Build this Antennalyzer

— you'll need a weekend

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Photo A. Front view of the dummy load/wattmeter/rf bridge. The resistance dial is a 2-1/4" diameter plastic skirt attached to a standard knob.

Here is a weekend project that combines two instruments and an old technique into a very handy gadget to have around the shack. First, it's an 8-to-10 Watt 52-Ohm dummy load with a calibrated wattmeter: perfect for tuning up low-power transmitters. Second, it's also a calibrated rf resistance bridge which can make antenna adjustments a lot easier by telling you more about the nature of a mismatch than a plain swr bridge will. The old technique provides a nice tie-in between these two instruments and gives some benefits besides: The dummy load is also a resistive power divider that provides a low-level driving signal for the rf bridge.

One benefit of this arrangement is that the power source sees a load which is essentially independent of the bridge load. That means you can load your QRP transmitter into this instrument, put that new antenna on the bridge output, and fool around to your heart's content without risk of damaging the transmitter or even detuning its output stage. In addition, the power delivered to a 50-Ohm load is only about 40 mW when the power coming out of the transmitter is 5 Watts. That is a 21 dB reduction, and it means that any signal you radiate while adjusting the antenna is 3-1/2 S-units less than it might have been — certainly a neighborly gesture on today's crowded bands.

Background Theory and Circuit Description

There is nothing new or unique about the circuits described here. Rf resistance bridges have been around longer than the more familiar high-power swr bridges and there are several examples in recent publications.[1,2] The dummy load/power divider technique was described in *Solid State Design for the*

Radio Amateur (ARRL) and recently used in a transmatch tuning circuit described in *QST*.[3]

What I hope to emphasize here is this instrument's usefulness as a matching aid, the simple and inexpensive nature of the circuit, and the fact that the same circuit can be used as a dummy load with a built-in calibrated wattmeter. It's like getting two instruments for the price of one, and the final result is a very handy piece of test gear.

The resistive rf bridge is a simple modification of the classic low-power swr bridge, so before getting down to circuit details let's consider swr bridges in general for a moment. There are two main types of bridges used for measuring swr, and the most common type is a high-power handling circuit meant to be left in the transmission line for continuous monitoring. Usually, this type of bridge requires a minimum of 5 Watts or so driving the load before the meter readings are large enough to interpret accurately. This occurs because the bridge itself is very loosely coupled to the transmission line, typically through a few picofarads or several inches of wire running parallel to the center conductor of the main line.

The other type of bridge is inherently a low-power instrument. The driving signal runs right through the resistive elements which make up the bridge, so the bridge itself must be able to absorb a large fraction of the input power. The resistive bridge doesn't find much use in amateur circles because it requires only a Watt or less of drive and can't be left permanently in the line; it's strictly an occasional-use test instrument.

There is nothing wrong with continuous swr monitoring. After all, the familiar deflections of the high-power monitor do give a constant verification that the transmitter is tuned and the antenna connected. The low-power test instrument described here has some advantages over the usual swr bridge, though, especially for initial antenna adjustments, because it tells you more than just the magnitude of a mismatch.

Swr can be defined several ways, and one is the ratio of a load impedance to the transmission line's characteristic impedance (which is almost always near 50 Ohms in current amateur usage). For example, to cause a 3:1 swr, a 50-Ohm cable could be terminated with either 150 or 16.6 Ohms. These are purely resistive loads, but there is also an infinite number of reactive loads which would give the same 3:1 swr, and a common swr bridge can't tell the difference between any of them. You can build a bridge to measure both the reactance and resistance present in a load,[4,5,6] but such bridges tend to be too complex for my taste and requirements.

When matching a load to a 50-Ohm line, I generally have two questions. Is it resonant, and what's its resistance? If a load is resonant (and that's how I want all my antennas to be), then it has no reactive component—just resistance. If I know the value of that resistance, then I know the swr and whether I need more or less resistance to get a match. I'll give an example at the end of the article, but right now let's look at the schematic shown in Fig. 1.

