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Bridge checks impedance, resonance, and SWR

If you are involved in building and testing antennas, you are probably already aware that the simple tape measure and SWR approach leaves something to be desired. A useful addition to these basic tools is an impedance bridge — a device which can provide valuable data about an antenna, is simple to build, and which need not cost a fortune.

by PHILIP WATSON

To set the record straight, let us look first at the SWR meter and consider its capabilities and limitations. The SWR meter is a useful device but, unfortunately, many people have forgotten, or never fully appreciated, its limitations.

For an SWR reading to be free from ambiguity, the following conditions must prevail:

(1) The antenna must be known to be resonant at the test frequency.

(2) The probable impedance of the particular antenna type should be known and the resultant SWR accepted if it is reasonably close or

(3) If the SWR is not acceptable, then a matching device of some kind — T match, gamma match, stub, etc — must be provided and the SWR meter used to adjust it.

It is in this last role that the SWR meter is most valuable: where there is a matching device which should be capable of providing a near-perfect match, but which needs to be adjusted. But, always, condition (1) must first be satisfied. If the antenna is not resonant, no amount of feedline fiddling will alter that fact.

This is where the impedance bridge fits into the scheme of things. As well as measuring the antenna impedance, it can indicate — by the nature of the impedance measurement — whether the antenna is resonant at the test frequency or, by varying the frequency, indicate at what frequency it is resonant. Additionally, with simple auxilliary equipment it can identify any reactive component as either inductive or capacitive, and measure its value.

But the ability to measure the antenna's resonant frequency is undoubtedly the most valuable of these characteristics. As anyone who has tried it knows, cutting an antenna to the right frequency — at least at VHF and higher — is not always as easy as theory suggests. Conductor diameter, often tapered or stepped, must be allowed for, along with other variables such as the physical layout of the feedpoint, and these can add up to a significant error.

Such problems can be avoided if we first use a bridge to determine the resonant frequency, and adjust it if necessary. At the same time we can measure the load the antenna is presenting and, from this, get a good idea of the likely SWR.

When the SWR has been determined, a decision can be made as to whether anything needs to be done about it. And if matching devices have to be made and adjusted, the impedance bridge will confirm when they are working as intended.

It is also very useful for cutting quarter-wave and half-wave stubs — always a tricky operation if the velocity factor of the cable is not precisely known, or where allowance has to be made for a terminating connector.

This particular bridge will do these things, and work all the way from the HF bands up to 432MHz if required. It is simple to build, uses readily available components and should cost less than $50.

All of which adds up to a very attractive proposition.

In one sense, this is not really a new project. It is a re-presentation, in modified form, of the Impedance Bridge described by Editor, Jim Rowe, back in June 1971 as part of his Powermatch system. For a number of reasons we felt that the time was opportune to

The bridge is built in a diecast box. Three sockets: "Zr", "Zx", and "RF In", are mounted on the left hand end, and there is a meter sensitivity control at the opposite end. The toggle switch and LED are part of a bias network which improves the null reading.

take another look at it.

In fact, it was work on some antenna projects which prompted the author to build this bridge, in an effort to clarify the problems already discussed. It started out as a purely private project but several points which arose suggested that there could be some merit in re-presenting it. Further emphasis resulted from the fact that the amateur scene, particularly on two-metres, has changed significantly since the original article appeared.

For example, the original article conceded the disadvantage that the bridge needed a source of RF at the relevant frequency, from either a high output generator or a low power transmitter. Not many amateurs have access to such a VHF (or UHF) generator, and doctoring an existing transmitter to deliver a fraction of its intended power was not always convenient.

But it is a rather different story today. Most commercial two-metre transceivers feature a low-power facility, typically from one to two watts, which is ideal for this application. In addtion, those sets using phase locked loops provide coverage across most or all of the band in steps (typically 5 or 10kHz) which are both usefully close together and highly accurate. For our purpose they are a good deal better than most VHF generators.

