Building a 50 ohm 150 watt RF dummy load

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Do you use a dummy load when testing your transmitters. Not only is it a good idea, it's a requirement of your licence to use one. Plus you don't want to cause interference on our bands. Here's a design that has good VSWR up to 500 MHz. It uses a Bourns™ 150 watt 50 ohm terminator chip, only 6 mm x 9 mm x 1 mm thick.

The need for a dummy load

I have a Yaesu FT-301 transceiver that I've owned since new. This transceiver, when introduced in 1976, was said to be the first solid state ham rig with a 100 watt output. My FT-301, after being in storage for many years, was put back into service with a SG-237 Smartuner and long wire. It has now been in use for around two years.

As the transceiver is now 33 years old, I decided that I should check the alignment to ensure that it was putting out a clean powerful signal.

First step was to download the user manual from the internet and print it. I decided to start with the carrier frequency adjustments. On reading the manual it says to inject a 1 kHz audio signal and to adjust the RF output to 50 watts. Then to inject a 300 Hz audio signal (same amplitude) and adjust the carrier frequencies for 12.5 watts output on each sideband.

The manual did not say to adjust the carrier frequencies to 8.9985 MHz for USB and 9.0015 MHz for LSB. This puzzled me so I placed the SSB filter onto the N2PK VNA (vector network analyser) and did an insertion loss trace to determine the filter's band pass shape.

My VNA software that drives the N2PK VNA has a matching tool that allows you to measure the filter at 50 ohm impedance, then to display the trace as if the filter was matched with 500 ohms.

Figure 1 shows that the centre frequency is not 9 MHz and that the carrier frequencies need to be set to suit each individual filter. This is why a power meter and not a frequency counter is used to adjust the carrier frequencies.

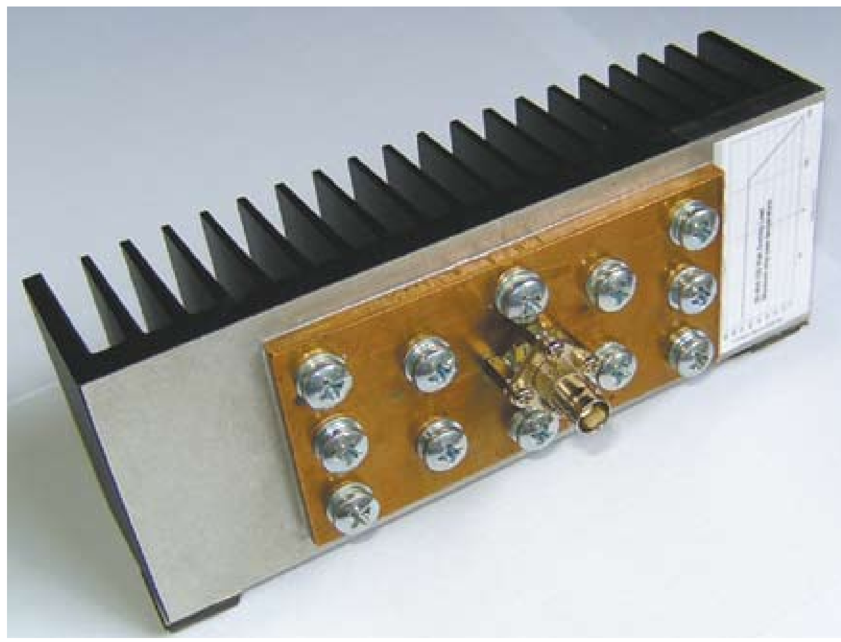

Photo 1: The 50 ohm 150 watt RF dummy load.