There really isn't much to the circuit diagram. The input signal is terminated in a 53-Ohm dummy load constructed with a series-parallel resistor assortment. The voltage development across the 10-Ohm portion of that dummy load drives a simple bridge circuit made up from a 250-Ohm pot, a 51-Ohm standard resistor, and the load impedance. The bridge error signal appears between the output connector and the potentiometer arm and is detected by a germanium diode. The result is then indicated by a 100-uA meter in a voltmeter circuit.

Bridge operation is equally straightforward. When input power is applied to the instrument, it develops a voltage across the 53-Ohm dummy load. About 1/5 of this voltage appears across the 10-Ohm portion of the dummy, and this is the driving voltage for the resistance bridge. Some fraction of this driving voltage shows up between the potentiometer arm and ground, the exact amount depending, of course, on the shaft position. Similarly, there is some other fraction of the bridge driving voltage appearing across the load terminal, this fraction depending on the load resistance connected there.

If there is no load connected, then the entire source voltage appears there and we'll make use of that fact later to calibrate the wattmeter portion of this instrument. If a 51-Ohm load is connected, then exactly half the source voltage will be there. The difference between the output voltage and the potentiometer arm voltage is rectified by the diode and drives the meter through the sensitivity control, so with the 51-Ohm load the bridge will show a null when the pot travel is exactly centered. Other load resistances will show nulls at other positions and the potentiometer dial may be calibrated by marking the nulls corresponding to a whole series of load resistances. In theory, the bridge should show nulls for every load resistance between zero and infinity, but in practice this doesn't happen because the potentiometer isn't infinitely adjustable.

The circuit can be calibrated pretty accurately for resistances between 5 Ohms and 1k, with the best resolution around the center of the dial at 20 to 150 Ohms. Notice that the bridge cannot be nulled completely if the load has a capacitive or inductive component since such a load would introduce a phase shift between the bridge source voltage and the bridge load voltage. As there is no corresponding phase shift between the bridge source voltage and the potentiometer arm voltage, there never will be a point where the diode voltage will be zero and the meter nulled. Even when the voltages at each end of the diode are equal in amplitude, the fact that they are phase-shifted with respect to each other guarantees that there will be a sine wave or error voltage for the diode to rectify. In practice this means that unless the load is a pure resistance there will not be a true null but only a partial dip in the meter reading as the potentiometer shaft is turned.

A true rf impedance bridge would have two null adjustments: one for rf resistance and one for reactance. With such a bridge you can completely define any mismatch, but, as noted earlier, that's often unnecessary, especially in antenna work where the goal is to tune out reactance by resonating the antenna. You can always tell when a load is resonant with the resistance bridge because at resonance the null will be complete. Then steps can be taken if necessary to transform the remaining impedance to match a 50-Ohm line.

