RF Power Meter

The requirement was for a 50Ω, 25W dummy load with a linear power meter.

The meter should have power ranges of 1W, 3W, 10W, 30W and 100W.
(Use on the 100W range was to be with caution to avoid damaging the 25W dummy load resistor.

Design considerations.

Assuming that the radio frequency signal is a sine wave, then the power is given by the formula

$$P = \frac{V^2}{2R}$$

where V is the peak power across the load,
R is the resistance of the load and
P is the r.m.s. power.

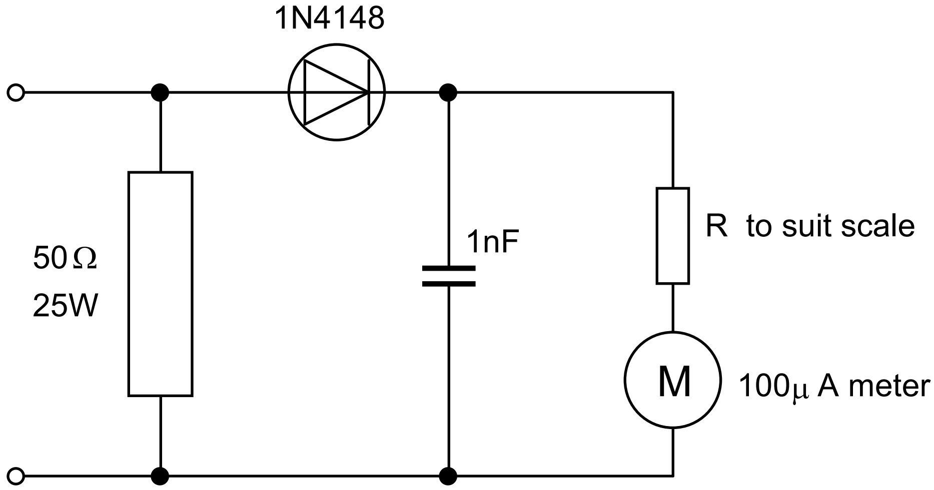
RF Power v Peak voltage.

Power W	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Peak voltage	3.2	4.5	5.5	6.3	7.1	7.8	8.4	8.9	9.5	10.0

Power W	1	2	3	4	5	6	7	8	9	10
Peak voltage	10	14.1	17.3	20	22.4	24.5	26.5	28.3	30.0	31.6

Power W	10	20	30	40	50	60	70	80	90	100
Peak voltage	31.6	44.7	54.8	63.2	70.7	77.5	83.7	89.4	94.9	100

The design for this power meter was based on the circuit below.



Details of the 50Ω resistor are given later on.
The multiplier for the meter was selected to give the required maximum power reading on the meter.

The requirement for the 1nF capacitor is that it will provide a smoothed direct current signal for the meter. The lowest frequency that this meter circuit is planned for is 1.8MHz, and the lowest full scale power reading is 1W. 1W corresponds to a peak voltage of 10V and so the effective resistance of the meter and multiplier is 100kΩ.
As a rule of thumb, the meter resistance and smoothing capacitor should have a time constant of at least ten times the period of the lowest frequency.
The period of 1.8MHz is 0.56μs.
So the time constant of the smoothing circuit should be 5.6μs.
Since T = RC,

