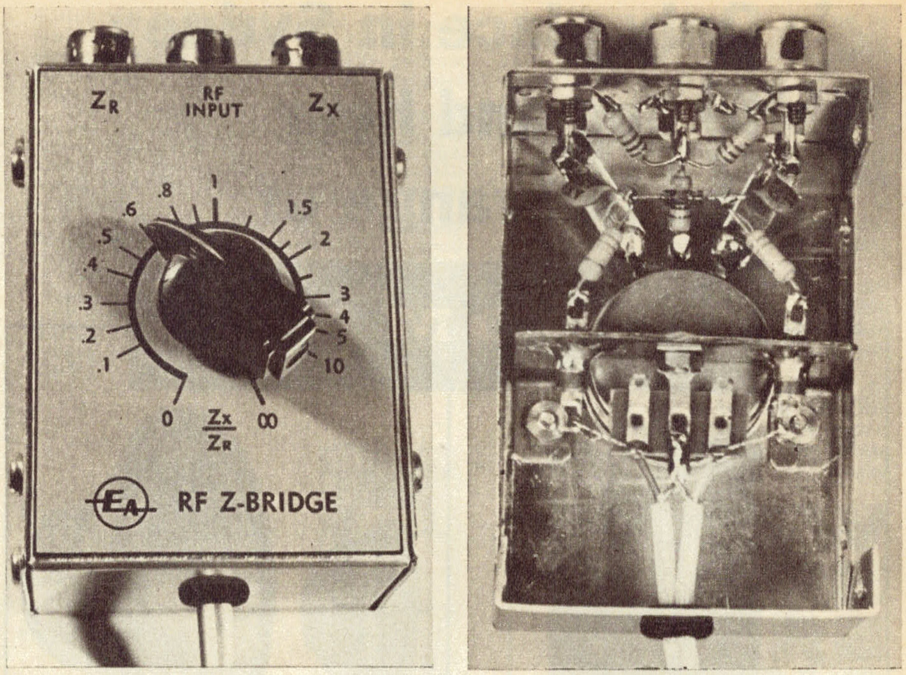
Naturally, because the bridge configuration has been arranged to permit earthing of one side of the RF input, this means that neither side of the detector may be earthed. A symmetrical diode detector circuit meets this requirement quite easily, as may be seen. The detector is basically the same as the familiar "shunt diode" half-wave detector, but has both the input capacitor and the series resistor effectively "split in two". Feedthrough capacitors are used at the output or "cold" ends of the 22K series resistors, from where the DC output of the detector is taken by cable to the VHF Powermatch.

The components used in the bridge and their physical layout are almost as important as its electrical configuration in determining the performance at VHF and UHF. As may be seen from the photographs, the physical construction has been chosen to minimise the length of interconnections, and to make the layout as compact and as physically symmetrical as possible.

The unit is constructed in a low-cost aluminium utility case which measures 3¼in x



A dimensioned drawing of the bracket which supports the feedthroughs.



Outside and inside views of the bridge, reproduced only slightly smaller than actual size. Great care must be taken to ensure accurate physical symmetry of the wiring if the unit is to give valid results at UHF.

2¼in x 1½in. The three co-axial connectors for the known and unknown impedances and the RF input are mounted side by side on one end of the case, with the RF input connector in the centre. The bridge ratio pot is mounted in the centre of the case, with its terminal lugs facing the co-axial connectors to ensure short connections. A cut-out bracket mounted centrally above the pot carries the feed-through capacitors and a small tagstrip to terminate the output cable.

The pot should be a low reactance moulded-track carbon type, and definitely not a wire-wound type. The prototype unit employs a high-grade moulded track pot kindly supplied by the Imported Components Division of Plessey Ducon Pty Ltd. We understand that identical units are available from this firm on order from trade suppliers.

The connections between the outer lugs of the pot and the spigots of the outer co-axial connectors should be made using metal strips, to reduce lead inductance. The strips in the prototype were ¼in wide, and were cut from 18G brass sheet. Before being soldered in place they were carefully bent into the same shape. They were also soldered in position with great care taken to ensure physical symmetry.