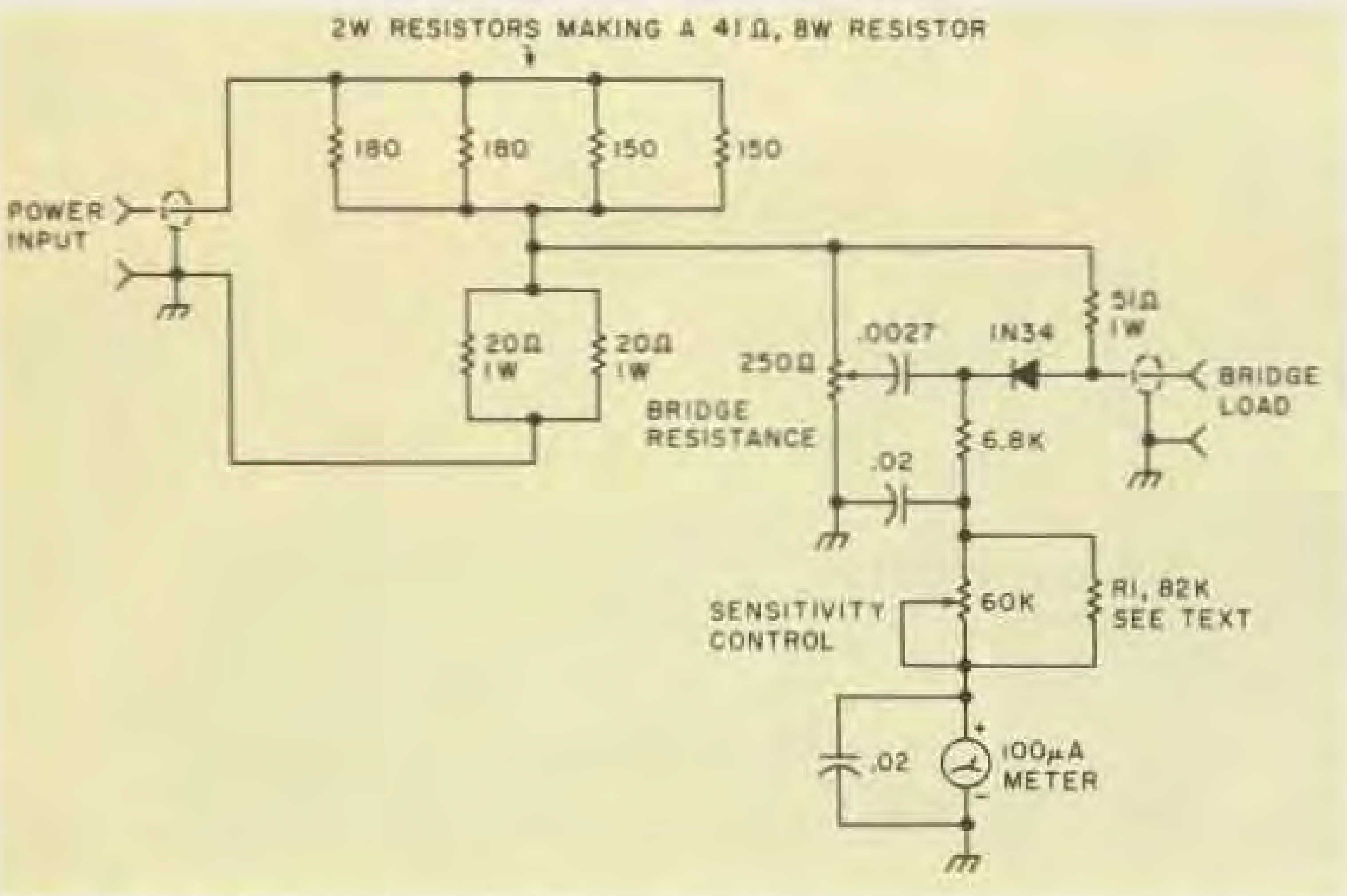

Fig. 1. Schematic diagram of dummy load/wattmeter/rf bridge. R1 is chosen as necessary to calibrate the wattmeter.

This same bridge circuit can be used to measure the power delivered to the dummy load by the transmitter. A glance at the schematic will assure you that with no load connected to the bridge and the resistance dial set to zero Ohms, the voltmeter circuit will indicate the rf voltage across the 10-Ohm portion of the dummy load. Knowing that voltage, we can easily calculate the voltage across the whole dummy resistance, and knowing that, we can calculate the power there from $P=V^2/R$. The calibration can be accomplished using only a dc voltmeter and will be described shortly.

Construction

A lot of articles begin their construction description with the assurance that "the layout is completely noncritical." That is certainly not true here, but "critical" is also too strong of a word, so let me just caution you to be careful with layout. There are three main areas that can cause trouble.

First, it's best to arrange the dummy load portion of the circuit so that current flowing in the ground path from the bottom of the dummy load back to the input terminal does not share any conductor with part of the bridge circuit. If it does, then variations in the input power will shift the null positions on the resistance dial. Photo B shows one way to solve that problem by bringing the input power and its ground return to the dummy resistors on a single piece of coax, thus avoiding the temptation to ground the bottom resistors to some point on the chassis.

Second, the detector diode should have one end connected directly to the output jack. My first few attempts had more compact physical arrangements with the diode connected to the bridge output terminal with lengths of wire or brass strips. This always interfered with getting good deep nulls on both ends of the resistance range.