The popularity of commercial equipment raised another point; the almost inevitable use of the PL259 plug and its matching S0239 socket for antenna connections. The original unit used Belling-Lee connectors, which were then quite appropriate, and these made possible a very compact unit. But when we considered fitting two S0239 sockets and one Belling-Lee connector to the same box it was immediately evident that it would be a squeeze at best.

The upshot was a decision to use a slightly larger die-cast box and, from this, came another idea. There was now room to fit a small meter in the same box, making it more of a self-contained unit than if we retained the original idea of using the meter in the Powermatch unit. The most logical meter seemed to be one of the low-cost edge type, the only query being whether the best sensitivity available, 200uA, would be adequate; the original circuit was designed for a 50uA meter. In the event, this was not a problem.

A further refinement was subsequently developed, in the form of a bias network for the detector diode, and which gives a somewhat improved null indication. We will have more to say about this later.

We estimate that the current cost of parts for this project is approximately

$50

This includes sales tax.

Apart from these minor changes, this version is electrically and physically similar to the original design. As the name implies it is a bridge; the classic wheatstone bridge configuration in fact, and a study of the circuit will confirm this. The four arms of the bridge are made up as follows: (1) A reference or standard resistor which plugs into the "Zr" socket and which may, typically, be a 50 ohm or a 75 ohm dummy load. (This need not have more than a 1W power rating.)

(2) The antenna or other device under test, which plugs into the "Zx" socket. Since it is seldom practical to operate the bridge directly at the base of an antenna, connection is made via a length of appropriate impedance cable. This must be either one half wavelength long, or an exact multiple of half wavelengths, in order that the impedance at the base of the antenna is reproduced as closely as possible at the bridge terminals. (Note: The length of an antenna cable is not critical, once it has been correctly matched.)

(3 & 4) These two arms are made up from the two sections of the 100-ohm pot, either side of the moving arm. When these two sections are exactly equal, the bridge will balance (or null) when the resistors "Zr" and "Zx" are also equal (to each other).

Conversely, if they are not equal, the amount by which the pot has to be moved from its centre position to achieve balance becomes an indication of the inequality, and the pot can be calibrated accordingly.

The null indicator consists of a diode in a simple shunt detector circuit, fed from the bridge via the two 470pF capacitors, and feeding the meter via two 560 ohm multiplying resistors. A 1k pot in parallel with the meter serves as a sensitivity control.

This brings us to the biasing network for the null indicator. The need for this arises from the fact that the diode has a

