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A Sensitive Thermal Power Meter

A measuring instrument is to be described that has seven measuring ranges from 100 μW to 300 mW, and whose upper frequency limit is way up in the X-band! Construction should not be difficult for those readers having adequate mechanical skill, and a magnifying glass; only a few special parts are required which are easily available.

1. POWER MEASUREMENT PROBLEMS

For radio amateurs, power measurement is probably one of the most difficult areas in radio frequency measuring technology. The various types of diode voltmeters, see **Fig. 1**, have three distinct disadvantages:

1. The junction capacitance of the test diode (1-4 pF) represents a parallel capacitance to the load resistance. For instance, the amount of the capacitive reactive impedance will be less than the 50 Ω load resistor when using a Schottky diode HP 2800 even at 1.6 GHz. In conjunction with the inavoidable circuit inductivity, this will lead to noticeable resonance effects, which limit this type of power measurement to frequencies up to approximately 1 GHz, if a special scale calibration is not used.

2. The non-linearity of the diode characteristic will be noticeable at low AC-voltages. This leads to a non-consent mathematical scale calibration inspite of subsequent amplification and delogarithming. If one is to avoid the very extensive compensation method, it will be necessary for the scales to be calibrated point by point, for instance by calibrating it against a precision meter.

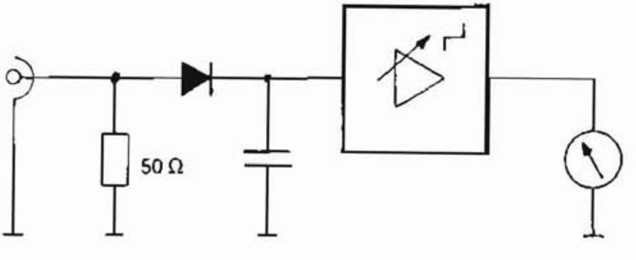

Fig. 1: A diode voltmeter as power meter

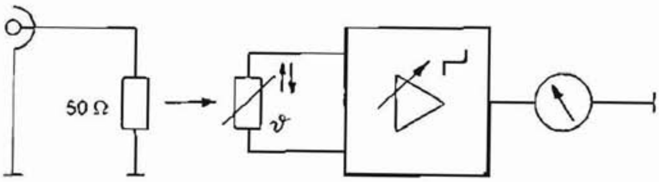

Fig. 2:
Principle of a thermo-power meter operating according to the bolometer principle

3. The calibration of the diode voltmeter is made in RMS-values, however, the measurements are made with peak voltages. In the case of subsequent measurements on amateur equipment, the required sinewave signal will be superimposed with harmonics, subharmonics, conversion products, and unwanted oscillations. When the maximum values of the individual voltages coincide, peak voltages are provided to the diode, which have no relationship to the RMS-value. The output power of oscillating stages can be even higher than the power consumption from the power line.

The described disadvantages of diode voltmeters can be avoided or at least reduced when using the bolometer principle (see **Figure 2**), since the load resistance is only to be found in the RF-circuit. The heating is a linear function of the RMS-value of the RF-power, at least at low temperatures. The temperature increase is measured with the aid of a NTC-resistor, which will lead to a power-linear scale calibration. Calibration and accuracy measurements on such a unit can be made with the aid of DC-voltages.

Fundamental considerations were made in (1), (2), (3) and (4). A suitable construction was described in (1) Higher sensitivities can be achieved with the aid of thermo-elements using thin-film technology (5).

The described meter has seven measuring ranges from 100 μW to 300 mW (FSD). Its upper frequency limit is in the X-band. One disadvantage is the somewhat long transient time of this method (50% of full scale after 1 s), which means that no modulation measurements can be made

2. COMPONENT SELECTION

The 50 Ω load resistor should be as small as possible. A small mass results in a short thermal transient time, as well as a high temperature coefficient (meter sensitivity), and has a positive effect on the upper limit frequency The smallest, inexpensive, and available resistor (51 Ω) uses a flat metal-glazed conductor and is sometimes designated as micro-miniature resistor (62.5 mW). It is in the form of a bead-type microchip resistor that has been dipped in lacquer, and they are usually used in layer circuits. After carefully removing the lacquer, one will obtain a ceramic chip whose dimensions are 2.2 mm × 1.2 mm × 0.8 mm.