Third, the detector should not be a silicon diode, since the 0.6-volt threshold of a silicon diode will cause the bridge nulls to be too wide. With a given load termination there should be a single, sharp deep null on the dial, not a dead zone covering several degrees of rotation. My collection of diodes is pretty large, and the best of the lot turned out to be some germanium 1N34 equivalents I paid 10¢ each for some 15 years ago! Radio Shack's 276-1123 diodes cost the same today and should work as well.

The dummy load nominal value is about 51 Ohms with the circuit shown. I used an assortment of resistors from the junk box, so feel free to substitute values, but do observe a few simple rules. Wire-wound resistors are definitely out because they look like coils at radio frequencies. Also, stick with carbon resistors having values less than 1k. When paralleling resistors, try to have them all of the same value so they dissipate equal amounts of power. Keep the leads short and the wiring direct; this keeps the dummy load looking resistive at the higher frequencies and prevents stray coupling which might interfere with the bridge nulls.

The rest of the physical arrangement is pretty clear from the photographs with the exception of the bridge potentiometer mounting. A similar bridge is described in W6SAI's 1962 *Radio Handbook*[7] and the author there cautions that stray capacitive coupling between the potentiometer resistive element and ground can cause frequency sensitive errors in calibration.

The suggestion made there, and followed here, is to cut a large hole in the box (say, 1-1/2" in diameter) and mount the pot in the center of this open space using a piece of insulating plastic, bakelite sheet, or unplated circuit board for support. This insulates the pot body from ground and thereby greatly reduces the capacitive coupling between the pot resistive element and ground. It seemed like a good suggestion so I followed it. I can't strictly say it is necessary because I didn't try it the other way, but it sure can't hurt.

The skirt on the resistance dial covers the hole from the front of the box. If you want to use a smaller knob with a pointer, you could mount a rectangle of insulation over the hole from the front side of the panel and use that to hold the pot and the calibration marks. The actual value of the bridge potentiometer is not too critical. It should be at least 50-Ohms so that it doesn't draw too much power, and anything over 1k is probably asking for trouble with stray capacitance. If you have anything inside that range, try it before you buy a new 250-Ohm unit.

The box shown is a cut-down Bud minibox that started out as 3" × 4" × 5". The 3" height was reduced to just under 2" because it fit the hand better, but there is nothing magic about these dimensions. Use anything of roughly the same size as long as it is made of metal. You also will note in the photographs that BNC connectors are used instead of the more common (in amateur circles, anyway) UHF series. I don't run enough power to require RG-8, and I find the smaller quick-connect BNC connectors more convenient for my home-brew projects. Naturally, if all of your antenna cables have UHF connectors, then you also should use them on your bridge.

Calibration

There are two things to calibrate here: the wattmeter and the bridge scale. The meter serves as a null indicator when using the bridge, so the wattmeter calibration can be done after the bridge has been checked out.

The bridge dial can be as simple or fancy as desired but it should be large enough to read easily. The skirt on my dial is 2-1/4" in diameter. You probably will want to start with a paper scale and save the fancy artwork until everything is working properly.

Assemble a collection of carbon resistors covering as many values as possible between 5 and 1000 Ohms and then cut the leads to about 1" in length. The leads are bent so the resistors can be spring loaded into contact with the bridge output connector. If you have a lot of spare connectors, you also could make up a number of dummy loads with the different resistors similar to the one shown next to the bridge in Photo B.

Any layout problems will be more pronounced at the higher frequencies, so fire up a 10-meter rig if you have one and feed several Watts of rf into the bridge. (I've used this instrument only on 10 meters, but it might work all right up to 6 meters.) With the bridge excited, check the nulls at both ends of the range, say, with a 10-Ohm then a 680-Ohm load.

