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UHF Power Measurements

By the Engineering Department, Aerovox Corporation

ALTHOUGH the methods used to measure the r.f. power output of ultra-high frequency oscillators and amplifiers differ considerably from the techniques employed at lower frequencies, they are in some respects more direct and accurate. Most of these methods convert the radio frequency energy to be measured into heat in a resistive material and then compare some manifestation of this heat with an equal effect produced by an easily measured d.c. or low-frequency a.c. power. Thus, such systems are self-calibrating, and are limited in accuracy only by the extent to which the incident power is totally absorbed in the lossy material, the sensitivity of the power indicating means, and the precision with which the calibrating power is substituted and measured.

The general types of UHF power meters may be classified according to which manifestation of heat is employed. The three most frequently used are;

(a) Lamp loads (light).

(b) Bolometers and thermistors (resistance change).

(c) Calorimetric loads (temperature rise).

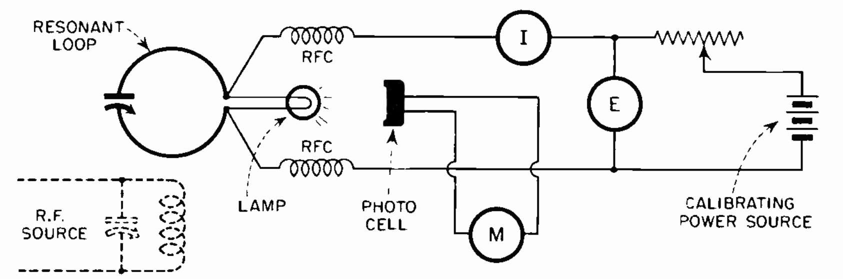
Because of the individual characteristics and limitations inherent in each of these methods, their use is generally confined to different fields of UHF power measurement. These characteristics and special applications will be considered here.

Power Determination By Lamp Load

At the low frequency end of the UHF spectrum, the power delivered by a signal source may sometimes be measured by using it to light the filament of one or more incandescent bulbs and then measuring the amount of power from a known source required to produce the same illumination. A photoelectric cell or photographic exposure meter is usually used to indicate the relative light intensity.

Fig. 1 shows the essentials of a typical system using a lamp load. The lamp is connected in series with a resonant L-C circuit coupled inductively to the r.f. power source. The calibrating a.c. or d.c. power is connected to this circuit through r.f. chokes which prevent the leakage of r.f. power into the calibrating circuit. The calibrating power source should be variable and metered by a wattmeter or voltmeter-ammeter combination.

Power measurement by lamp loads is usually limited to frequencies below 1000 megacycles/second by radiation losses, and by the fact that the filament in which the power is dissipated must be short compared with the wavelength of the power being mea-



SIMPLE LAMP LOAD POWER METER
FIG.1

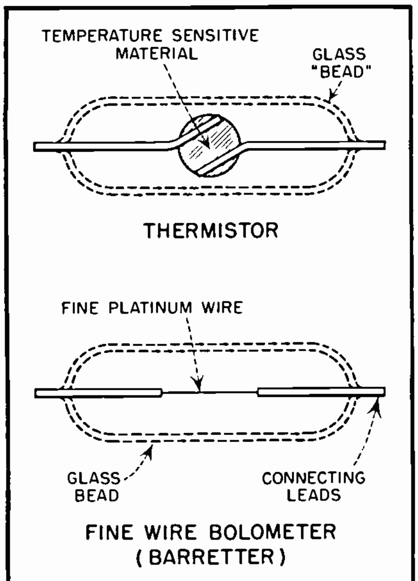


FIG. 2

sured. Otherwise, standing waves will exist on the filament, with corresponding variations in brightness. Power measurements are also limited to the range of powers which can produce incandescence in a filament. This range is from several hundred milliwatts to several hundred watts.

At best, power determinations by lamp load methods are capable of only fair accuracy and so are used principally for quantitative measurements with open-wire circuits.

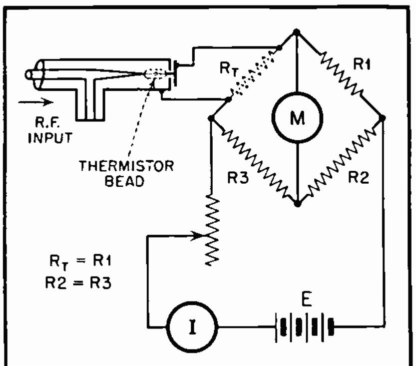
Bolometer and Thermistor Bridges

Most conducting materials, including all metals, exhibit a resistance change when heated. This property is utilized in a family of devices known as "bolometers" and "thermistors" to make accurate power measurements over a wide range of power and frequency. Typical constructions are illustrated in Fig. 2. The temperature sensitive element is hermetically sealed in a glass bead, or capsule, and fitted with connecting leads. In the case of the bolometer, the element is a fine platinum wire only a few ten-thousandths of an inch in diameter. Another name for such devices is "barretters". The element in thermistors consists of a compound of metallic oxides fused between the connecting leads. The resistance-temperature coefficient of thermistors is negative rather than positive, as in the pure-metal bolometers, and is numerically larger. Thermistors are therefore capable of somewhat greater sensitivity, as well as exhibiting better overload characteristics.