The RF input terminating resistors have their leads cut short and are soldered from the centre spigot of the centre co-axial connector to solder lugs clamped under the mounting screws of the two outer connectors. These lugs are connected to a similar lug clamped under the adjacent mounting screw of the centre connector, to ensure a reliable earthing bond. The RF terminating resistors are also positioned to ensure physical symmetry.

From the spigot of the centre co-axial connector, the 15-ohm RF isolating resistor connects to the centre lug of the pot. This resistor should have its leads cut to minimum length, and be positioned as centrally as possible to ensure balanced coupling to the remainder of the bridge wiring.

As may be seen, the 470pF detector input capacitors also have minimum-length leads, and connect to the bridge circuit directly at the spigots of the Zr and Zx co-axial connectors. The detector diode also has its pigtails cut to minimum length, and is soldered between the two capacitors. When soldering to the diode, a pair of long-nosed pliers or a surgical "mosquito" should be used to prevent overheating.

Although perhaps not essential, it is advisable to use a hot-carrier or Schottky-barrier diode in the unit if operation is to be maintained up to 432MHz. In the prototype unit we used the Hewlett-Packard type 5082-2800 device, as used in the other VHF Powermatch accessories, which is available by mail order from Hewlett-Packard Australia Pty Ltd. In NSW the address is 61 Alexander Street, Crows Nest, 2065, while in Victoria the address is 22-26 Weir Street, Glen Iris, 3147.

Other hot-carrier devices may also be suitable, such as the Fairchild type FH1100 or FH1200. These have lower breakdown voltages, but should be quite satisfactory at the low power levels handled by the RF bridge.

The 22K detector isolating resistors connect from each end of the diode to the nearby lugs of the .001uF feedthrough capacitors, to complete the basic wiring of the bridge. Again, care should be taken to ensure that these components are mounted symmetrically to ensure close balancing of the stray reactances. Connection of the output cable to the small tagstrip on the rear side of the feedthrough bracket then completes the unit, apart from the fitting of a top panel and knob.

Copies of the prototype front panel have been supplied to metal work manufacturers, so that these firms should have ready-made front panels available shortly. Actual-size bromide prints of the panel are also available via the Information Service, for those readers who prefer to "roll their own".

How is the bridge used? This will now be explained. The setup for measuring the resistive component of aerial impedance is basically the same as for any RF bridge, and is shown in figure 1. The detector output cable of the bridge is connected to the VHF Powermatch metering circuit, the Zr socket is connected to the dummy aerial of the Powermatch, and the Zx socket to the aerial to be measured – via a cable whose length should be either a half-wavelength, or a multiple of this length, allowing for the cable velocity factor.

Unless the cable between the aerial and bridge is a half-wavelength or a multiple of this length, the impedance reflected by the cable at the bridge may well be quite different from that of the aerial, making the measurement invalid. Needless to say, the cable should not involve a larger number of half-wavelengths than is necessary to permit convenient measurement with the aerial at a suitable distance from large metal objects, etc. This is because with a long cable, the cable losses will again tend to falsify the results.

The source of RF power connected to the centre socket of the bridge may be either a signal generator, or the amateur's transmitter for the band concerned. In the latter case it may be necessary to make a temporary

PARTS LIST

1 Utility case, 3¼in x 2¼in x 1½in.
1 Front panel to suit (see text).
3 Co-axial sockets.
1 100 ohm lin moulded track carbon potentiometer (see text).
1 Hot-carrier diode, type 5082-2800 or FH1100 or similar.
2 .001uF ceramic feedthrough caps.
2 470pF disc ceramic capacitors.
1 15 ohm ½ watt carbon resistor.
2 150 ohm or 100 ohm carbon resistors (see text).
2 22K ½ watt resistors.
1 5-pin DIN plug.
1 3-lug miniature tagstrip.
Length of twin shielded cable, scrap brass for bracket and connection strips, nuts, bolts, grommet, instrument knob, etc.

modification to the transmitter to reduce its output, in order to prevent damage to the bridge components. The RF power fed to the bridge should be in the order of one to two watts.