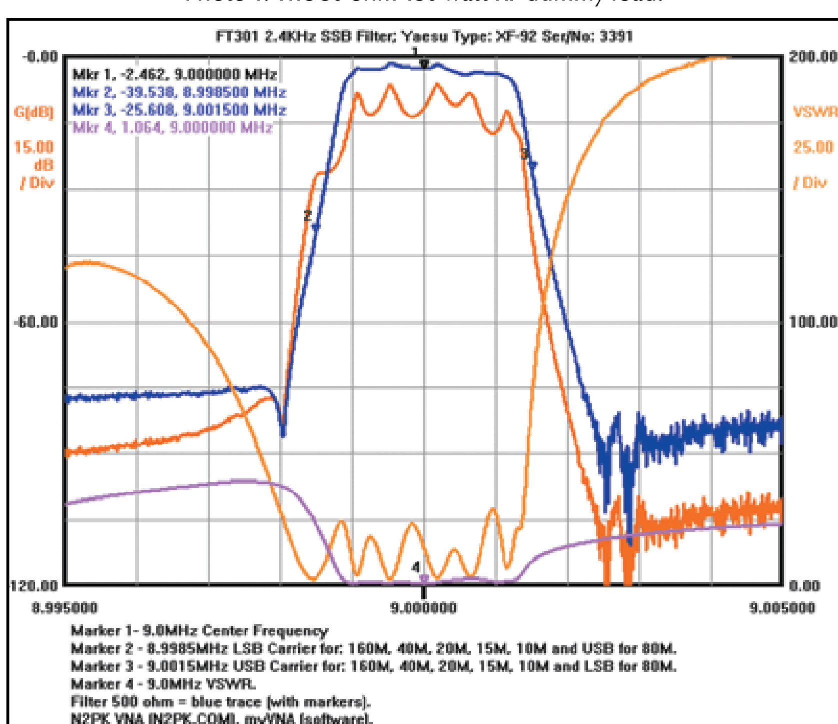

Figure 1: The FT-301 SSB filter trace.

I don't have a 50 ohm dummy load

Power measurements require a dummy load. Since I didn't have one, a hunt was on to source the parts to build a dummy load.

A search on the Farnell™ website found a Bourns™ 50 ohm 150 watt terminator 6 mm x 9 mm x 1 mm thick at a very reasonable price. Specifications were 150 Watts, DC to 3 GHz VSWR 1.2:1, +/- 5%. According to Bourns derating curve, it's able to dissipate 120% of rated power up to 100 °C, that is, 150 W x 120% = 180 watts . Farnell at that time were also shipping online orders free, so an order was placed. Refer Photo 2.

Flange and heat-sink

Now the fun had started. How was I going to dissipate 150 watts through a tiny 54 mm^2 area (6 mm x 9 mm) and into ambient air? Since copper is a much better heat conductor than an aluminium heat sink, then a flange has to be made from copper and have a large surface area, and be as thick as possible.

Peter VK3BPN gave me a piece of copper 120 mm x 60 mm x 6 mm thick. I didn't do any calculations. I decided that I would derate the power handling capability and/or duty cycle depending on the performance of the heat sink. Bourns specification indicates a roll off after 100 °C. I haven't tried it, but it may be possible to use a computer CPU cooler.

The Xigmatek HDT-S1283 CPU cooler has a thermal resistance of 0.16 °C/W. I decided to use a large heat sink, 0.55 °C/W, that I had purchased from Dick Smith™. A piece of copper as large as the heat sink would be better, but could not be found. A possible source of copper plate may be a scrap metal dealer.

While designing the flange, I also considered using water to cool the 50 ohm terminator. A small hose attached to a water tap and to a series of holes drilled into the flange is possible.

Making the copper flange

Marking the position for the resistor chip! The best position is in the middle of the flange as this is where total thermal resistance will be lowest. The flange also needs to be mounted onto the heat sink where thermal resistance is lowest, for my heat sink this is in the middle. Mark the hole positions and drill the holes for the flange/heat sink M6 mounting screws. Tap the holes in the heat sink for M6 screws.

No measurements are given because your flange and heat sink may be different. I used twelve M6 screws to ensure the heat sink compound is as thin as possible to reduce its thermal resistance. You may want to position the holes between the fins of the heat sink. This will then allow you to drill through the heat sink and to use a taper tap. I found that the bottoming (plug) tap I used didn't cut very well in aluminium as it kept clogging up. Hint, use tapping compound or if none to hand, grease or oil at a pinch.

Photo 2: A close up view of the copper flange

First try assembling the resistor chip onto the flange

The copper flange was placed onto an electric hotplate and heated to allow the flange surface to be tinned. I then placed the resistor chip onto the flange. While the flange was cooling down, a screwdriver was used to push the chip onto the flange. The solder between the flange and chip should be as thin as possible to reduce thermal resistance.