In measuring power with temperature sensitive elements of this type, the transmission line carrying the power is terminated in the bolometer or thermistor so that all incident power is dissipated in the temperature sensitive element. The resulting temperature rise causes a corresponding resistance change in the element, which is also connected to form one arm of a Wheatstone bridge circuit, as in Fig. 3. This bridge is usually balanced prior to the introduction of the r.f. power, so that the resistance change in the thermal element causes an unbalance current which is directly proportional to incident power to flow in the meter. The actual r.f. power is determined by measuring the amount of a.c. or d.c. biasing power which must be subtracted from the bridge circuit to re-balance it Bridges used in this manner are called "balanced bridges". The bridge may also be used as an "unbalanced bridge" by assuming that the meter deflection is linear with power, as it is when used within the power ratings of the element, and calibrating it against a balanced bridge at one or more points.

By the nature of their construction, temperature sensitive elements of the bolometer and thermistor type are limited to the direct measurement of low power. Very accurate power determinations are possible in the range between one microwatt and several milliwatts. This range may be extended to very much higher power levels through the use of attenuators or directional couplers of known attenuation.

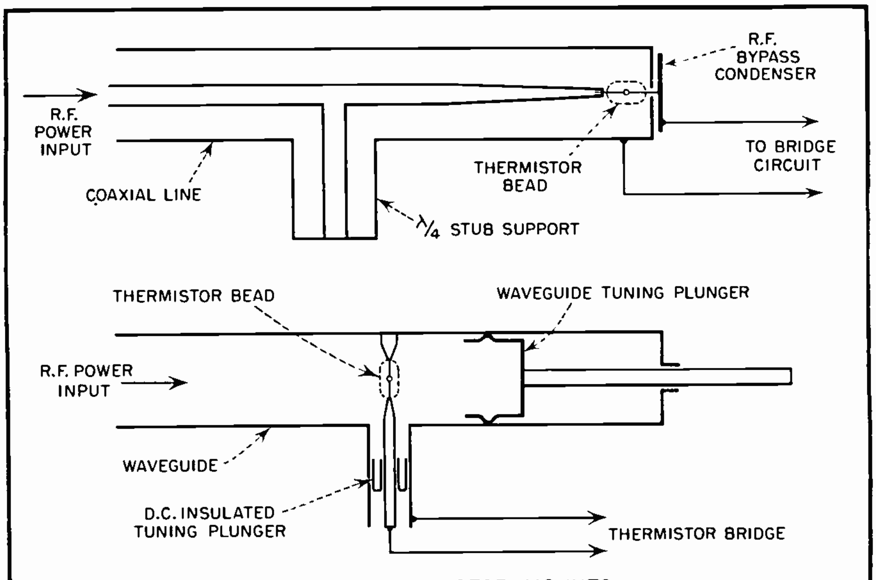
To achieve good accuracy with bolometer or thermistor bridge measurements, all of the incident power must be dissipated in the thermal element. In other words, the resistance of the element must match the impedance of the transmission line at the frequency of the incident power being measured. Methods have been evolved of mounting elements of this type in both coaxial and waveguide transmission lines so that a good match exists over bandwidths of at least 50%. Examples of typical "broad-banded" thermistor mounts are shown in Fig. 4. A standing wave indicator is usually used in conjunction with such mounts to measure the degree of match existing between the line and the load. Since the resistance of the thermal element varies with temperature, it may be made to present a better match by adjusting the bridge current flowing through it.



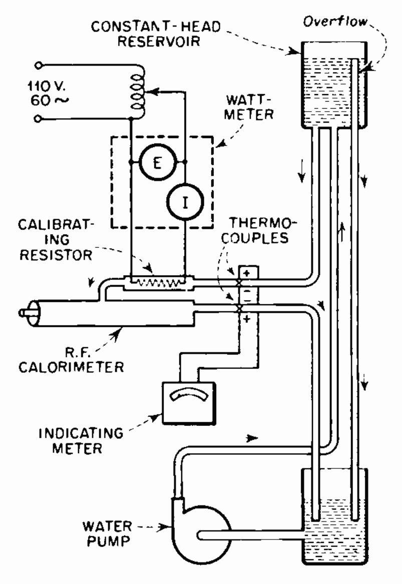
SIMPLIFIED THERMISTOR BRIDGE
FIG. 3

Calorimetric Loads

The third type of UHF power meter which is in common usage is the calorimeter or "water load". In this method, the power to be measured is absorbed in a column of water or other liquid which circulates through a section of the transmission



