High-Efficiency 2 kW Water-Cooled Dummy Load

This dummy load uses RF thick-film resistors and water cooling to permit continuous operation up to 2 kW.

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Testing and troubleshooting high-power amplifiers routinely requires a high-power dummy load (see Figure 1). However, dummy loads capable of handling sustained high power are difficult to find. Therefore, I endeavored to develop a dummy load with the following specifications:

1. Power capability of 2 kW continuous
2. Nominal resistance of 50 Ω ± 3%
3. Frequency range up to at least 30 MHz
4. SWR better than 1.05

RF thick-film chip resistors based on beryllium oxide (BeO) technology have excellent thermal performance. These chips typically have a resistance of 50 Ω ± 5%, and continuous power ranges up to

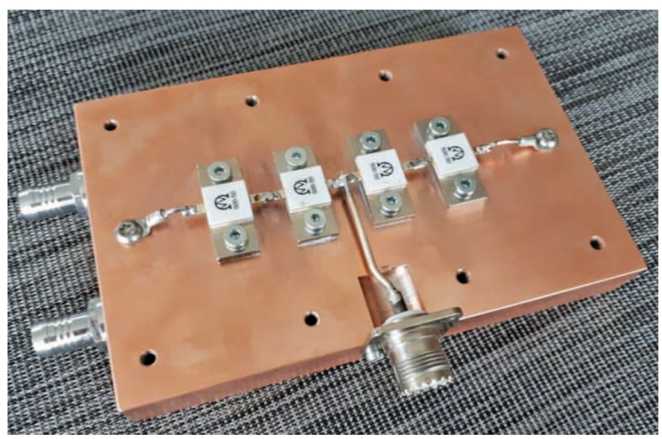

Figure 1 — The dummy load uses four 500 W, thick-film resistors.

1,750 W from –50 to 100 °C (available at **www.barryind.com/flanged_terminations.html**). However, these power levels can only be achieved with a good mechanical and thermal structure. Due to my professional involvement with cooling of sophisticated injection molds, I decided to pursue water cooling for this dummy load. Inexpensive components are available for the construction of a water-cooled dummy load (see my website at **www.nd2x.com/kd5fzx-h2o.html**).

The dummy load and cooling unit design was carried out with 3D CAD modeling (see Figures 2 and 3). Four 500 W chip resistors were mounted on a cooling plate, which consisted of two 160 × 100 × 10 millimeter copper plates (marked in green and dark blue in Figure 2).

A 9-millimeter-wide by 5-millimeter-deep, U-shaped channel (see Figure 4) was milled around the chip resistor locations in the top and bottom plates. Eight M4 threaded holes for fastening the chip resistors and ten M4 through-holes were made in the top plate. Then both inner (U-channel) sides of the copper plates were face-milled, coated with solder paste, and placed on a hotplate. After the solder began to melt, the copper plates were placed on top of each other. Solder was applied to the 10 through-holes so that the contact surfaces connected securely. This created a closed ring channel with a cross-section of 90 squared millimeters from the two channel halves. After cooling, all six outer sides were milled to size, and then two connectors were inserted for the water connections. A final pressure test showed that all the seams were tight (see Figure 5).

The milled top of the cooling plate was polished and cleaned prior to component mounting. The undersides of the chip resistors were coated with thermal paste and screwed onto the cooling plate with M4 10-millimeter Allen screws, followed by installation of the UHF connector. Next, the thin connection lugs of

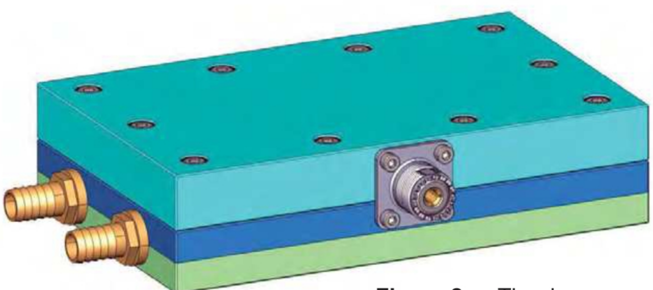

Figure 2 — The dummy load's 3D CAD model.