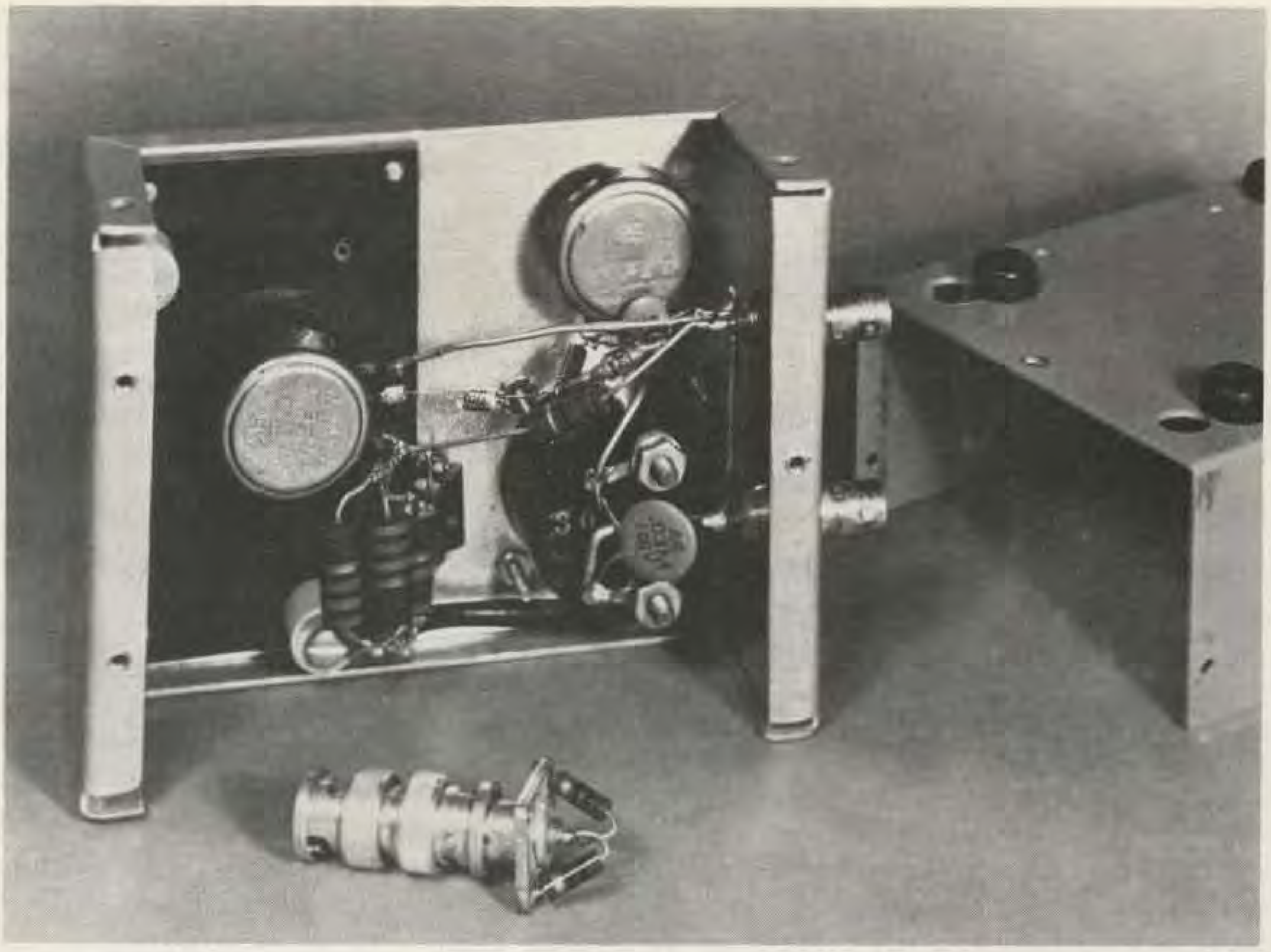

Photo B. Interior of the instrument, showing layout and construction details. The object in the foreground is a dummy load typical of those used during calibration.

Both nulls should be deep and well defined. If one isn't as deep as the other, then there is probably something wrong with the physical layout of the bridge elements. Try moving things around some or try another ground routing. If you followed the layout shown, then there really shouldn't be any trouble. Remember that this is an rf resistance bridge and with resistors on the bridge output, the nulls theoretically should be right down to zero meter movement. In practice, stray reactances prevent the nulls from being perfect but they should come pretty close to it. If the load does contain some reactance, there still will be a dip but it won't be to zero as previously mentioned.

