



## An Automatic DC To X-Band Power Meter For The Medium Power Range

**T**O measure high-frequency power in the range above the low milliwatt region where direct bolometric methods reach a limit, it has been usual practice to retain the basic bolometric method but to reduce the power actually measured by a known amount with attenuators and directional couplers. Although this approach provides useful information, a direct method is fundamentally more desirable, since it would avoid the inconvenience of cascading several components into a measuring setup and would also avoid the errors that additional components introduce into the measurement.

Such a direct approach is achieved by a new power meter that automatically measures average power in the range from 10 milliwatts to 10 watts. The instrument is useful to at least 12 kilomegacycles and is also capable of use down to dc if desired. It can be used to measure any of the common forms of power such as ordinary amplitude-modulated, pulsed ac, pulsed video, and dc. In distinction to methods where the rf load is built into a special external mount, the new instrument contains an internal 50-ohm load which acts as the rf termination and is provided with a type N coaxial connector on the panel.

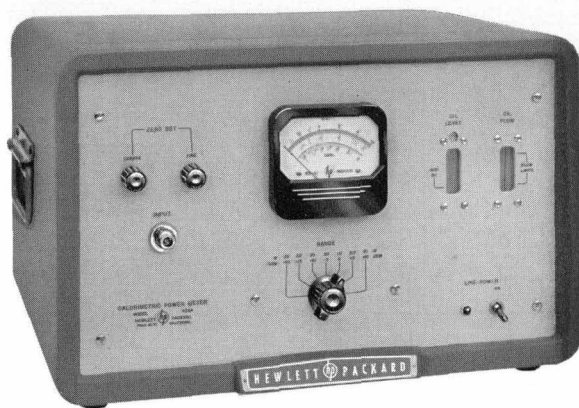


Fig. 1. New -hp- Model 434A Calorimetric Power Meter measures powers between a few milliwatts and 10 watts at frequencies from dc to 12.4 kilomegacycles. Self-balancing type circuitry makes operation automatic and gives reading in less than 5 seconds. Instrument is provided with 50-ohm coaxial input.

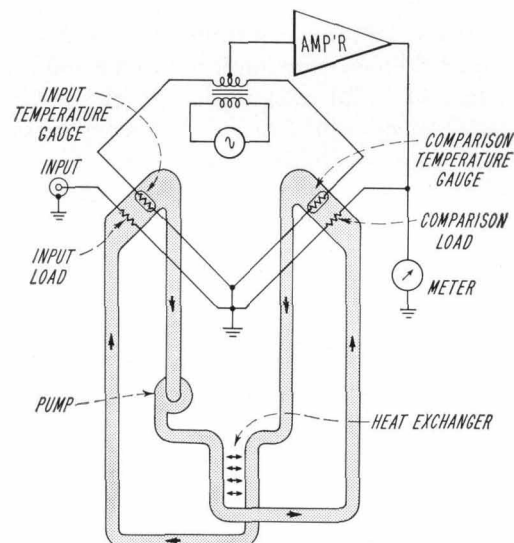


Fig. 2. Basic circuit and oil stream arrangement of Power Meter. Parallel-flow heat exchanger is located physically close to load resistors to bring oil streams entering the two load-gauge regions to same temperature. Arrangement also includes heat radiators (not shown) down-stream from gauge resistors to dissipate heat transferred from load resistors.

