An In-Line RF Wattmeter

Considerable attention was devoted to the resistance-type SWR bridge in the preceding section because it is the simplest type that is capable of adequate accuracy in measuring standing-wave ratio. Its disadvantage is that it must be operated at a very low power level, and thus is not suitable for continuous monitoring of the SWR in actual transmission. To do this the instrument must be capable of carrying the entire power output of the transmitter, and should do it with negligible loss. An RF wattmeter meets this requirement.

It is neither costly nor difficult to build an RF wattmeter. And, if the instrument is equipped with a few additional components, it can be switched to read reflected power as well as forward power. With this feature the instrument can be used as an SWR meter for antenna matching and Transmatch adjustments. The wattmeter shown in Figs 9 through 12 meets these requirements. The instrument uses a directional type of coupler for sampling the energy on the transmission line. The indicator sensitivity of this instrument is not related to frequency, as is the case with some types of directional couplers. This unit may be calibrated for power levels as low as 1 watt, full scale, in any part of the HF spectrum. With suitable calibration, it has good accuracy over the 3-30 MHz range. It is built in two parts, an RF head for inserting in the coaxial transmission line, and a control-meter box which can be placed in any location where it can be operated conveniently. Only direct current flows in the cable connecting the two pieces.

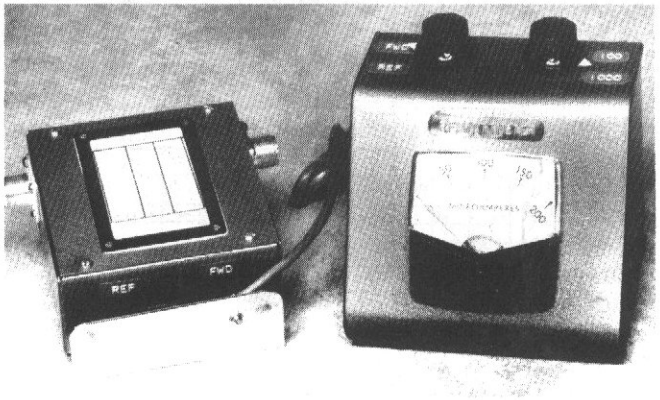


Fig 9—The RF wattmeter consists of two parts, the RF head (left), and the control-meter box (right). The paper scale affixed to the RF head contains the calibration information which appears in Fig 10.

Design Philosophy

See the circuit of Fig 10. The transmission line center conductor, W1, passes through the center of a toroid core and becomes the primary of T1. The multiturn winding on the core functions as the transformer secondary. Current flowing on W1 induces a voltage in the secondary which causes a current to flow through resistors R1 and R2. The voltage drops across these resistors are equal in amplitude, but 180° out of phase with respect to common or ground. They are thus, for practical purposes, respectively in and out of phase with the line current. Capacitive voltage dividers, C1-C3 and C2-C4, are connected across the line to obtain equal-amplitude voltages *in phase* with the line voltage, the division ratio being adjusted so that these voltages match the voltage drops across R1 and R2 in amplitude. (As the current/voltage ratio in the line depends on the load, this can be done only for a particular value of load impedance. Load values chosen for this standardization are pure resistances that match the characteristic impedance of the transmission line with which the bridge is to be used, 52 or 75 ohms usually.) Under these conditions, the voltages rectified by D1 and D2 represent, in the one case, the vector *sum* of the voltages caused by the line current and voltage, and in the other, the vector *difference*. With respect to the resistance for which the circuit has been set up, the sum is proportional to the forward component of a traveling wave such as occurs on a transmission line, and the difference is proportional to the reflected component.

Component Selection

R1 and R2 should be selected for the best null reading when adjusting the bridge into a resistive 52- or 75-ohm load. Normally, the value will be somewhere between 10 and 47 ohms. The 10-ohm value worked well with the instruments shown here. Half-watt composition resistors are suitable to 30 MHz. R1 and R2 should be as closely matched in resistance as possible. Their exact value is not critical, so an ohmmeter may be used to match them.