Four M3 holes were tapped into the flange for standoffs to mount the BNC connector. The next step was to solder the centre pin of the BNC connector onto the top pad of the resistor chip. But this is where I struck a problem. I couldn't get the top pad hot enough because the heat was being conducted through the chip body into the copper flange. That's good because when the chip is dissipating 150 watts you want it to be conducted into the flange and on to the heat-sink. But I needed to first make a connection.

Change the assembly procedure

There's only one answer to this problem. Due to the resistor chip body being a good thermal conductor, both connections would have to be reflow soldered at the same time. It's not possible to do them one at a time.

If you solder the wire onto the top pad, the heat will run through the chip body into the copper flange. If you solder the chip resistor onto the flange, the top connection will get hot and fall off. The solution is a spring loaded fixture that holds both connections to allow them to be reflow soldered at the same time. Figure 2 shows a fixture holding the two top wires onto the resistor chip, and the resistor chip onto the flange.

Referring to Figure 3, a 6 mm x 9 mm piece of vero board is used as a clamp to hold the two wires onto the top pad of the resistor chip. Use a triangle file to file a vee slot into the vero board for the wires. The slot should not be too deep, as the wires must not be loose while being reflow soldered. A spring and slotted cheese head screw holds the parts together while reflow soldering takes place.

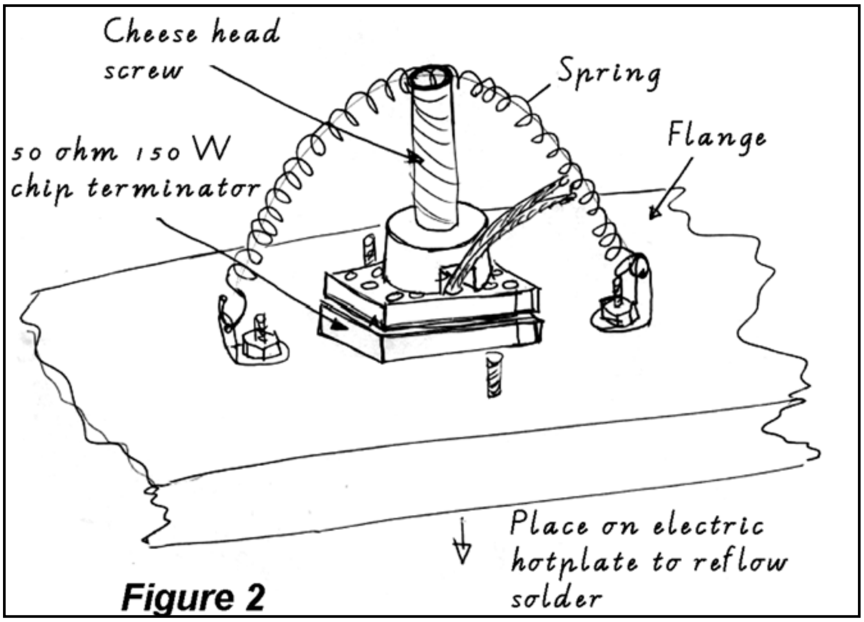

Figure 2: The soldering fixture.

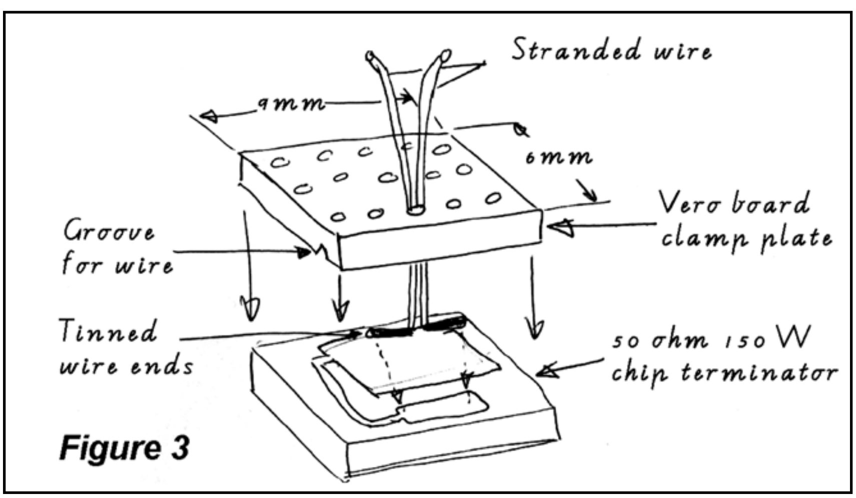

Figure 3: The vero board top clamp.