The procedure is quite straightforward. The function switch of the Powermatch should first be set to the "DIF" position, to suit the balanced detector circuit used in the bridge. Then the sensitivity control should be turned fully anti-clockwise, to prevent possible overload effects to the meter when the RF power is applied. The generator or transmitter may then be turned on, and adjusted to feed a modest level of RF into the bridge.

The sensitivity control of the VHF Powermatch should now be turned up, whereupon the meter (a 50uA movement) should present a significant reading. The aim is then to find the position of the bridge balancing pot which produces a minimum of this reading, whereupon the pot dial will indicate the aerial resistance as a ratio of the dummy load resistance. If the minimum is quite sharp, it may be necessary to turn up the Powermatch sensitivity control during the procedure, to make the null more evident.

The dial of the bridge pot theoretically extends from zero to infinity, but in practice reasonable accuracy can only be achieved over the range from about 0.1Zr to 10Zr. Accordingly the pot scale has only been calibrated over this range, as may be seen.

Nevertheless this gives a very useful range – from 7.5 ohms to 750 ohms for a 75-ohm dummy load as reference, or from 5 ohms to 500 ohms with a 50-ohm load.

When used in the foregoing way, the instrument is capable of giving quite accurate readings of the resistive component of aerial impedance. It may be used for this purpose with equal success on the VHF and UHF bands up to and including the 432MHz band, and on the lower HF bands. In fact there is no reason why it may not be used to measure the RF resistance of any aerial for any of the bands between 1.8MHz and 432MHz, providing a suitable source of RF is available, and the appropriate cables are made up.

Like all similar instruments, however, it is not in its basic form capable of dealing satisfactorily with any reactive component which may be present in the aerial impedance. If the reactive component is significant, the balancing null of this type of bridge tends to become broad and ill-defined, making measurement somewhat difficult.

Happily, there are ways of extending the use of the basic instrument which avoid this problem, although these methods are not widely known. In fact it is possible not only to arrange for the bridge to be balanced properly in the presence of significant aerial reactance, but also to make a measurement of the reactance. The methods which allow this are not complex, as the writer will now explain. They involve only a few extra cables and connectors, and one or more calibrated variable capacitors.

The basic idea is quite simple. All that is done is to balance out the aerial reactance using a variable capacitor, so that the phase angles of the known and unknown bridge impedances Zr and Zx become equal. This restores the sharpness of the bridge null, to make an accurate measurement again possible; and if the variable capacitor is calibrated, this makes it possible to obtain an accurate measure of the aerial reactance at the same time.

The variable capacitor to be used for the purpose should be mounted in a small box or "U" bracket with two co-axial connectors, as shown in the diagram of figure 2. For VHF and UHF work the capacitor need only be of low value – say 50pF or 100pF maximum. A larger value would be more appropriate for HF work, say 300pF or 400pF. The box should be of compact dimensions to ensure that the connections between the capacitor and the co-axial sockets may be as short as possible. In any case it is a good idea to make the connections with a triangular plate of brass or tinplate, if the unit is to be used at VHF and UHF.

The way in which the capacitor is connected into the circuit depends upon the form of the aerial reactance. If the aerial has a capacitive reactance component, then the connection of figure 3 will be appropriate. Here the variable capacitor is effectively connected in parallel with the dummy load, and is used to provide a capacitive reactance component for Zr, to balance that of the aerial.

If on the other hand the aerial reactance is inductive, then either of the connection methods shown in figure 4 will be appropriate. Method A is perhaps the more convenient, especially for HF use. Here the capacitor is used to effectively cancel or tune out the aerial reactance, thus converting Zx into a pure resistance as far as the bridge is concerned.

Method B is an alternative approach which becomes practical at VHF and UHF. Here the variable capacitor is connected into the dummy load or Zr side of the bridge, as in figure 3, but in this case via a quarter-wave section of line. The action of this section of line is to effectively convert the capacitor into a complementary inductor.