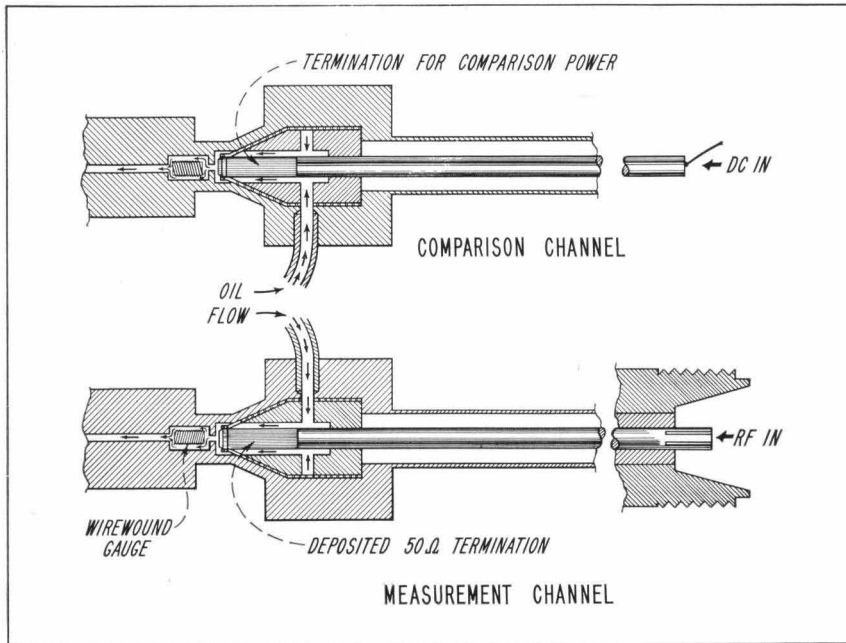


Fig. 3. Basic construction of power-absorbing and temperature-sampling arrangement in measurement and comparison channels.

From a design viewpoint the new power meter is interesting because it combines the self-balancing principle developed for bolometric type meters with the calorimetric principle used in high power measurements. Fig. 2 indicates how these principles are combined. The power to be measured is absorbed in a carefully-designed 50-ohm termination which is located in an oil stream. Immediately downstream from the termination is a temperature-sensitive gauge resistor which becomes heated by the heat the oil stream transfers from the termination. The gauge is part of a bridge circuit which becomes unbalanced by the change in gauge resistance and causes an amplifier to apply power to a second load resistor located in a second branch of the oil stream. The amplifier applies sufficient power to heat a second gauge resistor in the bridge circuit until the bridge is essentially balanced. The power supplied to the second load resistor is then equal to the power to be measured and is read by a calibrated meter. The system has a rapid response time of 3 to 5 seconds, which is of the same order as that of

self-balancing bolometric methods, and a measurement accuracy (nominally  $\pm 5\%$ ), which is better than typical bolometric methods.

Because of its self-balancing feature, the instrument makes a measurement automatically when power is applied. In operation it is only necessary to select the desired power range and to zero-set the instrument to initially balance the bridge. Two gauges are provided on the panel to insure that oil flow and oil supply are adequate, but these are in the nature of monitoring gauges and normally involve no adjustment.

#### CALORIMETRIC ARRANGEMENT

Fig. 3 shows the elements of the arrangement used in the instrument to absorb the power under measurement and to gauge the heat thus generated. The system consists of two channels, one for the measured power and one for the comparison power. In the measurement channel the power is carried from the type N input jack at the instrument panel through a rigid coaxial line to a 50-ohm termination consisting of a metallic film deposited on the far end of the center conductor. The center

conductor itself consists of a glass rod coated with a film of silver which is thin enough to offer low thermal conductivity to the heat produced in the termination. The outer conductor is tapered in the region of the termination to assist in obtaining a good high-frequency characteristic. The tapered portion is further formed with a very thin metal wall to offer relatively high resistance to the passage of heat through the outer conductor. From the standpoint of instrument operation, however, it is more important that the thermal performance of the two channels be identical than that highest thermal insulation be achieved.

In the region of the termination the center conductor is encircled by a split teflon bead which is arranged to permit oil from the circulating stream to flow uniformly over the termination itself. The heated oil then flows to the temperature-sensitive gauge resistor which is positioned immediately following the termination. The oil flows over the gauge resistor in a controlled manner to insure accurate temperature sampling and then passes to a radiator where it is cooled to air temperature before being circulated through the comparison channel portion of the oil loop.