When you're satisfied with the basic bridge operation, make a temporary scale and mark off the positions of the nulls due to the collection of sample resistors. Standard resistor values aren't nice round numbers, but with enough calibration marks you can make a final scale with lines at 5, 10, 20, 30, etc., Ohms as shown on the front panel in Photo A.

The wattmeter scale can be calibrated easily using a dc power supply and a good dc voltmeter. Remember that the wattmeter is actually reading the rf voltage across the 10-Ohm portion of the dummy load when there is no bridge load and the bridge pot is set to zero Ohms. Under these conditions, the 0.0027-uF coupling capacitor (that's not a critical value—anything from 0.001 to 0.05 will work as well) will charge to the peak value of the rf sine wave.

Since the peak value of a sine wave is 1.414 times the rms value, it is easy to calculate a dc value which, when fed into the instrument, will read the same on the meter as some given rf power. A conversion chart for the 53-Ohm dummy load is given in Table 1 along with the equation necessary to calculate your own equivalents should you use some other combination of resistors. Since I was interested in converting CB sets, I calibrated my wattmeter for a full-scale reading of 5 Watts, even though the resistors can handle 10 Watts for short periods. To make the 5-Watt calibration, feed a measured 22.9 volts into the unit, turn the sensitivity control all the way down (maximum resistance), and select a value for R1 that gives a full-scale meter reading.

Now comes the hardest part: making the meter face. I don't like conversion charts so I made a whole new face for my meter. It's not as difficult as you might think, but it does require a steady pair of hands.

Open the meter, remove the two screws holding the faceplate in place, and remove the faceplate while taking care not to damage the meter pointer. Glue a clean piece of white paper over the old faceplate using paper paste and not liquid white glue (which tends to dampen the paper so much that it wrinkles). Be sure to cover the faceplate evenly with paste so the paper won't have a chance to wrinkle. The pointer travels close enough to the faceplate that it can get stuck on wrinkles.

When the paste is dry, use a sharp knife to trim off the excess paper, and a pin to punch through the screw holes. Now a drawing set with an ink compass can be used to draw in a nice arc for the baseline of the new scale. Remount the faceplate, center the meter zero adjustment, and make a light pencil mark under the pointer tip to define the zero rest position. Reapply the 22.9 volts and make another pencil mark to spot the 5-Watt full-scale position. Now go down the list in Table 1 and mark off each intermediate point, checking occasionally that all of the points are repeatable and properly marked.