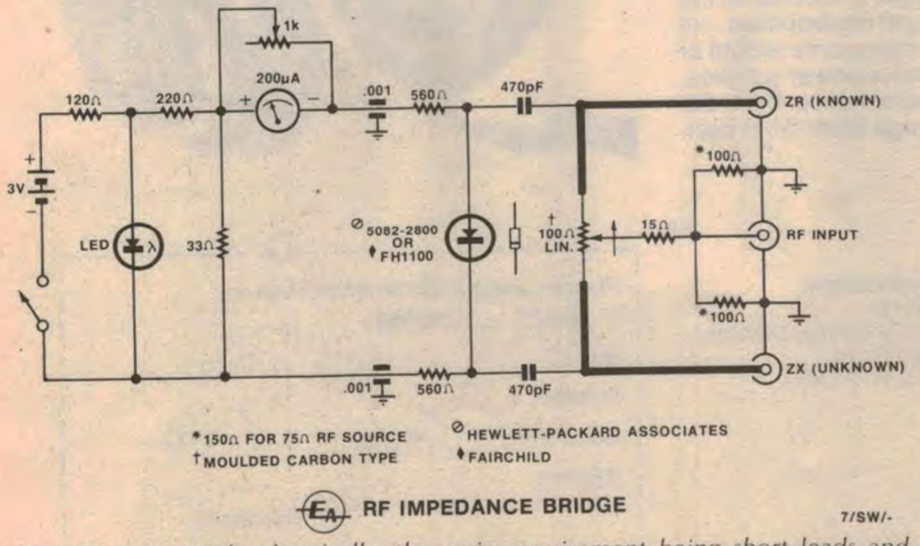
PARTS LIST

1 Die cast box, 115 x 90 x 50mm O.D. Eddystone 6908P or similar
1 200uA edge type meter
2 S0239 sockets
1 PL259 plug
1 Belling Lee socket
1 Belling Lee plug
1 Miniature toggle switch
1 Hot carrier diode, 5082-2800 or FH1100
1 LED
1 Label
1 Plastic battery holder to suit 2 x "AA" cells
1 Pair terminals to suit above
2 "AA" cells
1 8 terminal miniature tag strip
1 Pointer knob
1 Round knob

RESISTORS
(½W unless specified)
2 560 ohm
1 220 ohm
1 120 ohm
2 100 ohm
1 33 ohm
1 15 ohm
1 1000 ohm "C" taper pot
1 100 ohm linear moulded carbon pot, Plessey type 02000/326

CAPACITORS
2 .001uF feedthrough type
2 470pF disc ceramic

MISCELLANEOUS
Co-axial cable, impedance and length as required, hookup wire, solder lugs, nuts and bolts, brass for partition, etc.



The circuit is simple electrically, the main requirement being short leads and symmetrical layout in the RF portion, to the right of the feedthrough capacitors. The heavy lines indicate straps from the sockets to the pot.

threshold level, amounting to a few hundred mV, below which it will not conduct in either direction. Thus, as the bridge approaches a null condition, and the voltage across the detector falls below this threshold, the meter ceases to read before a true null is reached. It remains at zero until the bridge becomes unbalanced by a similar amount in the opposite direction, resulting in a "dead" zone around the true null.

With a little skill it is possible to interpolate the null between the threshold points and, also, to judge the depth of the null by noting the distance between them. But the need for such judgement is best avoided and this is the purpose of the bias circuit.

By applying a small voltage, at least equal to the diode's threshold voltage, in series with the meter and diode, the diode is made to conduct before a signal is applied to it from the bridge. As a result, the meter remains active right down to the null point, making the bridge more accurate and easier to handle.

The voltage is obtained from a battery and divider network. Part of this network is a LED which performs the dual function of warning indicator, to safeguard the battery, and a simple voltage regulator to compensate for changing battery voltage. The 120-ohm resistor is the normal current limiting resistor for the LED, while the 220-ohm and 33-ohm resistors across the LED divide the LED voltage to that required by the diode. These two resistors may need some adjustment to suit the individual LED.

The bias voltage should be such that the meter just starts to read, and is not particularly critical once this value is reached. The fact that the meter operates with a false zero in no way affects the accuracy of the system.

So much for the circuit and theory. To put this into practice at VHF or UHF calls for a very carefully designed physical layout; one that will minimise the effects of stray lead inductance and capacitance, and which is inherently symmetrical. Also, for practical reasons, it is necessary that the RF source, the antenna, and the reference resistor can all be earthy on one side.

This design takes care of these points particularly well, and the reader need only follow our layout to be assured of a bridge which is inherently balanced from the start. This should not be difficult if the photographs are studied carefully.