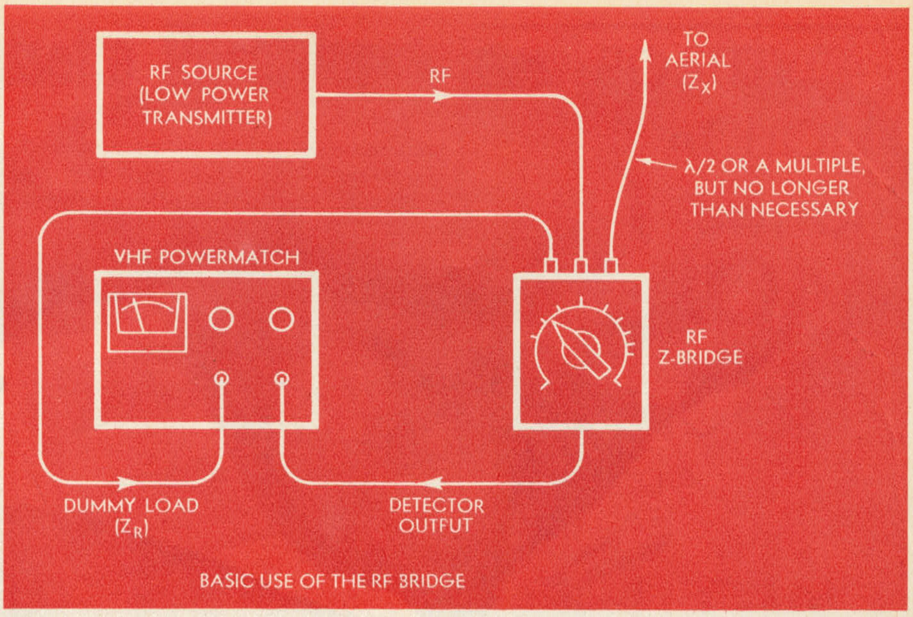


Figure 1: The way in which the bridge is connected up for measurement of the resistive component of aerial impedance. The RF source should deliver no more than about two watts, to prevent damage to the bridge components.

It may be recalled from theory that the action of a quarter-wave section of transmission line is to cause any impedance connected at one end to appear at the other as its "complementary" impedance, whose value may be found by dividing the original impedance into the square of the characteristic impedance of the line.

When the original impedance is an essentially pure capacitor, as we have here, the impedance reflected at the other end is virtually a pure inductor, whose reactance may be found from the expression

$$X1 = \frac{Zo^2}{Xc}$$

where X1 is the effective inductive reactance, Zo is the characteristic impedance of the cable used, and Xc is the reactance of the variable capacitor at the frequency concerned. All three are understood to be measured in ohms.

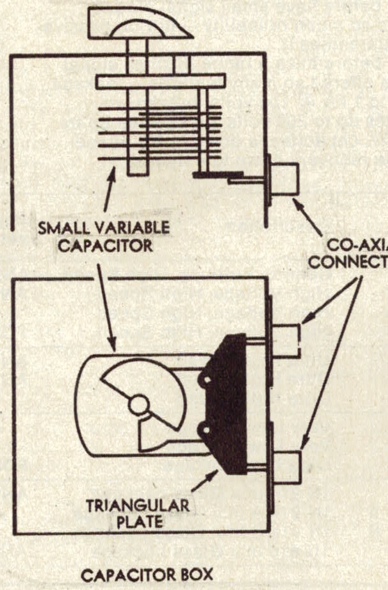


Figure 2: Construction of a variable capacitor box for reactance tests.

At this stage the reader may well be asking himself the obvious question – how does one know whether the aerial reactance is capacitive or inductive, in order to select the correct position for the capacitor? The answer to this is that one does not know initially. The technique is in fact one of finding this out by trial and error, whereupon the correct position becomes evident as the one which produces a deepening of the bridge null.