TYPICAL THERMISTOR MOUNTS
FIG. 4



COMPLETE WATER LOAD SYSTEM
FIG. 5

line. The power dissipated in the liquid results in a temperature rise which is measured by thermometers or thermocouples and is directly proportional to the r.f. power. If the liquid used is water, and the rate of flow and temperature rise are known, the power may be calculated by:

(1) $$\text{Average power (watts)} = 4.18\ F\ \Delta T$$

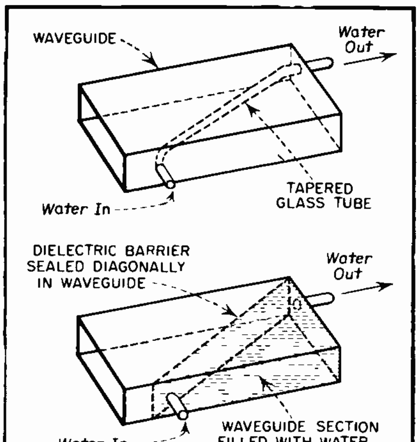
Where: F is the flow rate in cubic centimeters/sec.
ΔT is the temperature rise measured. (Degrees C.)

This calculation is eliminated in some modern calorimetric systems by resorting to power substitution. For this method no knowledge of the rate of flow is required, although a constant rate must be maintained. A diagram of a system of this type is given in Fig. 5. The transmission line is terminated by the calorimeter load. Water flows through this load at a constant rate, as determined by the constant-head reservoir. A pair of temperature indicating devices, such as thermometers or thermocouples, are mounted in the water stream near where it enters and leaves the calorimeter. An a.c. or d.c. calibrating load resistor is also mounted between the points of temperature measurement, which are arranged to indicate the temperature *rise* between them. In the case of thermocouples, this is done by connecting the "cold" and "hot" junctions in opposition. Thus, the meter reads zero until there is a temperature increment due to heat in the r.f. or a.c. loads.

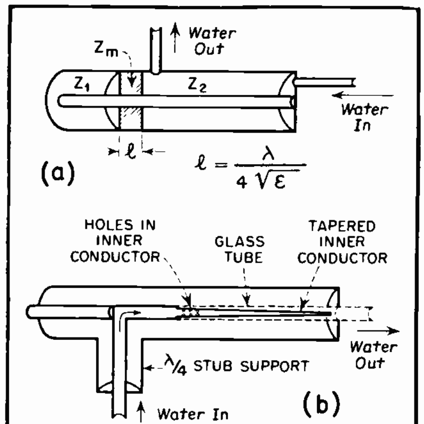
To measure power with this water load, the meter deflection is noted with the r.f. source turned on. This power is then removed and an equal deflection is produced by substituting low frequency calibrating power in the load resistor. If the thermal conditions for the load resistor are similar to those of the r.f. load, the calibrating power required to produce the same deflection will be equal to the r.f. power and can be read directly from the wattmeter.

The errors in this system can be reduced to a very low minimum. The water flow is usually selected so that the temperature rise is only a few degrees above room temperature, thus minimizing errors due to heat radiation from the water tube. Another possible error arises from the fact that heat produced in the r.f. load undergoes additional losses in flowing through the calibrating resistor, or conversely, depending on the direction of water flow. This error could be virtually eliminated by mounting the resistor in the same place in the calorimeter that the r.f. power is absorbed. However, for reasons of impedance matching which will be discussed later, this is usually impractical. A reasonable compromise can be had by designing the load resistor in two parts so that half of the calibrating power is substituted on each side of the r.f. calorimeter. In this manner half of the calibrating power undergoes more losses than the r.f. produced heat while the other half experiences less. Thus the error tends to average out.

In the design of calorimetric power absorbers, several requirements must be met. The water column must be a good impedance match over the frequency range, so that all power is absorbed. The volumn of liquid heated must be large enough to dissipate the power to be handled, but must



TYPES OF WAVEGUIDE WATER LOADS
FIG. 7



TYPES OF COAXIAL WATER LOADS
FIG. 6

not be too large; otherwise the response will be very sluggish.

Fig. 6 shows two designs which have been used with coaxial lines. The load illustrated at 6a makes use of a quarter-wave dielectric bead transformer to effect an impedance match between the air-filled line and the water-filled section. The impedance of the bead section must satisfy the familiar condition for quarter-wave transformers:

(2) $$Z_m = \sqrt{Z_1 Z_2}$$

Where: Z_m is the impedance of the matching section.
Z_1 is the impedance of the air-filled line.
Z_2 is the impedance of the water-filled section.