The temperature-probe resistor should also have a low mass and thus a short transient time. In addition to this, high-impedance resistors are preferable, since these exhibit the lowest intrinsic heating as result of the connected test voltage. The Siemens Thernewid-NTC resistor type K 19 is very suitable. This component comprises a glass bead of 0.4 mm diameter and possesses virtually invisible connection wires. This component is so sensitive that it will react to the radiation heat of one's hand without delay, even at a spacing of 1 meter. Unfortunately, this resistor, which can also be supplied in pairs, is not inexpensive, but it is also offered by several other manufacturers.

Experiments made with the thermoprobes SAK 1000 and KTY 11 resulted in an inferior limit sensitivity, and the transient time was at least ten times longer.

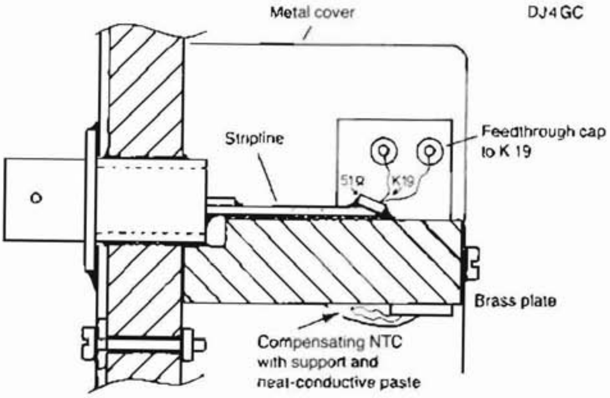

Fig. 3: Suitable construction of the bolometer

3. CONSTUCTION OF THE RF-CIRCUIT

Of course, the NTC-resistor must be directly glued to the load resistor (with very little two-component adhesive). However, due to its high sensitivity, it should be thermally decoupled from the input connector. For this reason, it is not recommended for the load resistor to be directly soldered to the RF-connector, since the mechanical tension passed via the inner conductor could destroy the chip resistor. A favorable solution was found by using a 50 Ω stripline in conjunction with a heat sink (brass plate) for interconnecting the load resistor to the input connector. This type of construction is shown in **Figure 3.**

In order to ensure a high cutoff frequency, the stripline should be ideally on a PTFE-material (double-coated). A stripline width of 2.3 mm will result when using 0.8 mm thick RT/duroid 5870 material. In the author's prototype, the stripline is 12 mm in length. Of course, epoxy PC-boards can be used up to several GHz without problems due to the non-resonant conductor lane. When using 1.5 mm thick epoxy PC-board material, the stripline width is 3.1 mm.

Special care must be taken in the transition between the coaxial connector and the stripline. Although N-connectors have more favorable RF-characteristics than BNC-connectors, the former will exhibit are more noticeable incontinuity at the transition. Professional users specify SMA-connectors up to 18 GHz.

In order to achieve the shortest possible transient time of the bolometer, a good heat dissipation is obtained at the cost of maximum sensitivity. Heat-conductive paste should be provided between the stripline board and the brass heat sink, which is also placed around the chip resistor. Temperature fluctuations coming from the input connector are compensated for with the aid of a second brass plate **(Figure 4).** Since the thermal probe still reacts to the radiation heat reaching the case, the whole bolometer is surrounded in a metal case.

Any excessive solder on the stripline should be removed with a file in order to ensure a low heat delay. The NTC-resistor should be glued into position only after this has been carried out.

The fragile connection wires of the K 19 are supported on the RF-side with the aid of feedthrough capacitors, and on the lower side with the aid of a small board that has been glued into place.

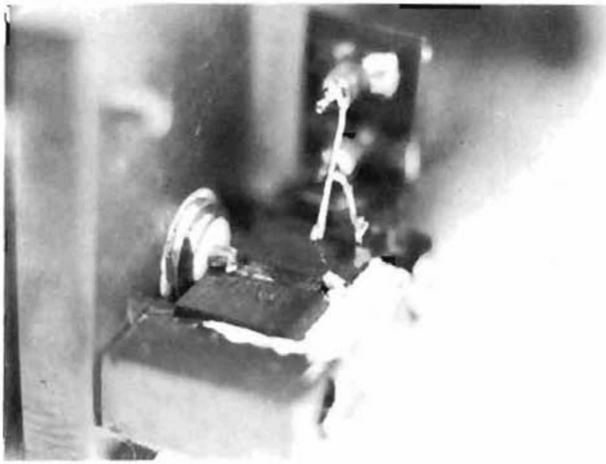

Fig. 4:
RF-circuit with bolometer and heat sink

The author's prototype is mounted in a compact, standard metal box whose dimensions are 111 mm × 73 mm × 50 mm (see **Figure 5**).