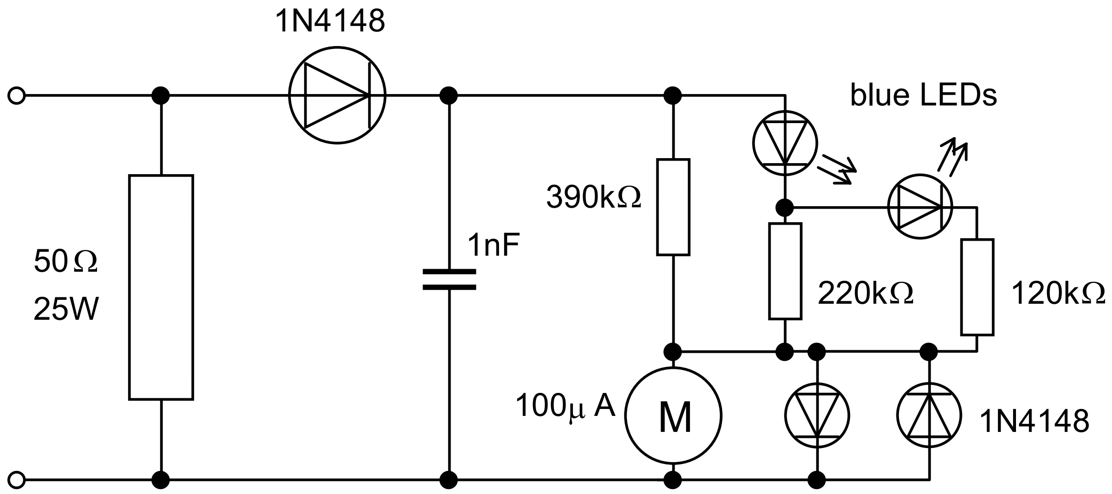
$$C = \frac{T}{R} = \frac{5.6 \times 10^{-6}}{100000} = 5.6 \times 10^{-11} = 56\text{pF}$$

So 1nF capacitor is more than adequate for smoothing the d.c. signal from the diode.

Since the formula that relates power and peak voltage is not linear, it is clear that the scale on the power meter will not be linear in its current form.
Experiments were undertaken to see if this difficulty could be simply solved, so that the meter scale would be 'acceptably' linear from 0.1W to 1W.

Circuit diagram.

The following circuit was found to be linear (within 10%) from 0.2W to 1W.

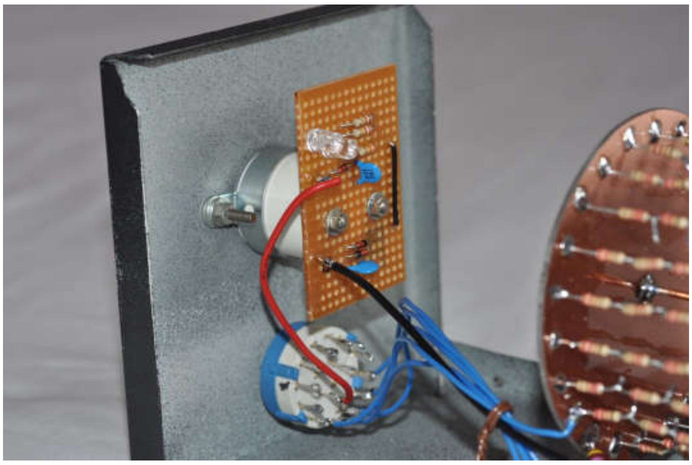


The system was calibrated by connecting a variable direct voltage supply across the circuit and varying the different meter resistors until an acceptably linear scale was achieved.
Blue LEDs were used which had a nominal forward voltage of 3.2V.

The table below shows the measured results. The largest error is at 0.1W (20%), with the rest being within the 10% goal.

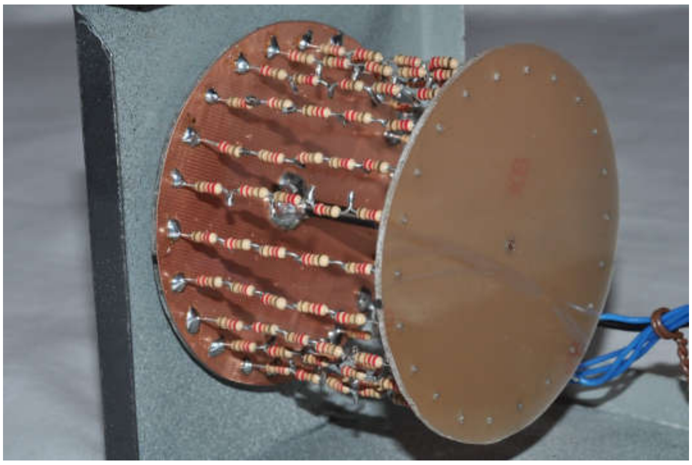
Power (W)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Peak voltage (V)	3.2	4.5	5.5	6.3	7.1	7.8	8.4	8.9	9.5	10.0
Meter reading of Power (W)	0.12	0.21	0.3	0.41	0.53	0.62	0.71	0.8	0.89	0.96

The two 1N4148 diodes connected back to back across the meter provide some protection for the meter in the event of being overloaded.
This circuit was constructed on strip board and mounted on the rear of the meter, as in the photo below.