The procedure is as follows: When a measurement using the basic bridge setup of figure 1 reveals that there is a significant aerial reactance, as indicated by a very broad and ill-defined null, the capacitor box is added to the system on the dummy load side, according to figure 3. It is then an easy matter to add capacitance to the dummy load, and note whether the null of the bridge becomes deeper or less deep. Some re-adjustment of the main bridge balance pot may be necessary, to ensure that the bridge "tracks" properly towards a fully balanced state (the null tends to move slightly as the reactance is balanced out).

If the null of the bridge increases in depth with the capacitor in this position, then the aerial reactance must clearly be capacitive. The procedure is then simply a matter of manipulating both the bridge pot and the capacitor to produce the deepest possible null. When this condition has been reached, the bridge dial reading will give the resistive aerial component as before, while the capacitor gives the capacitive reactance.

On the other hand if the null becomes less deep with the capacitor in the position shown in figure 3, then it is equally clear that the aerial reactance must be inductive. The procedure is then to change the setup to one of those shown in figure 4, and again manipulate both bridge and capacitor to produce the deepest null.

As before, when the deepest null position is found the bridge pot dial will give the resistive component of aerial impedance, while the inductive reactance may be calculated from the capacitor value. If method A of figure 4 is used, the inductance of the aerial is simply that value which resonates with the capacitor at the frequency being used. Alternatively if method B is used, the inductive reactance may be calculated using the simple expression given earlier.

It may have been noted that in the diagrams of figures 3 and 4 a recommended length of one half-wave is again shown for certain of the connecting cables. Unless the cables are of this length, the impedances reflected by the aerial and the capacitor at the bridge will tend to be quite different from their true values, making the measurements invalid.

Note that the half-wave length of the cables should take into account the velocity factor of the cable used – generally about 0.6. This should also be taken into account when making up quarter-wave cables for the measurement setup of "method B" of figure 4.

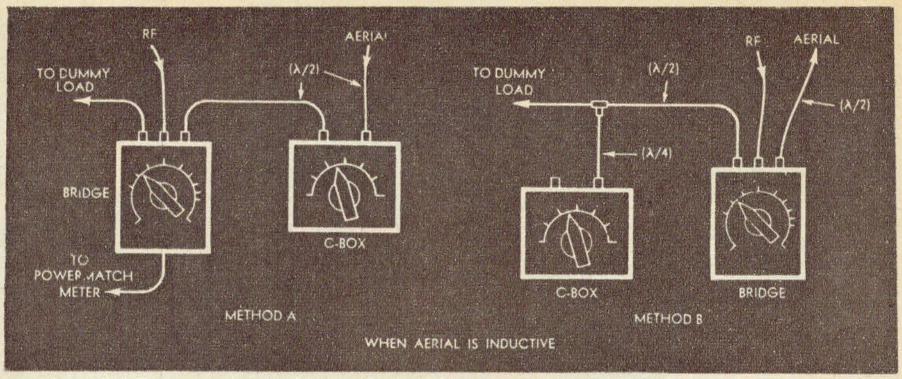


Figure 4: The alternative methods which may be used to measure aerial reactance and resistance when the aerial proves to have a significant inductance.

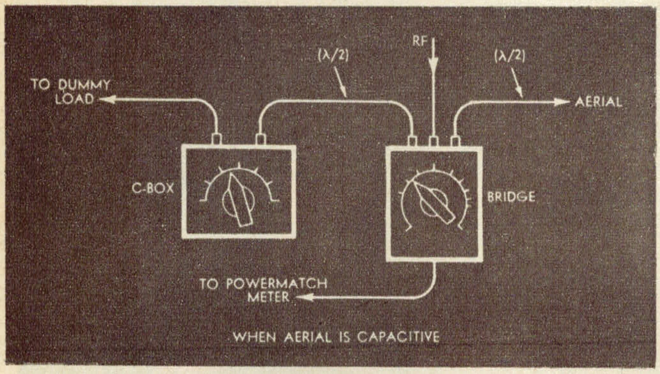


Figure 3: Method of measuring both the resistive and reactive aerial components when the aerial proves to be capacitive.

