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A Thermal Power Mount

The exact measurement of high-frequency power possesses, for most amateurs, an enormous problem. The most accurate results are provided by the so-called thermal power meters. These process the heat developed in an HF-mount resistor which has been subjected to the signal-under-test. The home construction of thermal power mounts has already been covered in VHF COMMUNICATIONS in (1), (2) and (3); they operate right up to 11 GHz but exhibit a very large inertia.

Another form of thermal mount will be described in this article which utilizes micro lamps as the measurement element. The electronic processing can be carried out by an easily modified power meter, indicator unit such as the Hewlett Packard 431 C. These items, without the thermal mounts, may be purchased at flea-markets etc, for a very favourable price.

1. A LITTLE POWER MEASUREMENT THEORY

The techniques involved in power measurements can be roughly divided according to (5), into two main caregories, thermal and diode rectification. The thermal technique can be further divided into direct and substitution methods. The calorimeter techniques, also mentioned in (5), for the measurement of large powers will be ignored in this article.

When the radio amateur thinks about the subject of HF power measurement, he immediately calls to mind the circuit of **fig. 1**. This is a typical power instrument using rectified HF by means of a diode. The power to be measured is absorbed into a resistor (typically 50 Ω) and thereby produces a potential difference across it, which is measured by a diode detector/voltmeter. This simple technique will yield accurate results only if two conditions are fulfilled. Firstly, the HF voltage to the diode rectifier must exceed a few volts in order that the diode barrier voltage becomes negligible in comparison. Secondly, the voltage to be measured must be sinusoidal, as the measurement circuit responds to the peak value of the voltage but the HF power is assessed from the root-mean-square of the input. Assuming a sinusoidal display, the peak value can be written down immediately as being $\sqrt{2}$ x rms value and the indicator scale may be calibrated accordingly – directly in terms of power.

A diode rectifier can, in principle, detect high frequency voltage right down to a milli-volt (approx.) i.e. a power of – 47 dBm/50 Ω. At very

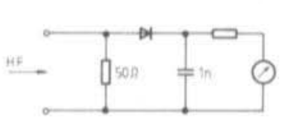

Fig. 1: Circuit of an HF power detector using diode rectification

low HF voltage inputs, however, the behaviour of the diode rectifier changes such that the output voltage is increasingly proportional to the input power, and not to the input voltage. If it is required only to measure very small powers, the rectifier characteristic has to be compensated for both linearity and temperature. Using this kind of attention to design detail, it is possible to construct a power meter which possesses a dynamic range which extends from − 50 dBm to + 20 dBm. The advantage of employing this complexity is that the end result is a responsive indicator system equally suited to sweep displays as well as for the momentary displays of transient signals. Commercial instruments, nowadays, carry the necessary information to correct the diode characteristic in an EPROM which is automatically called into service whenever a measurement is made.

As the complexity of the electronics is quite high, and the indication is still only true for sinusoidal signals, this type of realization for a precision HF power meter is not feasible.

The thermal method of power measurement is inherently capable of delivering an exact power value of the test signal quite irrespective of its form. The usual technique is to heat the load resistance with the test signal and then measure the heat expended by means of a thermistor. The advantage of this technique is that the resistor's physical form can be optimized to accomodate the frequency of interest, e.g. a chip resistor can be employed at very high frequencies. The indicator display's inertia, which is determined by the thermal mass of the resistor and its coupling to the temperature transducer, can be in the order of a few seconds.

A more responsive display is obtained when the measurement resistor and the temperature transducer are unified in one construction. The basic principle of the technique is the self-balancing bridge circuit of **fig. 2**. A temperature-dependent, measurement resistor is included in one arm of a Wheatstone bridge. The actual value of this resistor is dependent upon the converted power loss, and in consequence, upon the supply voltage to the bridge circuit. This implies that the bridge is only balanced at a certain bridge

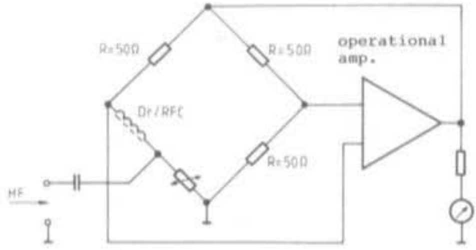

Fig. 2: Self-balancing bridge for the measurement of RF power

supply voltage, at which value, the measurement resistor is equal to the resistance of the other three arms of the bridge. An amplifier adjusts the bridge supply voltage to achieve this balance. If the HF power to be measured is increased, the measurement resistor heats up and the bridge unbalances. The operational amplifier reduces the DC supply current to the bridge until it again balances. The reduction in supply current is proportional to the increase in HF measurement power. This is a type of substitution measurement technique in which the DC power is substituting for HF power. Instead of a DC source, however, the bridge supply could work at a low, alternating frequency, say 10 kHz. The principle remains exactly the same but the advantage lies with the elimination of DC drift problems in the operational amplifier which would falsify the very small voltage changes involved.