The comparison channel is constructed to be as nearly identical to the main channel system as possible so that identical performance will be obtained. The main difference is that the load resistor in the comparison system has a higher value in order to suit tube ratings. To insure that the temperature of the oil stream as it enters the comparison channel is the same as that entering the measurement channel, the two portions of the oil loop that immediately precede the two load resistors are formed into a high-performance parallel-flow heat exchanger. The oil itself is a very low viscosity (about that of water) silicone oil of high stability.

## CIRCUITRY

Fig. 4 indicates the arrangement of the electronic portion of the instrument. The bridge containing the two gauge resistors is fed from a 1200-cps oscillator through a range-setting attenuator, while the bridge output is applied through an amplifier to a synchronous detector. The synchronous detector permits the system to sense in which direction the bridge is unbalanced and apply comparison power only if the measurement channel gauge resistance is larger (resistor at a higher temperature) than the comparison channel gauge resistance. The detector output is fed through a low-pass filter to a dc amplifier which applies comparison power to the comparison channel load resistor. This power is then monitored by the meter circuit. The meter circuit, however, is a voltage-operated circuit which, in order to be calibrated linearly in power units, must have a square-law characteristic. To achieve this, a shaping circuit consisting of a series of diodes separately biased from a suitable voltage divider is included in the meter circuit. The meter circuit also includes a range-setting attenuator ganged with the attenuator at the output of the oscillator.

An interesting aspect of the circuit is that the rate of flow of oil, although it must be equal in the two gauging regions, does not otherwise enter into the measurement. The reason for this is that, although different flow rates change the temperature rise of the oil for a given input power, the comparison channel matches whatever temperature rise does occur by producing an equal amount of power. No adjustment of flow rate is thus required in operation, and the simple flow rate indicator on the panel is provided only with maximum and minimum acceptable rate calibrations.

Flow rate does, however, enter into the dissipation of the rf termination and it is necessary that the instrument be on and oil circulating

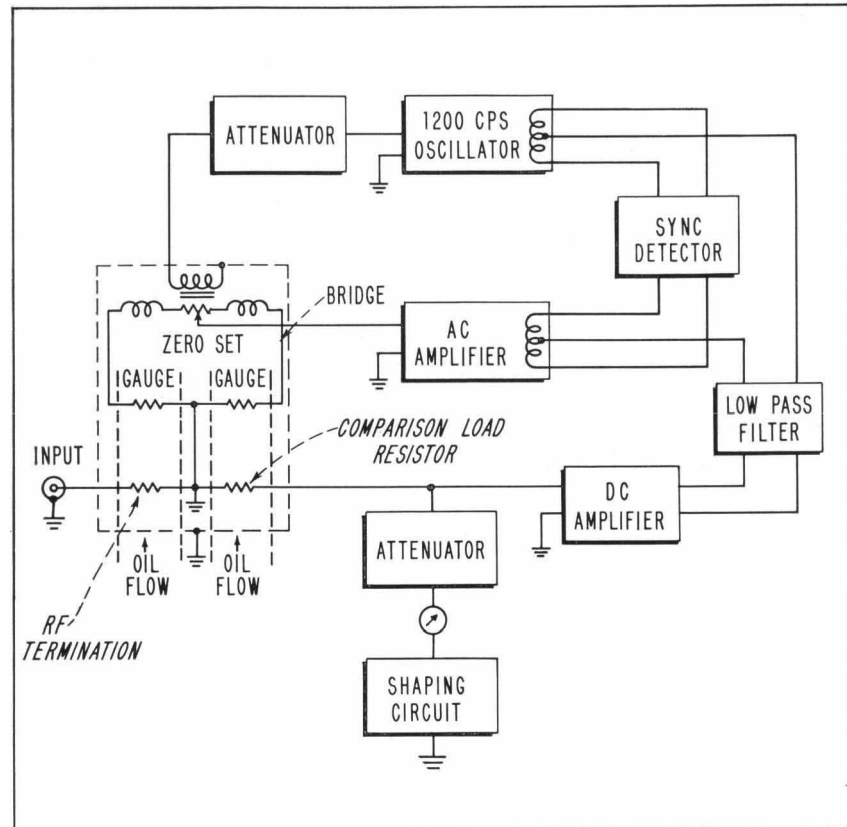


Fig. 4. Basic arrangement of instrument circuitry.

before significant external power is applied. A precautionary note to this effect is permanently marked on the instrument panel near the input connector.