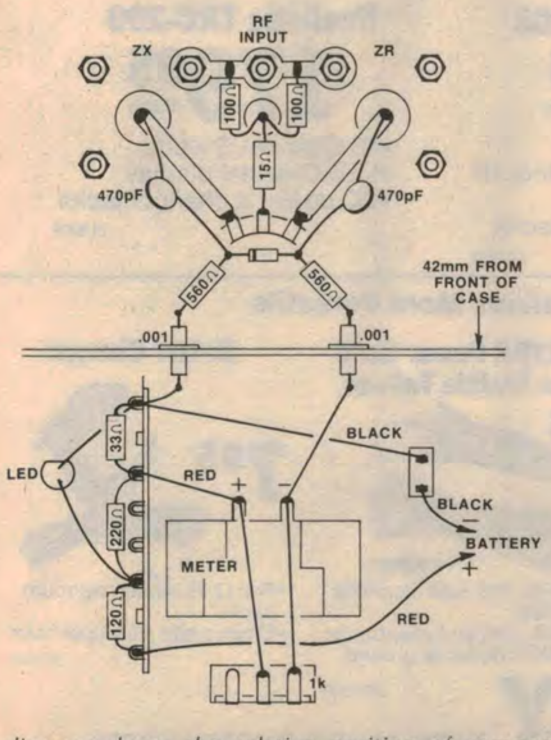
Most of the components are standard off-the-shelf items, but one special item is the 100 ohm pot. It must be a good quality carbon track (not wire wound) with a linear law. They are supplied by Plessey Components and at least one advertiser, Radio Despatch Service, has acquired stocks in anticipation of this project.

The meter is simply a null indicator and so the ultimate accuracy, calibration, or scale are not important; a simple "0-10" scale would be a logical choice if available.

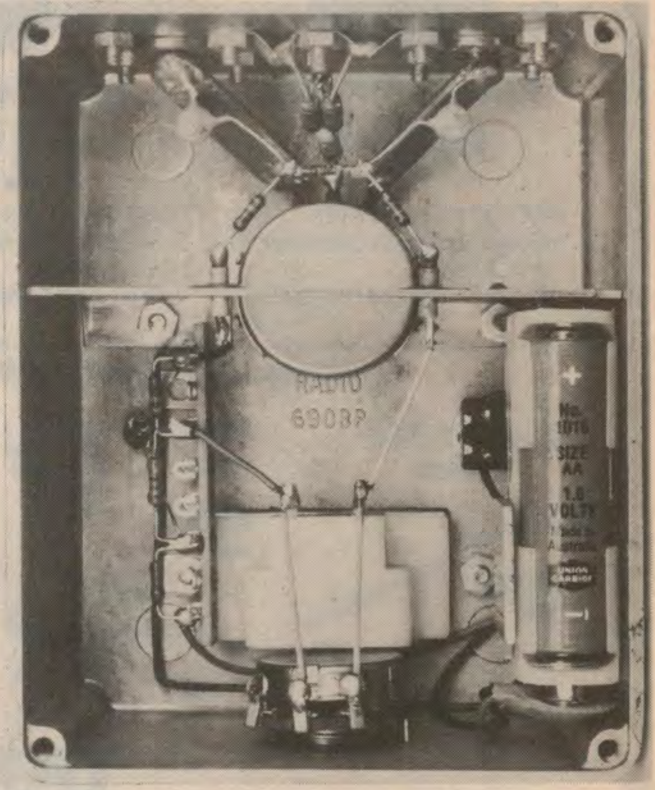
About the only other component worthy of comment is the detector diode. This is a hot carrier type to cope with the frequencies involved, and should have an adequate PIV rating. Two suitable types are specified and the Hewlett-Packard version is in good supply. The Fairchild version is no longer being imported, but small stocks may be available from individual dealers. Note that, while the polarity of the diode is not critical as far as the circuit is concerned, the way we fitted it suits the polarity of the meter terminals and the associated wiring.

The unit is constructed in a die-cast box measuring 115mm (L) x 90mm (w) x 50mm (D) O.D. Three holes need to be drilled in one end to accommodate two S0239 sockets and one Belling-Lee socket, or, at a pinch, three S0239 sockets. A hole is needed in the opposite end for the sensitivity pot. Several circular holes and one rectangular cut-out are required in the top of the box, and the panel label, reproduced here, can be used as a template. (Art work for this label will be distributed to manufacturers and labels may be available through your parts supplier.)

The photographs clearly show the short leads and symmetrical layout which are the essential features of the unit. The central (Belling-Lee) connector provides the RF input and three resistors connect to its active pin. Two



This diagram shows the relative position of components, and should make wiring very simple. The layout is critical only for components above the partition.