50Ω dummy load resistor.

The 50Ω dummy load resistor was constructed nominally from 110 × 220Ω, ¼W carbon film resistors. This value was chosen only because there were significant numbers of these resistors 'in stock'!
Five 220Ω resistors were connected in series to make a 1100Ω resistor and then 22 of these 1100Ω resistors were connected in parallel.
The photograph below shows the construction of the 50Ω dummy load resistor.



The resistors are mounted between two circular pieces of fibre glass printed circuit board, 8cm in diameter. A BNC socket was soldered into the middle of the board nearest to the case and so is a ground potential.
The centre connection to the BNC socket is extended and connected to the centre of the other p.c.b.

Meter ranges.

The basic meter only displays power measurements up to 1W.
At 1W, there is 10V peak voltage across the 50Ω load resistor.
For 3W maximum scale reading, there will be 17.3V across the 50Ω load resistor. So if this voltage is reduced to 10V using a voltage divider, the basic meter circuit will then display up to 3W.
The same principle can be applied for the other ranges.
To preserve the resistance of the 50Ω dummy load, one of the 1100Ω series resistor chains was removed and replaced with the range voltage divider. This meant that the voltage divider must have a total resistance of 1100Ω.
To calculate the values for the 3W range, the following method was used.

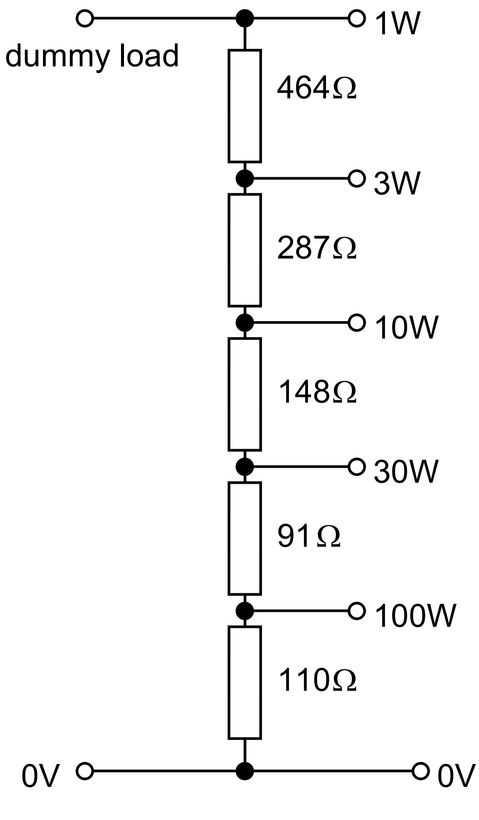
$$V_{out} = \frac{V_{in} \times R_2}{R_1 + R_2}$$

$$\Rightarrow 10 = \frac{17.3 R_2}{R_1 + R_2}$$

But $R_1 + R_2 = 1100\Omega$

Rearranging gives $R_2 = 636\Omega$ and $R_1 = 464\Omega$

Repeating this process for the other ranges gives the values below.