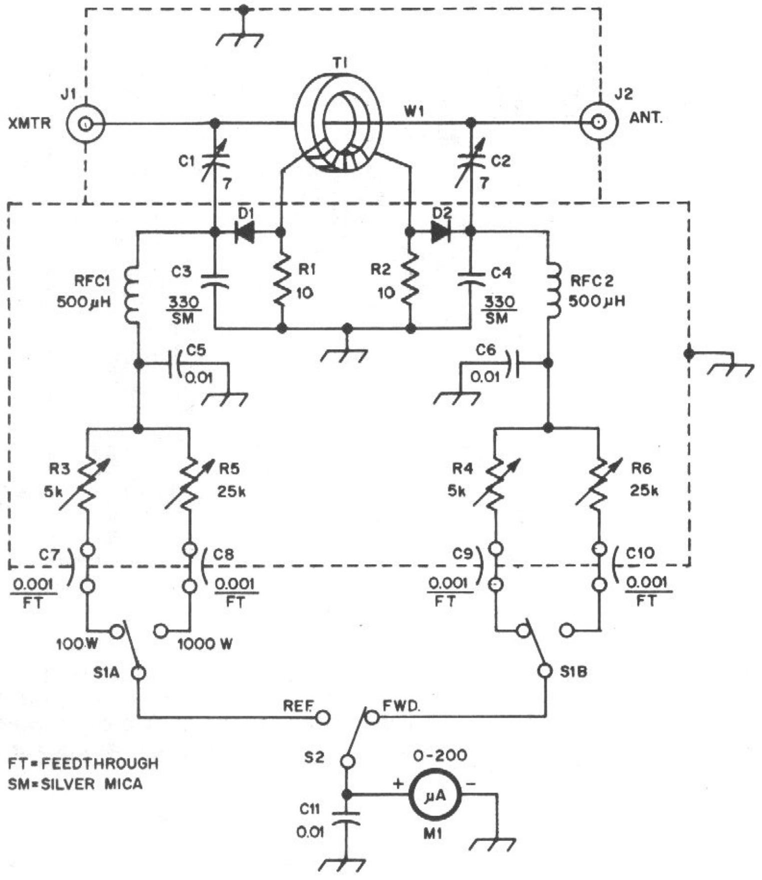
Ideally, C3 and C4 should be matched in value. Silver-mica capacitors are usually close enough in tolerance that special selection is not required, providing there is enough leeway in the ranges of C1 and C2 to compensate for any difference in the values of C3 and C4.

Diodes D1 and D2 should also be matched for best results. An ohmmeter can be used to select a pair of diodes having forward dc resistances within a few ohms of being the same. Similarly, the back resistances of the diodes can be matched. The matched diodes will help to assure equal meter readings when the bridge is reversed. (The bridge should be perfectly bilateral in its performance characteristics.) Germanium diodes should be used to avoid misleading results when low values of reflected power are present during antenna adjustments. The SWR can appear to be perfect when actually it isn't. The germanium diodes conduct at approximately 0.3 volt, making them more suitable for low-power readings than silicon diodes (conduction at 0.7 V).

Any meter having a full-scale reading between 50 μA and 1 mA can be used at M1. The more sensitive the meter, the more difficult it will be to get an absolute reflected-power reading of zero. Some residual current will flow in the bridge circuit no matter how carefully the circuit is balanced, and a sensitive instrument will indicate this current flow. Also, the more sensitive the meter, the larger will have to be the calibrating resistances, R3 through R6, to provide high-power readings. A 0-200 μA meter represents a good compromise for power ranges between 100 and 2000 watts.

Construction

It is important that the layout of any RF bridge be as symmetrical as possible if good balance is to be had. The circuit-board layout of Fig 12 meets the requirement for this instrument. The input and output ports of the equipment should be isolated from the remainder of the circuit so that only the sampling circuits feed voltage to the bridge. A shield across the end of the box which contains the input and output jacks and W1 is necessary. If stray RF gets into the bridge



WATTS	M1	WATTS
100	200	1000
90	180	900
80	170	800
70	155	700
60	145	600
50	125	500
40	105	400
30	85	300
20	65	200
10	40	100
5	20	50

Fig 10—Schematic diagram of the RF wattmeter. A calibration scale for M1 is shown also. Fixed-value resistors are ½-watt composition. Fixed-value capacitors are disc ceramic unless otherwise noted. Decimal-value capacitances are in microfarads. Others are picofarads. Resistance is in ohms; k = 1000.

C1, C2—1.3- to 6.7-pF miniature trimmer (E. F. Johnson 189-502-4, available from Newark Electronics, Chicago, Illinois)

C3-C11, incl—Numbered for circuit-board identification.