This photograph shows the finer points of layout and should be compared with the diagram at left. Note particularly the symmetrical layout above the partition.

are 100-ohm resistors which connect to a network of chassis lugs under three adjacent bolts. These resistors provide a 50-ohm load for the transmitter or other RF source, which is coupled via a 50-ohm cable. (Two 150-ohm resistors should be used for 75-ohm cable.)

The third resistor is a 15-ohm unit which connects to the moving arm of the pot. This is to prevent a dead short being presented to the transmitter in the event of careless handling in some test configurations.

The active pins from the "Zr" and "Zx" S0239 sockets connect to the outer terminals of the pot. To minimise inductance we used two strips of copper about 8mm wide. One end of each is drilled to enable it to slip over the active pin of the S0239.

From these same active pins two 470pF capacitors run to the hot carrier diode, which is suspended between them and, from these two junctions, the 560-ohm meter multiplying resistors run to the two .001 by-pass capacitors. These are feed-through types mounted on a metal shield straddling the pot.

The main purpose of this shield is to minimise the chance of stray RF from the transmitter reaching the bridge components. However, it also provides a couple of handy anchor points on which to support the bridge components via the feed-through capacitors.

Ours was made from a piece of 18g scrap brass, cut to the pattern shown. Alternative materials would be tinplate or blank P/C board. In the latter case, feet would have to be provided by brackets or solder lugs, possibly with extra support points on each side.

Wiring and layout on the other side of the shield is not particularly critical, the arrangement we chose being simply one that happened to be convenient. The battery is held to the side of the box by a clamp made from a scrap of aluminium.

Having built and wired the unit, it is simple enough to get into operation. The first job is to adjust the null indicator bias network. Ideally, it should cause the meter to read slightly when switched on, but it may be necessary to modify the 220-ohm resistor, decreasing it if there is insufficient movement or increasing it if there is too much.

Fit the knob to the 100-ohm pot so that it swings evenly to each end of the scale, then set it to "1" at mid-scale. Set the sensitivity pot for maximum resistance and switch on the bias. Then feed about 1W of RF into the "RF Input" socket.

The meter may read slightly, but it should be possible to adjust the pot for a virtually perfect null, ie, no movement of the pointer when RF is either applied or removed. If the null does not coincide exactly with the "1" position, this is probably due to slight nonlinearity of the pot. Re-set the knob on the shaft to allow for this.

Incidentally, although the meter will go hard over with gross imbalance, it is unlikely to be damaged, the order of overload being only about five times. The sensitivity pot is needed to bring such a reading back on scale so that the effect of the balance pot can be more easily observed.

To use the bridge you will need an antenna cable which is a multiple of a half wavelength long. In theory, it should be possible to use any convenient number of half wavelengths but, in practice, various losses and tolerances have a significant effect and the cable must be kept as short as possible.