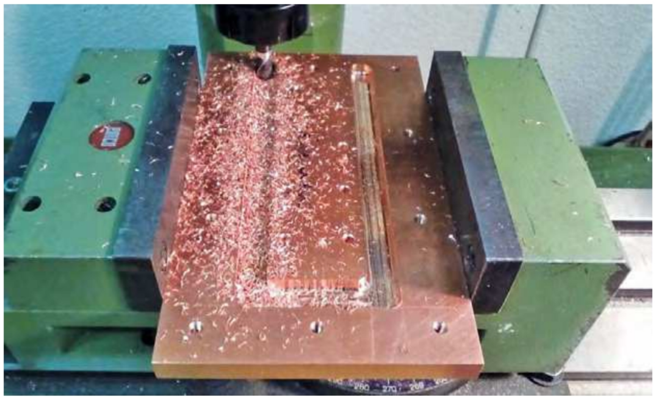

Figure 4 — The milled channel is for water cooling.

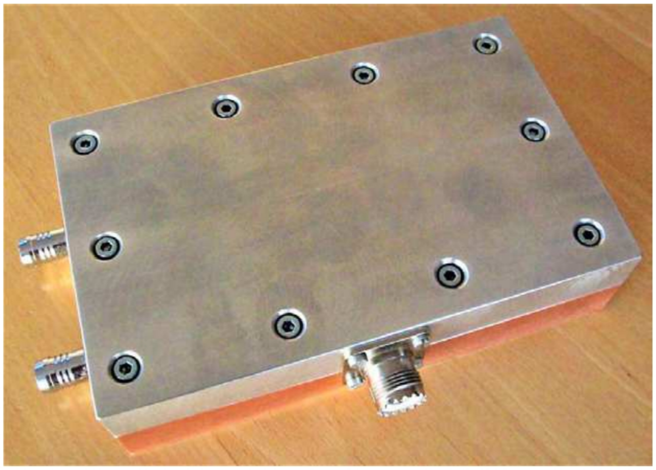

Figure 3 — The completed water-cooled dummy load, with the water intake/exhaust connectors on the left.

Figure 5 — The plates are soldered together.

the resistors were soldered together, and the ends were connected to ground with short wires, as seen in Figure 1. Finally, the aluminum cover plate was screwed on. A milled pocket on the inside of the cover provided space for the chip resistors. This cover provided an RF-tight housing and protection against accidental contact (see Figure 3).

Cooling Unit

The cooling process is shown in Figure 6. Two special 200 × 200 millimeter coolers with filigree copper fin radiators provide efficient heat transfer to the air and make optimal use of the installation space. Both radiators are equipped with thermal sensors for temperature monitoring of the cooling water. The heated water from the dummy load is cooled in the first cooler before it flows through the pump into the second cooler then back into the dummy load.

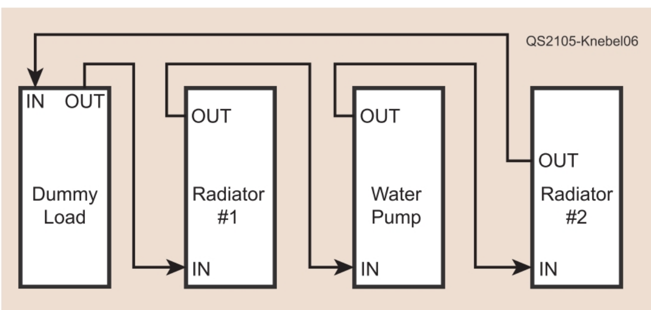

Figure 6 — The water flow is shown during the cooling process.

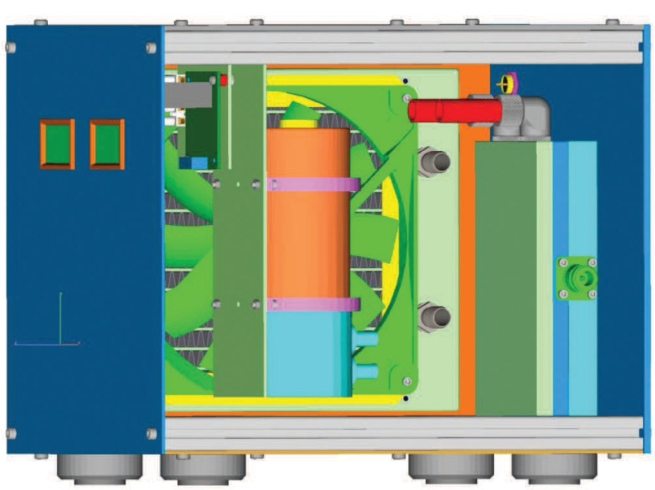

Figure 7 — The final CAD model.