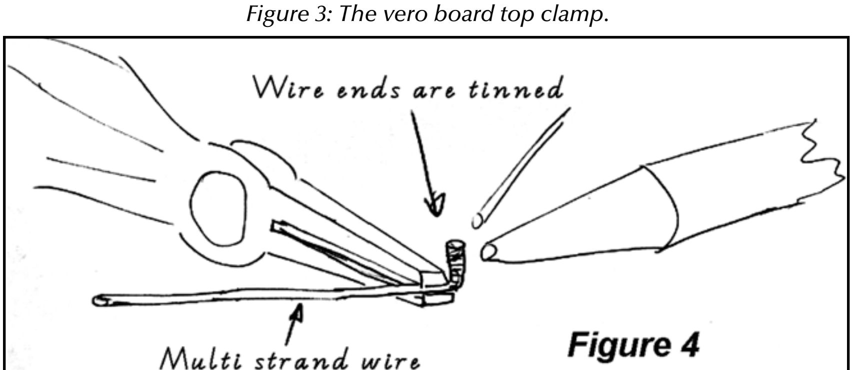

Figure 4: Tinning the wires.

Tightly twist the strands and tin the ends of two wires as in Figure 4. Pliers were used as a heat sink to stop the solder from flowing up the multi strand wire. The multi strand wire between the resistor chip and BNC connector must be free from solder and must be flexible. Warning! If the wire is stiff, it's easy to pull the top pad off the resistor chip. Be careful, the pad appears to be the weakest point on the resistor chip. How do I know, because I now have a resistor chip with a missing top pad!

When the flange has been tinned for the resistor chip, assemble the wires and resistor in the fixture. Place the flange onto an electric hot plate. Heat the flange until the parts are reflow soldered. Wait for the flange to cool and remove the fixture. Be careful when removing the vero board from the wires, you don't want to pull the top pad off. Make sure the wire hole in the vero board is large enough for the wires to easily slide through.

Connecting the BNC connector

To make room for the wires between the connections, I shortened the insulator and centre pin on the back side of the BNC connector. Then add the standoffs and mount the BNC connector. Solder the two parallel wires onto the centre pin of the connector. Use pliers as a heat sink to stop the solder from flowing down into the multi strand wires. Because there isn't much room under the connector, I used a rubber band on the handles of the pliers to clamp the wires while soldering the connection.

Final assembly

The base of the copper flange should be flat and free of burrs. Clean the base with Brasso™ before coating it with silicon heat transfer compound. With a spring washer and flat washer on each M6 screw, mount the flange onto the heat sink.

For maximum heat sink efficiency, the heat sink fins should be vertical and clear of the top of the workbench. Attach four stick-on rubber feet to allow this. I also attached a derating curve to remind me to derate the power/duty cycle above 100°C. Copy the label from Figure 5 or download from the WIA website, refer to the URL link listed below. I used clear book covering to protect and hold the label.

Performance

Glenn VK3PE was kind enough to use a HP8753C VNA to measure the return loss, and the results are shown in the graph - refer Figure 6.

Frequency	VSWR	Frequency	VSWR
Below 50 MHz	1.01:1	500 MHz	1.07:1
100 MHz	1.02:1	1 GHz	1.16:1
200 MHz	1.03:1	2 GHz	1.39:1
300 MHz	1.04:1	3 GHz	1.85:1

Bourns specify the resistor chip as 1.2:1 VSWR at 3 GHz. High frequency return loss can be improved if the connector is mounted as shown in Figure 7. Bourns also have a 100 watt version that is specified as 1.1:1 VSWR at 5GHz.