This circuit cannot, however, distinguish between a temperature change which is due to the power to be measured and a change in the ambient temperature. For this reason, a practical measurement instrument contains two bridges, one for the actual measurement, and another which is influenced by the ambient temperature. The indicated reading is then the difference evaluation of the two bridge balances.

Thermal power meters from General Microwave and Hewlett-Packard (4) work according to this principle, and use bead thermistors as the measurement element. This type of instrument, together with its measurement mount, is exceedingly expensive but the instrument itself can be picked up quite cheaply. The author therefore set himself the task of designing and constructing a replacement power mount which could be reproduced by the radio amateur.

2. MICRO LAMPS AS MEASUREMENT ELEMENTS

The first thoughts for the design of a power mount involved the use of a thermistor as the measurement element. Experiments with glass encapsulated bead thermistors resulted in a disappointing outcome.

An alternative is the use of a PTC resistor: in the beginning of the microwave technology, barretters were used for power measurements. These are thin tungsten filaments which are heated by HF power and thereby change their resistance. The resistance change per degree of temperature change is lower than with the thermistor and the temperature characteristic is opposite to the thermistor being positive with increasing temperature. In addition, the barretter is not so rugged and can easily be destroyed by an electrical overload. Barretters are therefore considered as being obselete for professional purposes.

It suddenly became apparent, when watching the behavior of some micro lamps of the type used to illuminate LCDs. These lamps are tubular, wire ended, and extremely small, approx. 4 x 1 mm, the filament is not coiled, and the thermal resistance of the lamps is about 100 Ω to 200 Ω. These lamps just had to be suitable for HF measurement elements! Accordingly, a test circuit was constructed as shown in **fig. 3**. It may be seen that it conforms exactly to the circuit of a normal coaxial thermister mount but the thermistors have been replaced by the micro lamps. A Hewlett Packard micro-wave power meter 431 C was employed as the display instrument. As this instrument was designed for operation with thermistors, the control sensing of the two self-balancing bridges had to be reversed. This is simply accomplished by merely changing over the bridge supply connections. The best way of doing this is to exchange the polarity of primary windings of the bridge transducer which is designated in the HP circuit diagram with T1A and T2A. A change-over switch may be inserted at this point, if operation with either a thermistor or a PTC mount is contemplated. This operation is easily accomplished if the circuit diagram is available.

The results of the test circuit with the modified power meter were so good that a reproducible RF mount was developed which will be described.

3. CONSTRUCTION OF THE RF MOUNT

An "N" panel plug forms the basic for the construction. This plug has on its rear side a metal

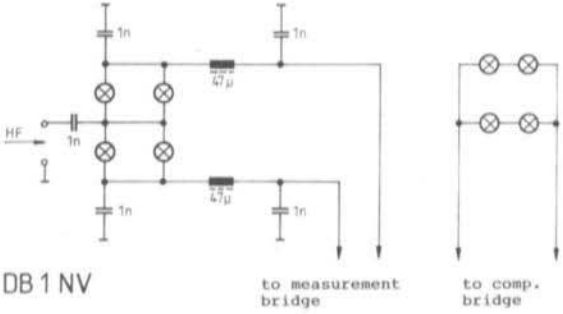

Fig. 3: Circuit diagram of micro-lamp RF-mount

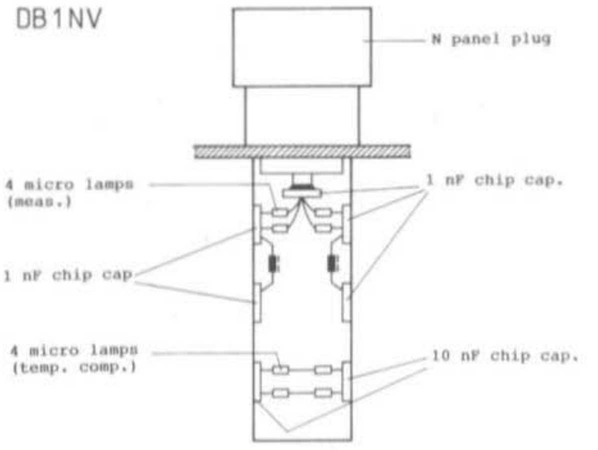

Fig. 4: Mechanical construction of RF mount

collar of approx. 11 mm diameter. From a 16 x 30 x 0.5 mm brass plate, a semi-circular (in cross-section) channel is fabricated which is then soldered on to the collar of the plug. The plug's inner connector is then shortened to 1.5 mm approx. The rest of the components may then be soldered on as shown in **fig. 4**.