The bridge itself may be used to cut cables accurately to the quarter-wave and half-wave lengths and multiples of these lengths required for such purposes as baluns, matching stubs and transformers, and the cables used for the foregoing aerial measurements. This is done by making use of the fact that an open circuited half-wave line provides an effectively infinite load resistance, while an open circuited quarter-wave line provides an effective load resistance of zero.

The most convenient way of using the bridge for this purpose is also the most accurate. It involves setting the bridge pot carefully to the "unity" position (midscale), and balancing the cable against either an open circuit or a short circuit. In the case of a half-wave line, the "Zr" socket of the bridge is simply left unconnected, to provide an effective open circuit. For a quarter-wave line a shorting plug is fitted to the "Zr" socket, providing an effective short circuit. (See figure 5.)

The procedure is quite simple, A coaxial connector is fitted to one end of the cable to be cut to length, so that it may be connected into the bridge at the "Zx" socket. The "Zr" socket is then either left unconnected, if the cable is to be cut to a half-wave or multiple, or fitted with the shorting plug if it is to be cut to a quarter-wave or odd multiple. The RF power is then applied, and the cable length progressively reduced by means of clean cuts with a razor blade until the Powermatch meter indicates a null.

Note that in cutting the cable to length, care should be taken to make clean cuts, so that after each cut the cable effectively ends in an open circuit. Make sure that braid wires do not remain, to risk contact with the centre conductor and cause a short.

The shorting plug used as a reference when cutting quarter-wave sections was made up from a standard co-axial plug. The internal "short" was achieved using a small disc of sheet brass, to ensure a very low series inductance.

Using the foregoing technique, the author has used the prototype bridge to cut cables to accurate quarter-wave and half-wave lengths, even at 432MHz. This was easily done, as the null obtained was quite sharp and distinct. Naturally, at these frequencies the short lengths of cable involved in the connecting plugs and sockets must be taken into account when the resulting cable sections are used.

Note: There have been one or two isolated complaints from readers regarding the availability of the Comalco aluminium extrusion used in the slotted line accessory described in the April issue. In one case a reader was told that this extrusion is no longer being made.

As with all E-A projects, we checked on the availability of this extrusion before the article was published. A further call to the Comalco national office since then has confirmed that the extrusion is still very much a stock line, obtainable from any of the Comalco distributors.

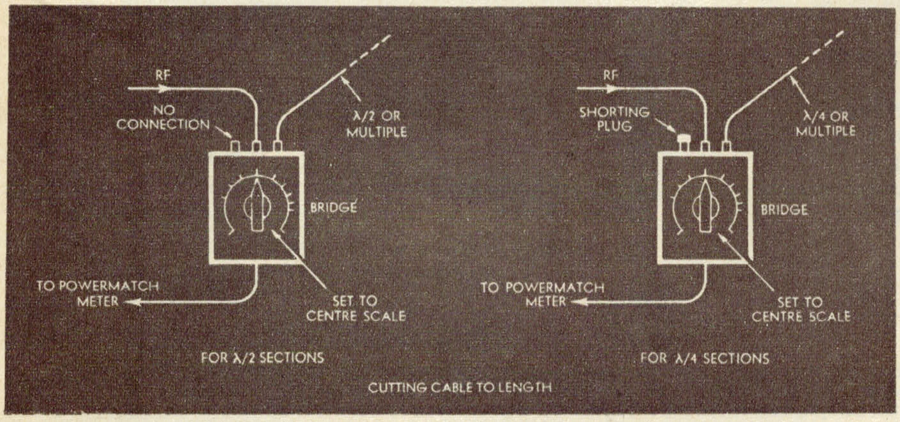


Figure 5: Using the bridge to cut cables to accurate multiples of electrical half-wave and quarter-wave lengths. The methods shown will give accurate results to beyond 432MHz, if care is taken.

REFERENCES

GLEDHILL, C. S., **VHF Line Techniques**, 1960. Edward Arnold Ltd, London.

JESSOP, G. R., **VHF-UHF Manual**, 1969. The Radio Society of Great Britain, London.

TILTON, E. P., **The Radio Amateur's VHF Manual**, 1965. The American Radio Relay League, Newington, Connecticut.