Determining maximum continuous power rating

Maximum continuous power rating depends on: (1) Ambient temperature (T_{amb}), (2) Thermal resistance between the resistor chip case and ambient air ($R_{\theta CA}$ in °C/W), (3) Resistor chip maximum temperature (T_{Cmax}), (4) and, of course, it can't be above the maximum power rating of the resistor chip. Interesting in that thermal resistance is similar to series connected resistors. Total thermal resistance is the sum of the series connected thermal resistance.

$R_{\theta CA} = R_{\theta CF} + R_{\theta FH} + R_{\theta HA}$.

Also refer to the 'Thermal Resistance' URL links below.

Thermal resistance between the resistor chip case (T_C) and ambient temperature (T_{amb}) must first be determined. A test was done by dissipating 36 watts in the dummy load and then measuring both T_C and T_{amb} when the case temperature has stabilised. I started at 9 watts and increased the power until the case temperature was 88º C; do not go over 100º C. Ideally this test should be as close to 100º C as possible and with ambient temperature as high as possible. My results were:

Power Watts	Ambient Temperature	Resistor case Temperature	Thermal Resistance
9W	23º C	35º C	1.33 ºC/W
20 ¼ W	23º C	52º C	1.43 ºC/W
36W	23º C	88º C	1.80 ºC/W

Using the following formula, thermal resistance is calculated.

$$R_{\theta CA}(^{\circ}C/W) = \frac{T_c - T_{amb}}{Q} = \frac{88^{\circ}C - 23^{\circ}C}{36W} = 1.8^{\circ}C/W$$

For 36 Watts when ambient temperature is 23º C, thermal resistance is: 1.8°C/W between resistor chip case and ambient air.

A rough guide can be obtained for other ambient temperatures by using the following formula.

Maximum continuous power dissipation if ambient temperature is 25º C:

$$\text{Continuous Q (in watts): } Q = \frac{T_c\max - T_{amb}}{^{\circ}C/W} = \frac{100^{\circ}C - 25^{\circ}C}{1.8^{\circ}C/W} = 41W$$

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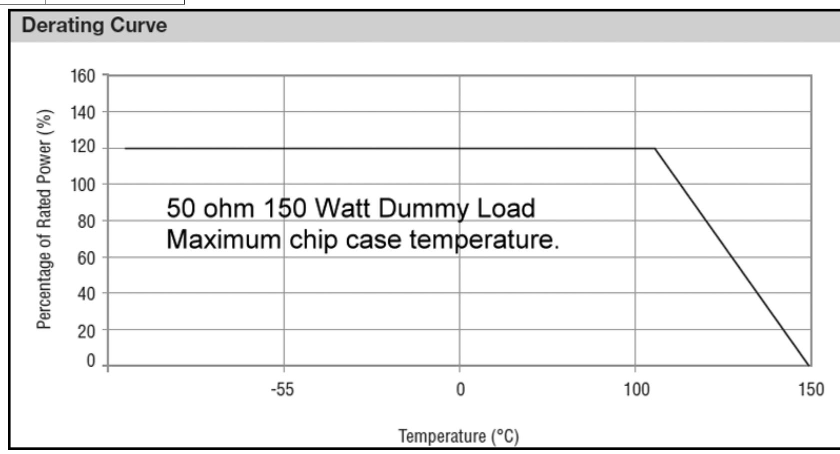