First of all, a 1 nF disc capacitor of 5 mm diameter is soldered concentrically to the tip of the plug's (shortened) centre pin. Afterwards, four other 1 nF chip capacitors are soldered on to the inside lip of the brass channel. Four micro lamps are then soldered from the central chip capacitor, as directly as possible, to two adjacent 1 nF capacitors on the brass channel piece. Each leg carries two parallelled micro lamps as shown in **fig. 4**. Two small 47 µH RF chokes are then extended to the second pair of 1 nF chip capacitors. These chokes, together with the 1 nF capacitors, form an additional filter which prevents low-frequency RF components of the test-signal from being carried along the cable mantle and directly to the instrument. The four other micro lamps are soldered on to stand-off insulators formed here by 10 pF chip capacitors. The given values should be used, as the indicator unit is adjusted for this value (4).

Now, the connections from the mount to the indicator unit may be made. The pin number, given in **fig. 5**, refer to the HP 431 C power meter. The connecting cable is a 6-way, screened, LF cable – the screening may be dispensed with if

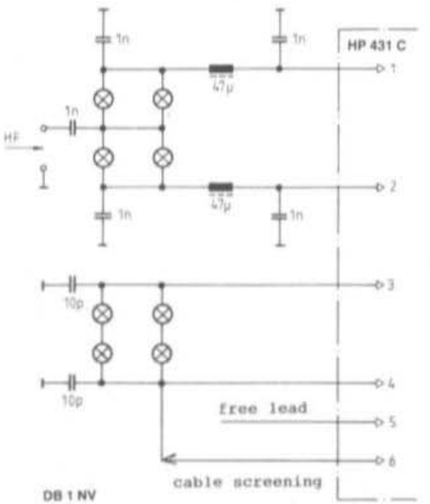

Fig. 5: Wiring diagram of RF mount connections to HP power meter

lengths under 1 meter are used. The lead to pin 5, apparently doing nothing, is is fact used for cable capacity compensation purposes. As the HP cable connectors cannot be obtained for a reasonable price (to buy the complete mount, cable assembly from HP will cost you more than you paid for the indicator unit!-G3ISB) it is advisable to put a 6-pole plug in the rear of the instrument and wire up the mount to a socket to suit it. The whole HF mount is then encapsulated fully by a metal housing which will prevent the movement of air from causing temperature differentials thereby unbalancing the bridge. A suitable enclosure is the "circuit box" by Greenpar or "sucobox" from Suhner.

3.1. RF-Mount Components

1 Piece 16 x 30 x 0.5 mm brass plate (see text)
8 micro lamps 1,5 V
4 x 1 mm: e.g. Conrad Electronics, Hirschau
1 "N" panel plug
5 1 nF chip capacitors
2 10 pF chip capacitors
2 micro chokes 47 μH (Siemens, Jahre)
1 enclosure (Suhner, Greenpar)
1 length of 6-way screened cable
1 plug or socket to suit the one used in the instrument (see text)

4. ADJUSTMENT

The indicator unit is switched to the 10 mW range and the unit is switched on. All lamps will then glow weakly but not necessarily with the same intensity, due to manufacturing tolerances. The "zero" potentiometer on the front panel is then adjusted for a meter null reading. If this is not possible, it is due to the lamps being too dissimilar from each other in both measurement and temperature compensation bridges. The temporary inclusion of 10 - 20 Ω small, series resistors between the power meter and the bridges could be tried in order to effect a balance. When the null has been achieved, the capacitive symmetry is effected by the screw-driver adjustment on the front panel – just as it is described in the HP instrument handbook. The RF mount is now ready for service.

5. RESULTS

No major differences could be detected between the manufacturers "power mount" and the RF mount described here, except perhaps, the drift in the lower measurement ranges is somewhat greater.

A network analyzer was employed to measure the RF mount's return-loss in the range 500 MHz - 18 GHz. It proved to be constant at about 14 dB (vswr = 1.5) to approx. 6 GHz, and deteriorating to 6 dB (vswr = 3) at 18 GHz. There were no spurious resonances. This result indicates that the RF mount may be used as a measurement instrument up to 6 GHz, and as an indicator up to 18 GHz.

6. REFERENCES

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