4. MEASURING AMPLIFIER

In order to maintain the zero-point stability, and the calibrated meter sensitivity, it is recommended that a brigde circuit be used together with a second K 19 (paired to have the same temperature coefficient), in order to

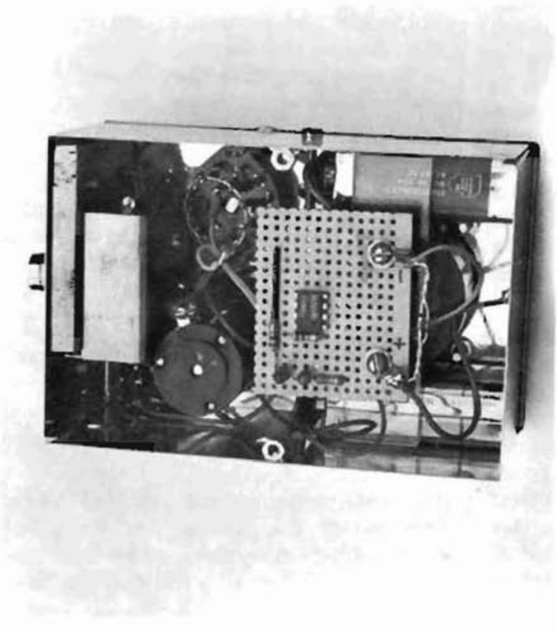

Fig. 5:
Photograph of the author's prototype; RF-portion under the metal cover.

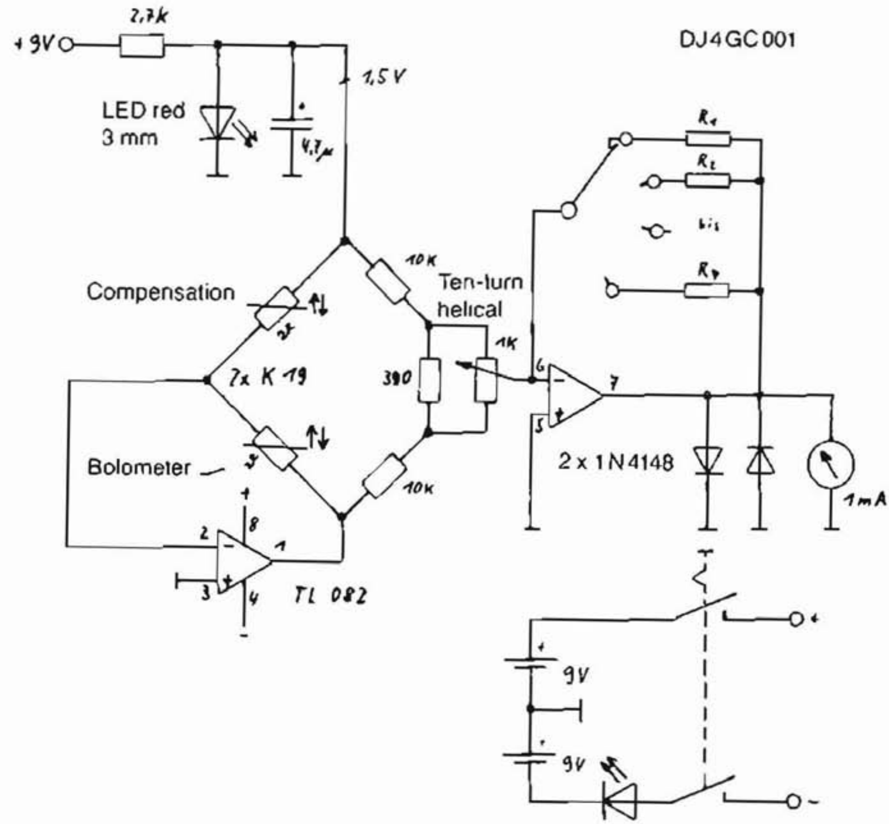

Fig. 6: Circuit of the thermo-power meter

compensate for ambient temperature fluctuations, (see **Figure 6**).