Figure 5: The derating curve label

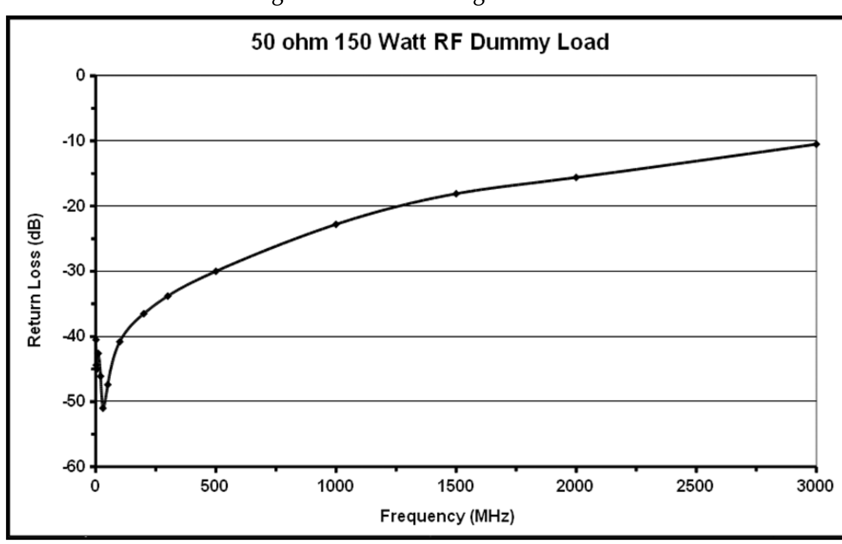

Figure 6: The return loss graph

Figure 7: Bourns S-Parameter test

Note, only use this as a guide. Because thermal resistance increases when the temperature difference between ambient and resistor chip maximum rating (100º C) gets less. As shown in the above table, thermal resistance also increases with increased power.

I don't have an environment chamber to do tests for different power levels and ambient temperatures. Warning! you need to make sure the resistor chip temperature never exceeds 100º C.

Heat sink efficiency also depends on what the air movement is around the heat sink. Adding a fan will reduce thermal resistance and increase the maximum continuous power dissipation rating.

I did a series of calculations for different ambient temperatures. A text editor was then used to generate a stick-on table that gives a guide for maximum continuous power dissipation for different ambient temperatures. See table below.

Maximum power dissipation can be higher than 41 watts if the ON duty cycle is less than continuous. If the duty cycle is 50% ON and 50% OFF then power dissipation can be increased to 82 watts. Further, if the duty cycle is 25% ON and 75% OFF, then the full power of 150 W can be dissipated.

Maximum continuous power dissipation is perhaps misleading. Because 150 watts can be dissipated for short ON duty cycles, you only need to ensure the resistor chip case never exceeds 100ºC.

I have only ever used my dummy load for low duty test cycles. I found that I can dissipate 100 watts, do any tuning as required, switch off and the heat sink only got warm.

Of course your thermal resistance calculations will be different as your flange/heat sink will not be the same.

Power measurement

The dummy load has been built, but I need to do power measurements. Since I was only going to use it for HF from 1 MHz to 30 MHz. I used an oscilloscope and calculator to measure the power.

The oscilloscope 10 x probe was connected to the BNC centre pin, not to the pad of the resistor chip as I didn't want to pull the pad off!

$$P(Watts) = \frac{V_{peak}^{2}}{2R} = \frac{V_{pk.to.pk}^{2}}{8R}$$

For power calculations, I use a freeware program called Mini dB-Calculator. It can be downloaded from Softpedia's website. Softpedia's URL is listed below. Mini dB-Calculator is handy as it's also able to do other types of RF calculations.

References

Derating curve label: http://www.wia.org.au/

*Bourns 50 ohm 150 W resistor chip: Now available from http://au.mouser.com/

Thermal resistance: http://en.wikipedia.org/wiki/Thermal_resistance_in_electronics

Thermal calculators: http://www.novelconceptsinc.com/

Mini dB-Calculator: http://www.softpedia.com/get/Science-CAD/mini-dB-Calculator.shtml

CPU cooler: http://www.xigmatek.com

N2PK VNA: http://n2pk.com

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Maximum Continuous Power Dissipation							VK3YC		
Watt	55	52	50	47	44	41	38	36	33
Ambient Temperature	0ºC	5ºC	10ºC	15ºC	20ºC	25ºC	30ºC	35ºC	40ºC

BILL OF MATERIALS

Reference	Part No	Quantity	Purchased from/Comments
R1, 50 Ω 150 W	Bourns CHF3523CNT500LW	1	*Farnell - S/N1435944
Flange	Copper 120 mm x 60 mm x 6 mm	1	Or a size to fit your heat sink
Heat sink	0.55 □C/W 200 mm x 75 mm x 48 mm	1	Dick Smith Cat: H 3406
	Silicon heat transfer compound		Dick Smith Cat: N 1205
	Multi strand copper wire	40 mm	Around 0.5 mm diameter
BNC connector	BNC panel mount connector	1	Or your favourite connector
Connector mount	Metal spacers M3 x 10 mm long	4	
Connector mount	M3 screw 5 mm long	8	Cut the head off four screws