Finally, remove the faceplate again and finish off the scale graduations with

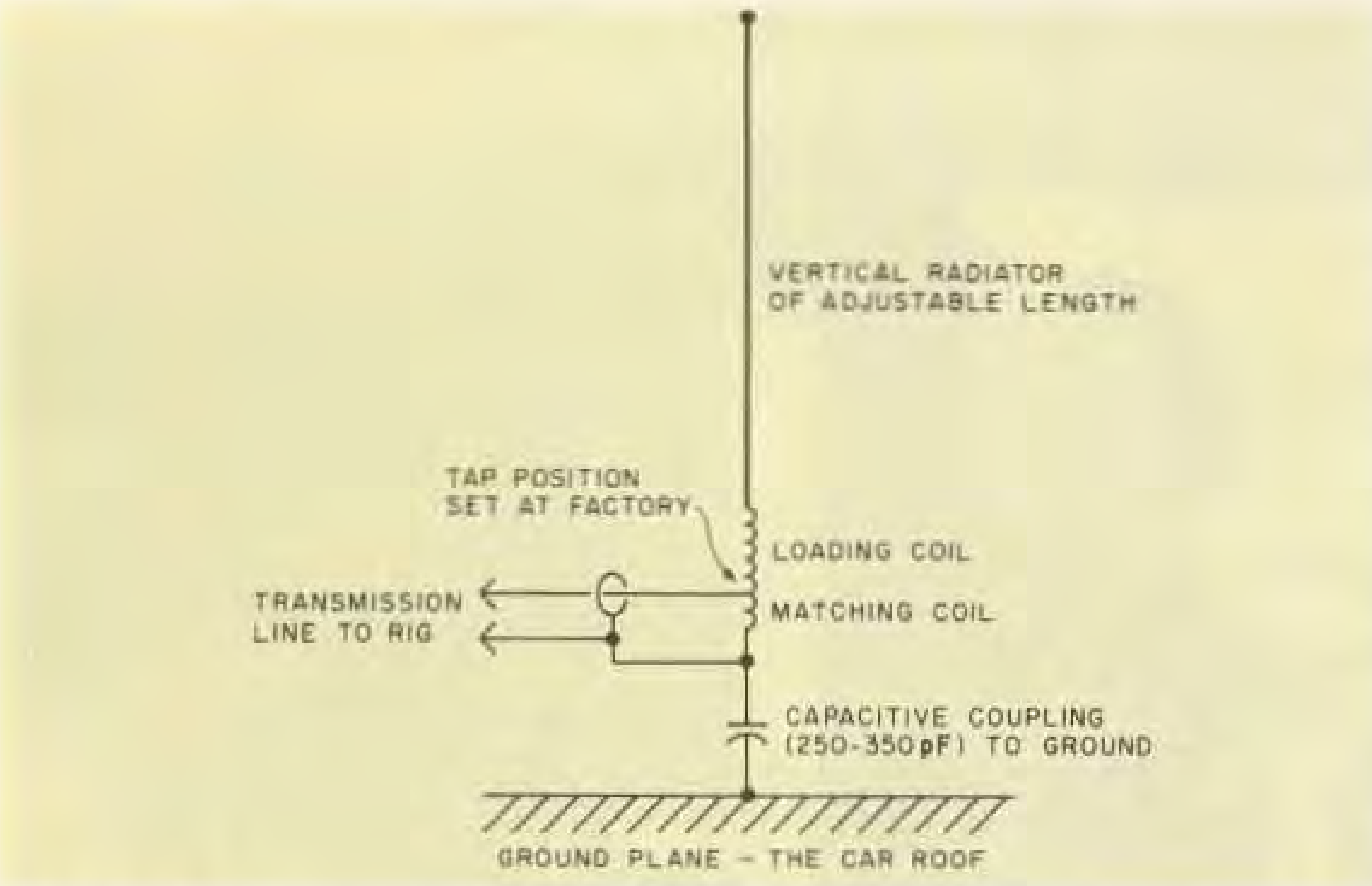

Fig. 2. Shortened loaded vertical, a CB mag-mount whip.

ink or dry transfers using the light pencil marks as a guide. With a little care, the results can be pretty professional. One real bonus of this technique is that the calibration is correct with the particular diode, resistors, and meter actually used, since the whole circuit is calibrated at once. That's important because the diode is not a perfect rectifier and the meter scale will be influenced slightly by the characteristics of the particular diode used.

An Application Example

The most obvious use for the rf resistance bridge is in making matching adjustments to antennas. Some antennas, dipoles, for example, are easy to adjust with an swr bridge since their feedpoint impedance at resonance is already close to the typical cable impedance. When a dipole is fed with either 52- or 73-Ohm coax, its swr at resonance is bound to drop to somthing like 1.5:1. This isn't true with shortened antennas such as mobile whips since their feed impedance may be only a few Ohms.

Input Power Watts	Dc Voltage Equivalent
5.0	22.90
4.0	20.49
3.0	17.74
2.0	14.49
1.0	10.24
0.5	7.24
0.4	6.48
0.3	5.61
0.2	4.58
0.1	3.24

Table 1. Wattmeter calibration. Input power levels corresponding to dc voltage equivalents. Values are calculated using $E = \sqrt{2RP}$, *where* P = *rf power (in Watts),* R = *total dummy resistance, and* E = *dc input voltage (where* E *is peak value of rf sinewave). Caution: With these dc inputs, the dummy load is dissipating twice the indicated rf power, so be careful not to overheat the resistors.*

There are two adjustments necessary to get a low swr with such an antenna: one for resonance and one for impedance matching. Making these two adjustments with only an swr bridge can be very difficult because a low swr will result only when both settings are correct. With a resistance bridge, the adjustment is much easier.