The first operational amplifier maintains a constant current via the test NTC resistor, which allows a linear transfer of its resistance value to the actual test amplifier. The zero-point should be adjusted before commencing the measurement with the aid of a low-impedance, shunted, ten-turn helical potentiometer. If a larger case is used, it is also possible for less-expensive coarse and fine controls to be used.

The reference voltage is provided by a LED, which is connected as zener diode. Higher voltages than 1.5 V will, however, improve the sensitivity of the reading, however, will lead to considerable intrinsic heating of the thermal probe

In order to change the measuring range, the feedback resistors of the second operational amplifier are switched.

The resistance values and the measuring ranges (full-scale deflection) are:

R_1 = 2.2 MΩ (0.1 mW)
R_2 = 680 kΩ (0.3 mW)
R_3 = 220 kΩ (1 mW)
R_4 = 68 kΩ (3 mW)
R_5 = 22 kΩ (10 mW)
R_6 = 6.8 kΩ (30 mW)
R_7 = 1.4 kΩ (300 mW)

The meter cannot be overloaded since the operational amplifier possesses an internal current limiting. Since an offset alignment is not required, it is advisable to use a low-drift dual-operational amplifier in an eight-pin case, such as the TL 082. In the most sensitive range, the flicker noise of the operational amplifier will cause a certain fluctuation of the meter reading.

The operating current is only in the order of 5 mA, which means that two 9 V-batteries can be used as power supply. The meter will also operate perfectly at ± 5 V.

5. ALIGNMENT

The calibration of the meter is made with direct current. It is advisable to adjust the current to the full-scale deflection of the appropriate range with the aid of a digital multimeter.

The feedback resistors R_1 to R_6 of the test amplifier are selected to have the highest accuracy from a large selection of resistors. Since the sensivity of the bolometer is greatly dependent on the mechanical construction, the given values are only for orientation.

Due to the non-linear relationship between the temperature and the resistance value of the NTC-resistor, it is necessary for the highest range of 300 mW to be calibrated independently on the scale, (see Figure 7). In the 30 mW-range, the deviation is still only a maximum of 4%, and should thus be acceptable

Fig. 7: This photograph shows the scale calibration with the 300 mW scale at the bottom

6. MEASURED VALUES

It was possible before manufacturing the power meter to measure the input return loss of the RF-circuit with the aid of a network analyzer It was found that a return loss of 20 dB (corresponding to approx. 1.2 VSWR) can be achieved up to a frequency of 2 1 GHz. The return loss of 10 dB (approx. 2 VSWR) is only exceeded at 11 GHz.

A 3 GHz oscillator having an output power of 25 mW with an accuracy of ± 01 dB was now connected to the meter and this power was indicated with an accuracy of the meter-needle. The Gunnplexer manufactured by Microwave Associates (15 mW at 1036 GHz) provided 12 mW of heat after being adapted from waveguide to BNC.

The meter reaches 50% of the full-scale value after approximately 1 second; 90% of the final value is passed after 3.4 s. The transient time τ (63% of the final value) is in the order of 1.5 s.

7. PRACTICAL EXPERIENCE

Due to the short length of the stripline used, a certain temperature sensitivity exists via the inner conductor of the input connector, since both NTC-resistors are not heated simultaneously. In the very low power range, it is advisable to work together with an intermediate cable which remains connected to the meter. Otherwise, the zero-point stability is so high that it is possible to carry out measurements directly after switching on. In the case of the two most sensitive ranges, it is advisable to leave a warm-up time of appoximately three minutes

The calibration was made at 20°C. A further test in a refrigerator at 5°C did not show large deviations.

The speed of the reading is approximately as high as that of a dampened laboratory meter. Taking all advantages of this measuring system into consideration, it will not be found that alignment work is made more difficult due too slow an indication

The dynamic range of the power meter can be increased by adding wideband amplifiers (e g as described by DJ7VY), attenuators, or directional couplers. However, the frequency range will be limited by this. It is possible, for instance, to use a directional coupler with an attenuation of 40 dB to increase the measuring range up to 3 kW. The exact value of the loss can be measured previously using this meter.

The high sensitivity of this meter (the resolution is in the order of 1 µW) allows one to also measure the frequency, or attenuation characteristics of filters, bandpass filters, directional couplers, frequency multipliers, mixers, low-signal amplifiers, etc., in addition to purely power measurements, and its high dynamic range can be used right up to X-bands.

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