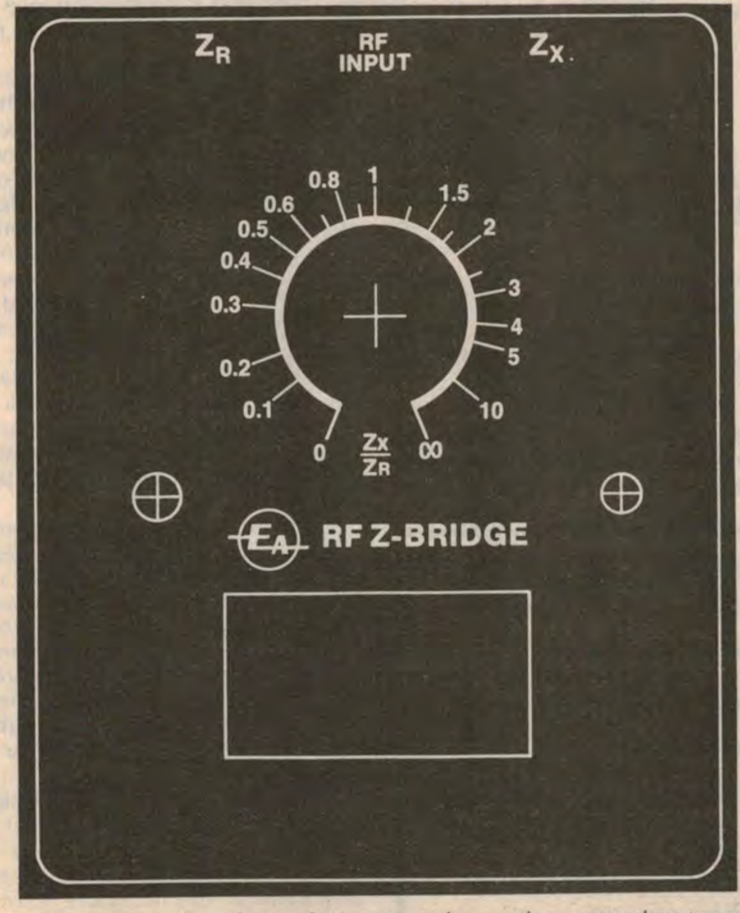
The author suggests that two half wavelengths for the 2m band is a good compromise between keeping losses to a minimum while still being able to set up the antenna reasonably clear of the test gear and operator — plus, of course, the ground, trees, buildings, and other objects. If necessary, the transmitter can be connected via any convenient length of cable, but it will be necessary to extend the press-to-talk circuit in some way.

Another potential source of minor inaccuracies is the dummy load, and how it is connected to the bridge. Ideally, such a device should be purely resistive and of exactly the same value as the characteristic impedance of the connecting cable. In these circumstances, the length of such a cable should not be critical.

Unfortunately, such ideal conditions seldom occur in practice. Dummy loads are seldom purely resistive, particularly at VHF. Nor do they necessarily exactly match the cable impedance, due to either their own minor inaccuracies, or to tolerances in the cable itself, which can be as high as 10%.

As a result, the length of this cable can also be critical and the author suggests that it, also, be made two half wavelengths long. At the same time, it is worth going to some trouble to provide the best dummy load possible. At the very least, check and, if possible, trim the resistance to the nominal cable impedance.

A further check is to measure the SWR of the dummy load on the end of its length of cable. Ideally, it should read "1/1" and we actually achieved this with a simple arrangement using two 100-ohm resistors and a Belling Lee socket (see photograph). The resistors were old fashioned IRH carbon types, without a spiral, and Radio Despatch Service have some stocks if needed for this application.



The front panel reproduced actual size. It can be used as a template to set out the holes on top of the box, and as the panel for the finished instrument, possibly under a transparent sheet for protection.

IMPEDANCE BRIDGE

A half wavelength of cable is equal to 150 divided by MHz, then multiplied by the velocity factor of the cable, which is usually .66. The frequency chosen should be in the centre of the band of interest, say 147MHz for the FM portion of the two-metre band.

The author suggests that the cable to be used be first fitted with a PL259 plug. Then calculate the required length and measure it from the mating end of the plug (but not including the pin). Mark this length with (say) a piece of sticky tap, but cut the cable at least 75mm longer. Insert the plug in the "Zx" socket, and leave the "Zr" socket open.

Ideally, a cable any number of half wavelengths long should reflect the open circuit at its far end exactly, allowing this to be compared with the open circuit "Zr" socket. In practice, this works out well for one or two half wavelengths and a good null should be obtained close to "1".