The transit time for the oil stream to conduct heat from the comparison resistor to the gauge resistor enters into the circuit operation as a non-minimum phase shift network in which the phase shift increases linearly with frequency and in which the signal undergoes no attenuation. In the loop design this is controlled by use of the low-pass filter which has an unusually low cutoff frequency of about 1/30 cps.

The circuitry also includes a special arrangement for obtaining a zero set. A zero set is required to enable the bridge circuit to be initially balanced, but unless special measures are taken "overbalancing" (i.e., moving the meter pointer to the left beyond zero) could not be detected since power to the comparison channel load resistor would become zero

both when the bridge was balanced as well as when it was unbalanced in the reverse direction, as it would be when the zero controls were over-set. This situation is prevented and normal zero region operation obtained by biasing the feedback circuit in such a way that moving the zeroing controls to the left of zero causes a small reverse current from the dc supply to flow through the comparison channel load resistor. This current causes the meter pointer to move below zero to achieve typical zero region operation. The amount of reverse dc that can be applied to the comparison resistor is limited, however, so that uncontrolled regeneration can not occur.

## INPUT VSWR

A typical VSWR characteristic for the measurement channel, which is the VSWR effective in a measurement, is shown in Fig. 5. Below about 5 kmc the VSWR is typically below



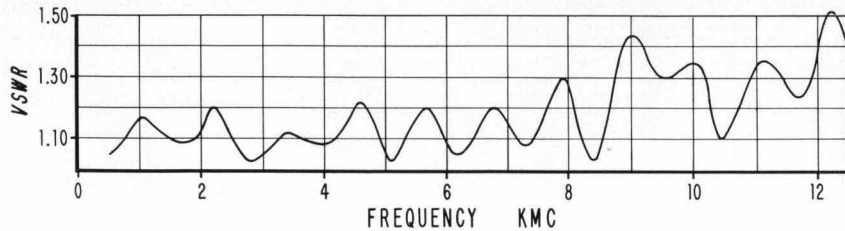


Fig. 5. Typical VSWR characteristic of Power Meter.

1.2, while at the higher frequencies one or two peaks typically approach the rated maximums of 1.5 below 10 kmc and 1.7 below 12.4 kmc.

#### PULSE MEASUREMENTS

The effective time constant of the instrument is such that it will indicate the average power of pulse trains down to very low repetition frequencies in the order of 1 pps. Power-wise, pulses of up to 1 kilowatt peak power can be applied.

#### ACCURACY AND MEASUREMENT CONSIDERATIONS

Since the new power meter represents the most accurate method available for measuring high-frequency power in the medium power range, it is anticipated that it will be used in many instances as a laboratory standard power meter. Where this is the case or in any case where measurements with the instrument are desired to maximum accuracy, suitable techniques should be employed to minimize frequency and impedance mismatch effects, as described below.