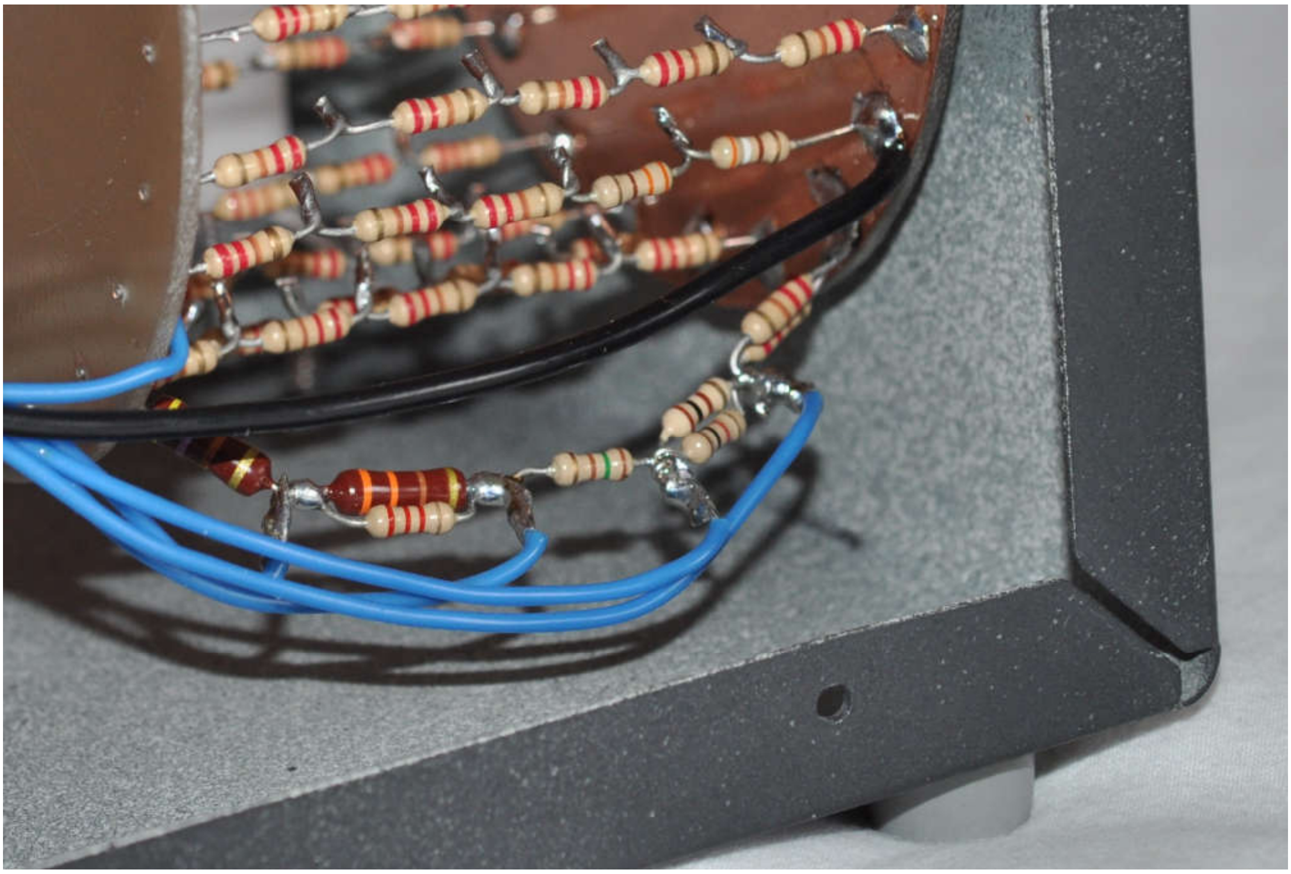


Many of these resistor values are near E24 preferred values and the following were used:-

470Ω, ½W for the 464Ω
330Ω, ½W in parallel with 2200Ω resistor for the 287Ω
150Ω for the 148Ω
100Ω in parallel with a 1kΩ resistor for the 91Ω
220Ω in parallel with a 220Ω resistor for the 110Ω.

All resistors were ¼W unless otherwise stated.

The photograph below shows this resistor chain connected to the 50Ω dummy load.



The blue wires lead off to the range switch.

The 50Ω resistor was measured, it was found to have a value of 49.6Ω. Although only in error by 0.8%, it was decided to adjust one of the 1100Ω resistor chains to make the value nearer to 50Ω. One of the 1100Ω resistor chains was removed and the value of the resistor network re-measured, giving a value of 51.9Ω. The parallel resistor formula was used to calculate the resistor value needed to give 50Ω, as below:-

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$\Rightarrow 50 = \frac{51.9 \times R}{51.9 + R}$$
$$\Rightarrow R = 1365.8\Omega$$

The 1365.8Ω resistor was made from three 220Ω resistors, a 330Ω and a 390Ω resistor connected in series, which gave a measured value of 1369Ω. Inserting this resistor chain in parallel with the other resistor chains gave a measured value of the complete dummy load resistor of 50Ω.
This resistor chain can be seem in the photograph above.