Consider the antenna shown in Fig. 2, a magnetically-mounted, base-loaded CB whip. The antenna really has two adjustment points, although the tapped loading coil is normally adjusted and sealed at the factory and all that is necessary for 27-MHz operation is a slight height adjustment. Putting this antenna to use on 10 meters or using a different length whip section may change things enough that a low swr cannot be achieved without a change to the coil size or tap position.

For example, I am using one of these antennas on the roof of my house as a loaded ground plane. The eight 1/4λ radials laid out on the roof do not provide the same type of ground return as the roof of an automobile. In addition, a 5′ whip is being used as a radiating element in place of the original 3′ length. This longer length lets me use a smaller loading coil with lower losses. I built this test instrument partly because of the difficulty I was having trying to tune this antenna with only an swr meter and grid dipper.

Adjusting such an antenna is a lot simpler with the rf resistance bridge, but first the bridge must somehow be connected to the base of the antenna. It would be nice to locate the bridge physically at the base of the antenna but this isn't always practical. For one thing, the bulk of the operator's body would probably upset the antenna tuning. If the bridge is connected to the antenna through a length of coaxial cable then that cable length must be chosen carefully because the impedance seen looking into a transmission line depends on three things: the line impedance, the load impedance, and the line length.

Luckily, it happens that a section of transmission line which is some multiple of a half wavelength in length will have an input impedance almost exactly equal to its load impedance. Using such a line makes it possible for the bridge to be located at some convenient position and still indicate the antenna base impedance. At 28.5 MHz, a half wavelength in free space is 16′ 5″ and in coaxial cable it will be about 2/3 of that or 10′ 11″.

If you have a section of cable this length, it is easy to check its electrical length with the bridge. First put a 10-Ohm resistor directly on the bridge and check for the null at 10 Ohms. Then insert the cable section between the bridge and resistor and see that the bridge still reads a resistive 10 Ohms. If it is a little off, as indicated by an incomplete null somewhere near 10 Ohms on the dial, you may want to change the transmitter frequency a bit to adjust the operating wavelength to the line's physical length.

Just for fun, you might try a quarter wavelength of cable and verify that it transforms the 10 Ohms into 270 (52-Ohm cable). In fact, you might get out a good article on transmission-line matching sections and try a number of things with different loads and line lengths—it's fun and really brings that dry old theory to life.

With the antenna fed through some multiple of a half wavelength of cable, the radiator length can be adjusted for resonance as indicated by a complete null of the meter reading. The resistance indicated at resonance is the feedpoint impedance of the antenna, and the ratio of that impedance to 52 Ohms is the swr on the cable—assuming you're using 52-Ohm cable. If the swr is more than 2:1 (antenna impedance greater than 100 or less than 25 Ohms), then you may want to change the coil tap position. It probably is easier to change the inductance below the tap by squeezing or separating the coil turns there slightly than it is to unsolder and move the tap itself. These adjustments can be pretty fine and you probably won't end up changing the coil size by a whole turn's worth anyway.

With the inductance changed, look for the new null on the bridge and, once again, adjust the antenna height until the feedpoint impedance is pure resistance. Depending on whether that resistance is closer or further from the 52-Ohm target, you now know in what direction the coil must be altered to effect an acceptable match.

Conclusion

Of course, there are many other tuning applications for this instrument besides CB antenna conversions. You will find it more useful than an swr bridge for any application which requires both resonating a load and transforming its impedance. As a bonus, you can use it to measure swr when the load impedance is mostly resistive. The internal dummy load lets you adjust and modify antennas without danger to your transmitter and without putting a big signal on the air. You'll also find that the dummy load and calibrated wattmeter are a valuable QRP tune-up aid. Last, but not least, you can develop a real understanding of transmission-line matching techniques by using the bridge to verify some of the theory you read when studying for your ticket! ■

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