The frequency effect referred to is known as "rf efficiency." In the high-frequency power measurement field, this term in the past has principally been applied to bolometer mounts and is intended as a measure of internal losses other than the desired absorption in the termination. It can be defined as the percentage of net applied power that is absorbed by the rf termination. In the bolometer mount field considerable work is currently being done to determine this factor with accuracy. Considerable work has also been

done to establish an rf efficiency factor for the new power meter. To date no rigorous value has been established because the value must be determined through indirect methods and because a large amount of experimental evidence is required. As a result of this work, however, it is recommended that an efficiency decrease factor of  $\frac{1}{4}$  of 1% per kilomegacycle be arbitrarily applied to the measurement. In other words, at 10 kilomegacycles the reading obtained on the meter should be assumed to be 2.5% low when it is desired to correct for the rf efficiency factor. At 10 kmc this rating is thought to be accurate within 1% of the corrected value, since that value of repeatability has been obtained in the investigations to date using two different approaches in the measurements. The rating also appears compatible with the results obtained by other investigators for bolometer mounts.

Accuracy of measurement also requires that the instrument's input VSWR be tuned out with a suitable tuner. These techniques are well-known, but it should be noted that in the kilomegacycle region when it is desired to measure power available from a source, rather than the power available at the end of a cable, it is desirable that the power be carried in waveguide. This not only reduces cable loss but permits a waveguide slide-screw tuner to be used (ahead of a waveguide-coax transition at the instrument connector). Such tuners normally give less loss than arrangements involving coaxial tuners. Consideration should also be

given to whether the measurement is intended to measure the power available to a  $Z_0$  load, in which case the tuner should be adjusted in conjunction with a slotted section to give a flat line. If maximum available power is to be measured, the tuner should be adjusted for maximum reading on the power meter.

Although a nominal figure of  $\pm 5\%$  is put on the instrument accuracy, this figure includes rf efficiency as well as dc calibration. If the rf efficiency factor is applied and tuner loss evaluated, the actual accuracy attainable is generally better than this, depending upon power level, frequency and technique.

On the upper ranges, the calibration at dc is within  $\pm 1\frac{1}{2}\%$  of full scale from range to range, but can easily be set at any desired power level to be within  $\pm \frac{1}{2}\%$  of full scale if suitable dc instrumentation is available to the user. If the rf efficiency correction is applied and the VSWR tuned out as described above, an accuracy of  $\pm 3\%$  may be achieved at 12.4 kmc. On the two lowest ranges, drift and jitter limit the accuracy to  $\pm 2\%$  at dc and  $\pm 5\%$  at 12.4 kmc. —B. P. Hand

#### SPECIFICATIONS

-hp-

#### MODEL 434A

#### CALORIMETRIC POWER METER

Input Power Range: 10 milliwatts to 10 watts in seven ranges with full-scale values of .01, .03, .1, .3, 1.0, 3.0 and 10 watts. Meter scale also calibrated from -10 to 0 DBW, providing continuous reading from -30 to +10 DBW. Power range can be extended upward with attenuators or directional couplers.

Frequency Range: DC to 12.4 kilomegacycles. D-C Input Impedance: 50-ohms  $\pm 5$  ohms at type-N input jack.

Input VSWR: Less than 1.3 to 7 kilomegacycles; 1.5 to 10 kmc, and 1.7 to 12.4 kmc.

Response Time: Less than 5 seconds for full-scale deflection.

Accuracy: Within  $\pm 5\%$  of full scale.

Peak Power: One kilowatt maximum.

Power Supply: 115/230 volts  $\pm 10\%$ , 50/60 cycles, approximately 150 watts with no input, 175 watts with 10 watts input.

Dimensions: Cabinet Mount: 20 $\frac{1}{2}$ " wide, 12 $\frac{1}{2}$ " high, 14 $\frac{3}{4}$ " deep. Rack Mount: 19" wide, 10 $\frac{1}{2}$ " high, 13 $\frac{1}{2}$ " deep behind panel.

Weight: Cabinet mount, 50 lbs. net, 70 lbs. shipping; rack mount, 43 lbs. net, 64 lbs. shipping.

Price: -hp- Model 434A Calorimetric Power Meter, Cabinet Mount \$1,115.00 f.o.b. Palo Alto, California.

-hp- Model 434AR Calorimetric Power Meter, Rack Mount \$1,100.00 f.o.b. Palo Alto, California.

Data subject to change without notice.