D1, D2—Matched small-signal germanium diodes, 1N34A, etc (see text).

J1, J2—Chassis-mount coax connector of builder's choice. Type SO-239 used here.

M1—0-200 µA meter (Triplett type 330-M used here).

R1, R2—Matched 10-Ω resistors (see text).

R3, R4—5-kΩ printed-circuit carbon control (IRC R502-B).

R5, R6—25-kΩ printed-circuit carbon control (IRC R242-B).

RFC1, RFC2—500-µH RF choke (Millen 34300-500 or similar).

S1—DPDT single-section phenolic wafer switch (Mallory 3222J).

S2—SPDT phenolic wafer switch (Centralab 1460).

T1—Toroidal transformer; 35 turns of no. 26 enam wire to cover entire core of Amidon T-68-2 toroid (available from Amidon Assoc or Radiokit).

W1—Numbered for text discussion.

circuit, it will be impossible to obtain a complete zero reflected-power reading on M1 even though a 1:1 SWR exists.

All of the RF head components except J1, J2 and the feedthrough capacitors are assembled on the board. The board is held in place by means of a homemade aluminum L bracket at the end nearest T1. The circuit board end nearest the feedthrough capacitors is secured with a single no. 6 spade bolt. Its hex nut is outside the box, and is used to secure a solder lug which serves as a connection point for the ground braid in the cable which joins the control box to the RF head.

T1 fits into a cutout area of the circuit board. A 1-inch long piece of RG-8 coax is stripped of its vinyl jacket and shield braid, and is snug-fit into the center hole of T1. The inner conductor is soldered to the circuit board to complete the W1 connection between J1 and J2.

The upper dashed lines of Fig 10 represent the shield partition mentioned above. It can be made from flashing copper or thin brass.

The control box, a sloping-panel utility cabinet measuring 4 × 5 inches, houses S1, S2 and the meter, M1. Four-conductor shielded cable—the shield serving as the common lead—is used to join the two pieces. There is no reason the entire instrument cannot be housed in one container, but it is sometimes awkward to have coaxial cables attached to a unit that occupies a prominent place in the operating position. When built as shown, the two-piece instrument permits the RF pickup head to be concealed behind the transmitter, while the control head can be mounted where it is accessible to the operator.

Adjustment

Perhaps the most difficult task faced by the constructor

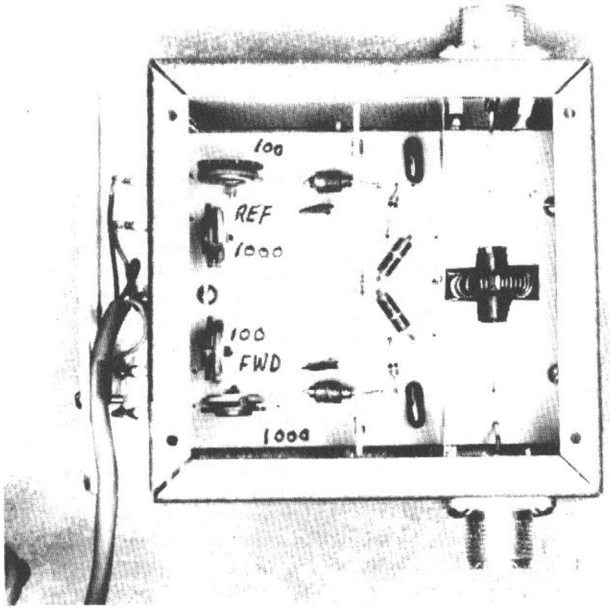


Fig 11—Top view of the RF head for the circuit of Fig 10. A flashing-copper shield isolates the primary RF line and T1 from the rest of the circuit. The second shield (thicker) is not required and can be eliminated from the circuit. If a 2000-watt scale is desired, fixed-value resistors of approximately 22 kΩ can be connected in series with high-range printed-circuit controls. Instead, the 25-kΩ controls shown here can be replaced by 50-kΩ units.