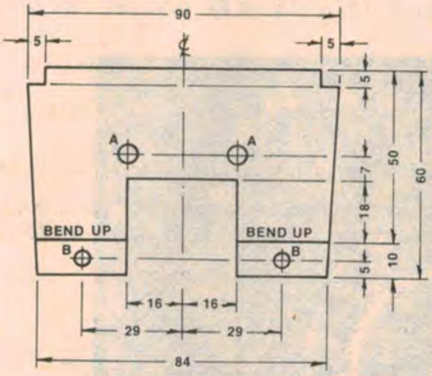
Unfortunately, for greater numbers of half wavelengths the cable losses begin to become apparent, mainly as a tendency for the null to become less perfect and to shift to less than one.

If the transmitter is tunable (PLL), make the first tests at the lowest available frequency; say 144MHz if you are aiming for 147MHz. Assuming the cable is too long (even at 144) the result should be a poor null at a value well below "1". As the cable is shortened the null should improve, and move towards "1". Immediately the null worsens, even if it is slightly short of "1", it indicates that you have, in fact, overshot for that frequency. Moving up in frequency will confirm this, by restoring the null.

At this point proceed very carefully, trimming only a few millimetres at a time. At these frequencies, 1MHz is equal to something less than 5mm of cable. A new blade in a trimming knife is a convenient tool for cutting the cable.

It is also necessary to consider the ultimate termination for the open end of the cable. Fitting an S0239 socket, for example, will probably shift the frequency back from 147MHz to near 144MHz, and it will be necessary to trim it still further. Other fittings, such as the Belling Lee plug for example, may not extend the cable significantly, or may even shorten it slightly, so proceed very carefully. On the other hand, if it is planned to fan the cable out to terminals, this portion should be treated as additional to the effective length.

This simple dummy load was made from two 100-ohm carbon resistors mounted on a Belling Lee Socket. The third resistor was used to trim the value to exactly 50 ohms. Checked on an SWR meter it gave a 1/1 reading.



A = TO SUIT FEED-THROUGH CAPACITORS
B = 3.5 DIA.

DIMENSIONS IN MILLIMETERS
MATERIAL: 1mm BRASS

The partition enclosing the RF section can be made from sheet brass, tinplate, or blank printed board material.

Unfortunately, the unshielded section of cable, even if only a few inches long, will radiate, and this makes it difficult to get a good null. Keep the unshielded section as short as possible and use the braid to bridge the gap between terminals.

All the foregoing probably suggests a process which is both tedious and hopelessly critical. This isn't really so, because practical experience indicates that very good results can be obtained using a cable which is somewhat less accurate than we can actually achieve. Provided the foregoing instructions are followed, things will work out okay at these frequencies.

It should also be appreciated that the various cable losses are greatest when the load provides a poor match to the cable impedance. When the match is correct, the losses are at a minimum.

Which brings us to the antenna measurement itself. Connect the antenna cable to the "Zx" socket, the dummy load to the "Zr" socket, and energise the bridge. Adjust the 100-ohm pot in search of a null, and note carefully the depth of the null. If it is shallow the load (antenna)) is reactive, meaning that it is off resonance. If it is on resonance it should give a perfect null.

If it is off resonance, and you have the means to do so, try it at other frequencies to determine which way it is in error. Then it can be lengthened or shortened accordingly. If a suitable range of frequencies is not available try lengthening the element(s), with clips or similar devices, while checking for a better null. If the nulls worsen, the element(s) should be shortened.

Once the antenna is resonant, we can take note of the dial reading, which gives the ratio of antenna resistance to "Zr". This should give at least a rough idea of the SWR, but a more accurate reading will probably be obtained with an SWR meter. The important point is that it will now be of real value, because the antenna is resonant.

Whether you decide to do anything about it depends on how bad it is, how fussy you are — and what can be done about it! But remember this: at anything less than 2 to 1 the transmitter will probably be quite happy, provided it sees a resistive load, while the cable losses will be negligible in a mobile installation, and only slightly worse in the average base station.

If you want to do something about it, you will have to consult the text books regarding matching stubs or other devices, or consider a different type of aerial which, but its nature, provides a match to the chosen cable.

But at least you will know what you are doing.