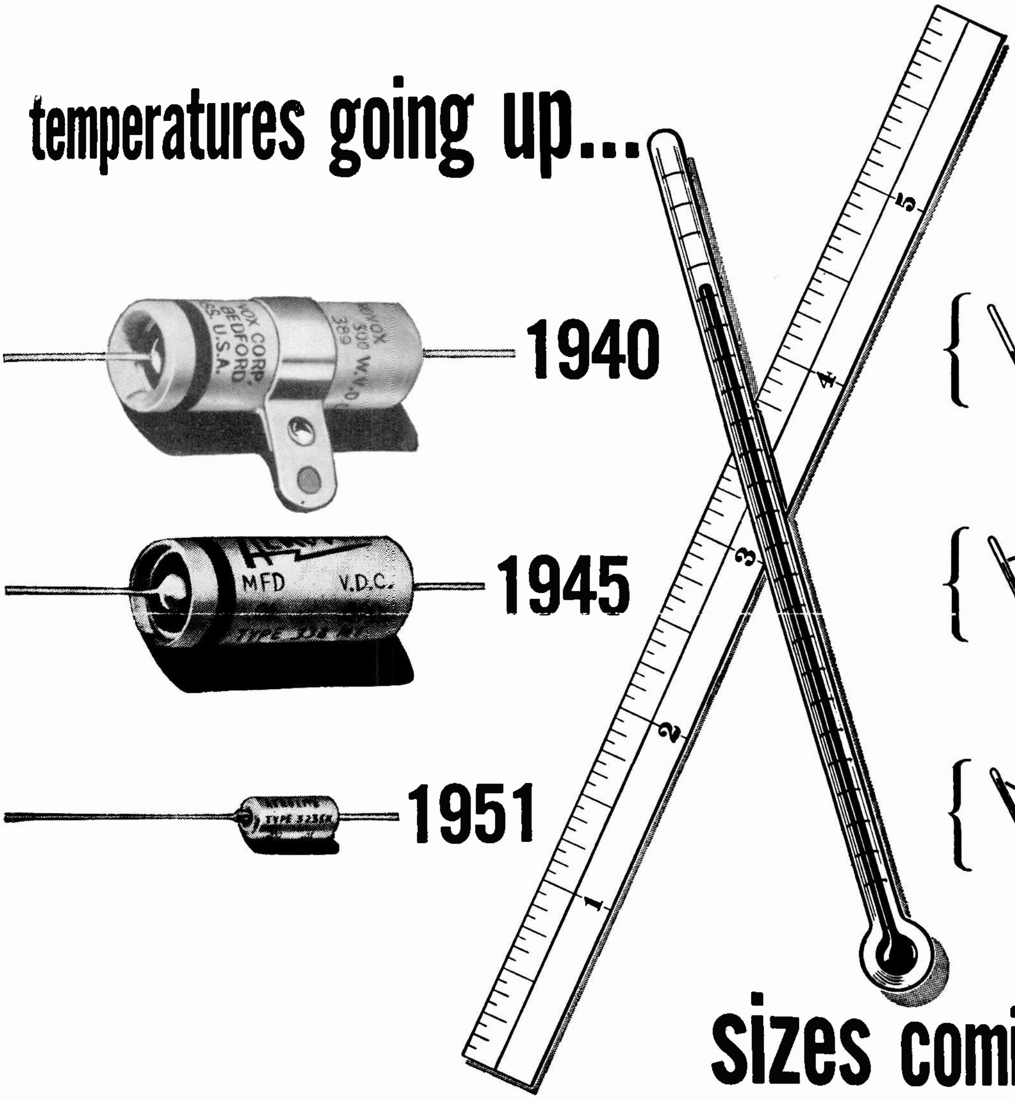
This is achieved by selecting a material for the bead which has a dielectric constant of about 9, which is the geometric mean between that of air (1) and water (about 81).

The load depicted in Fig. 6b is effective over a greater bandwitdh than the quarter-wave transformer type discussed above. This is because impedance matching is done gradually by tapering the water column rather than introducing it abruptly. The center conductor of the load is gradually replaced by the water stream. The water is introduced through the stub support, which is the only frequency-sensitive element in the load.

Two types of water calorimeter loads which are used with waveguide transmission lines are shown in Fig. 7. The kind which employs a glass water tube diagonally across the guide is usually preferable because of less thermal lag.

Water loads are useful as power indicators over the range of several watts to several thousand watts. They are not generally applicable to lower power measurements.

temperatures going up...



65°C TYPE 89
$\frac{1}{2}$" x $1\frac{7}{16}$"

85°C TYPE 38
$\frac{5}{16}$" x $1\frac{3}{16}$"

125°C TYPE 323SX
.312" x $\frac{7}{8}$"

sizes coming down...

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