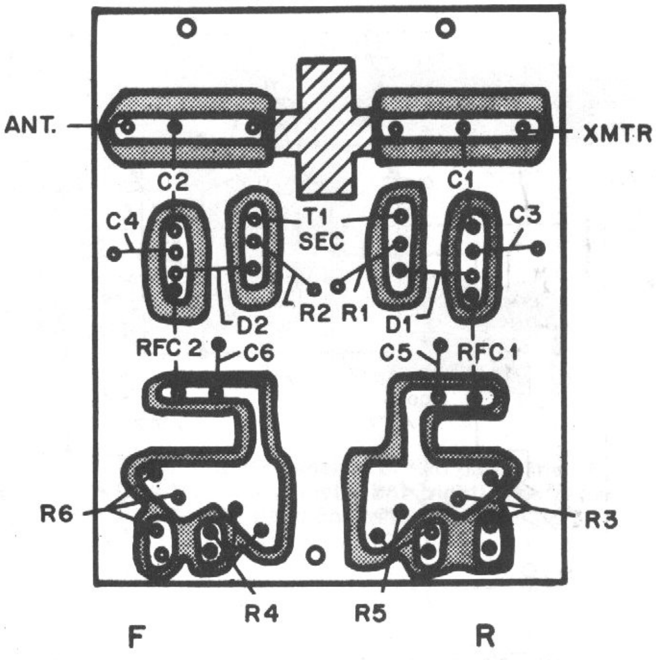


Fig 12—Etching pattern and parts layout for the RF wattmeter, as viewed from the foil side of the board. The etched-away portions of the foil are shown as darkened areas in this drawing. The area with diagonal lines is to be cut out for the mounting of T1.

is that of calibrating the power meter for a desired wattage range. The least involved method is to use a commercial wattmeter as a standard. If one is not available, the power output of the test transmitter can be computed by means of an RF ammeter in series with a 52-ohm dummy load, using the standard formula, $P = I^2R$. The calibration chart of Fig 10 is representative, but the actual calibration of a particular instrument will depend on the diodes used at D1 and D2. Frequently, individual scales are required for the two power ranges.

Connect a noninductive 52-ohm dummy load to J2. A Heath Cantenna or similar load will serve nicely for adjustment purposes. Place S2 in the FORWARD position, and set S1 for the 100-watt range. An RF ammeter or calibrated power meter should be connected between J2 and the dummy load during the tests, to provide power calibration points against which to plot the scale of M1. Apply transmitter output power to J1, gradually, until M1 begins to deflect upward. Increase the transmitter power and adjust R4 so that a full-scale meter reading occurs when 100 watts is indicated on the RF ammeter or other standard in use. Next, switch S2 to REFLECTED and turn the transmitter off. Temporarily short across R3, turn the transmitter on, and gradually increase power until a meter reading is noted. With an insulated screwdriver, adjust C2 for a null in the meter reading.

The next step is to reverse the coax-connections to J1 and J2. Place S2 in the REFLECTED position and apply transmitter power until the meter reads full scale at 100 watts output. In this mode the REFLECTED position actually reads forward power because the bridge is reversed. Calibrating resistance R3 is set to obtain 100 watts full scale during this adjustment. Now, switch S2 to FORWARD and temporarily place a short across R4. Adjust C1 for a null reading on M1. Repeat the foregoing steps until no further improvement can be obtained. It will not be necessary to repeat the nulling adjustments on the 1000-watt range, but R5 and R6 will have to be adjusted to provide a full-scale meter reading at 1000 watts. If insufficient meter deflection is available for nulling adjustments on the 100-watt range, it may be necessary to adjust C1 and C2 at some power level higher than 100 watts. If the capacitors tune through a null, but the meter will not drop all the way to zero, chances are that some RF is leaking into the bridge circuit through stray coupling. If this is the case, it may be necessary to experiment with the shielding of the through-line section of the RF head. If only a small residual reading is noted it will be of minor importance and can be ignored.

With the component values given in Fig 10, the meter readings track for both power ranges. That is, the 10-watt level on the 100-watt range and the 100-watt point on the 1000-watt range fall at the same place on the meter scale, and so on. This no doubt results from the fact that the diodes are conducting in the most linear portion of their curve. Ordinarily, this desirable condition does not exist, making it necessary to plot separate scales for the different power ranges.

Tests indicate that the SWR caused by insertion of the power meter in the transmission line is negligible. It was checked at 28 MHz and no reflected power could be noted on a commercially built RF wattmeter. Similarly, the insertion loss was so low that it could not be measured with ordinary instruments.

Operation

It should be remembered that when the bridge is used in a mismatched feed line that has not been properly matched at the antenna, a reflected-power reading will result. The reflected power must be subtracted from the forward power to obtain the actual power output. If the instrument is calibrated for, say, a 52-ohm line, the calibration will not hold for other values of line Z_0.

If the instrument is to be used for determining SWR, the reflected-to-forward power ratio can easily be converted into the corresponding voltage ratio for use in Eq 2 given earlier. Since power is proportional to voltage squared, the normalized formula becomes

$$\mathrm{SWR} = \frac{1 + \sqrt{k}}{1 - \sqrt{k}}$$

where k is the ratio of reflected power to forward power. The *power* curve of Fig 8 is based on the above relationship, and may be used in place of the equation to determine the SWR.

An Inexpensive VHF Directional Coupler

Precision in-line metering devices capable of reading forward and reflected power over a wide range of frequencies are very useful in amateur VHF and UHF work, but their rather high cost puts them out of the reach of many VHF enthusiasts. The device shown in Figs 14 through 16 is an inexpensive adaptation of their basic principles. It can be made for the cost of a meter, a few small parts, and bits of copper pipe and fittings that can be found in the plumbing stocks at many hardware stores.

Construction

The sampler consists of a short section of handmade coaxial line, in this instance, of 52-ohms impedance, with a reversible probe coupled to it. A small pickup loop built into the probe is terminated with a resistor at one end and a diode at the other. The resistor matches the impedance of the loop, not the impedance of the line section. Energy picked up by the loop is rectified by the diode, and the resultant current is fed to a meter equipped with a calibration control.

The principal metal parts of the device are a brass plumbing T, a pipe cap, short pieces of 3/4-inch-ID and

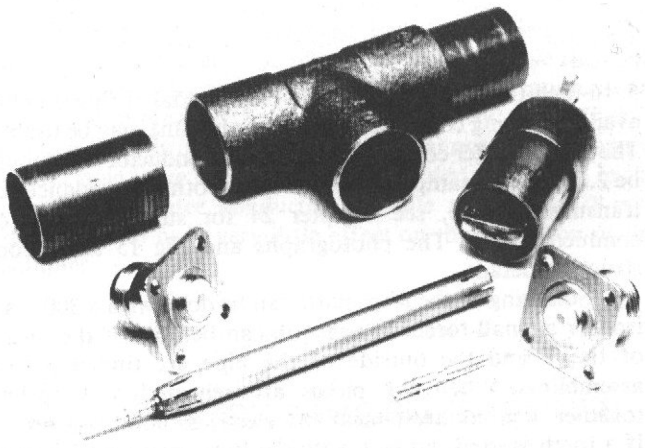


Fig 14—Major components of the line sampler. The brass T and two end sections are at the upper left in this picture. A completed probe assembly is at the right. The N connectors have their center pins removed. The pins are shown with one inserted in the left end of the inner conductor and the other lying in the right foreground.

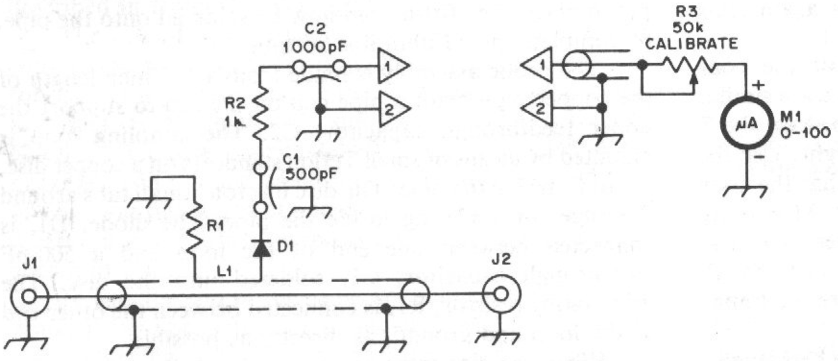


Fig 13—Circuit diagram for the line sampler.
C1—500-pF feedthrough capacitor, solder-in type.
C2—1000-pF feedthrough capacitor, threaded type.
D1—Germanium diode 1N34, 1N60, 1N270, 1N295, or similar.
J1, J2—Coaxial connector, type N (UG-58A).
L1—Pickup loop, copper strap 1 in. long × 3/16 in. wide. Bend into "C" shape with flat portion 5/8 in. long.
M1—0-100 μA meter.
R1—Composition resistor, 82 to 100 ohms. See text.
R3—50-kΩ composition control, linear taper.