The air required for cooling utilizes two slow-running 180-millimeter fans that draw in air via slots in the base plate. Both 12 V dc fans run continuously from an external power supply. The moving air flows through the high-performance radiators and then back to the outside through slotted side plates. The final CAD model of the cooling unit with the integrated dummy load on the inside of the rear wall was created over several iteration steps (see Figure 7). Attention was paid to a symmetrical arrangement of the cooling components and good accessibility. Aluminum sheets for the cabinet were laser cut, with the necessary data generated directly from the 3D CAD model. This provided mechanically precise parts and a nice appearance. The top cover, a 3-millimeter-thick acrylic panel, allows a look inside the cooling unit and also provides a nice overall impression thanks to the blue LEDs in the two fans (see Figure 8).

Finally, an LCD provides analog and digital information of the water temperature. The LCD is supplied with 5 V dc via a voltage regulator board.

Figure 8 — The completed dummy load.

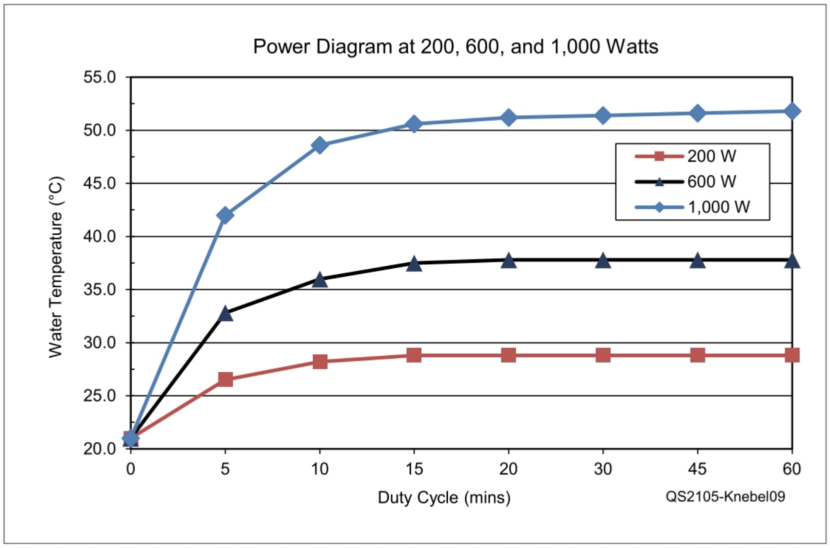

Figure 9 — The water temperature versus time is shown at 200, 600, and 1,000 W.

Measurements

Using an AA-35 ZOOM, the SWR of the completed dummy load was measured at less than 1.05:1 from 1 – 35 MHz. Next, power tests were carried out at 100 W without water cooling to observe the heat transfer from the chip resistors to the heatsink. After 20 minutes, both the chip resistors and the cooling plate became just lukewarm. Then, the cooling unit was connected. With a pump output of 500 liters/hour, approximately 1.5 liters was constantly circulating in the two coolers. Next, the water temperature was measured over periods of 1 hour at 200, 600, and 1,000 W. The results are shown in Figure 9. Incidentally, after 1 hour at 1,000 W, the surface temperature of the copper plate was 65 °C.

Optimization Potential

While this dummy load performance was quite good, there is always room for improvement. In a first optimization phase, an expansion tank with a capacity of approximately 1 liter was placed between the two fans. This provided additional cooling due to the increased water volume of the expansion tank, pump, dummy load, and the two radiators.

In a second iteration, the dummy load was screwed onto the outside of the rear plate. Besides providing easier access to the UHF connector, it also permitted mounting an additional aluminum cooling plate on the inner side of the back plate to enhance heat transfer.

Finally, heat transfer can be further improved by replacing the thermal paste with eutectic alloys made of gallium, indium, and tin. These so-called liquid metals provide extremely high thermal conductivity compared to synthetic polymers. Because the alloy is liquid at room temperature, unevenness can be leveled out much better than with conventional thermal pastes. However, liquid metals are electrically conductive, so care must be taken to ensure short circuits don't occur. Contact with aluminum should also be avoided because gallium attacks the protective oxide layer, and thus leads to embrittlement. Copper or nickel-plated copper surfaces have good long-term stability.

Conclusion

Efficient cooling of high-power chip resistors or LDMOS-FETs can be implemented with water cooling. The main focus must be on constant circulation and a sufficiently large amount of water and large radiators. Additionally, careful design of the cooling channels is required so that the heat is distributed quickly into a sufficiently thick copper plate without creating local hotspots that can destroy a component. I would be happy to provide CAD models to anyone interested in duplicating the high-power dummy load described here.

All photos by the author.

Guenther Knebel, DK6ET, has been an amateur radio operator for almost 50 years. He received his VHF license in 1972, then upgraded to a General and then an Amateur Extra-class license shortly after. He holds a Master's degree in applied physics and received his PhD in pharmaceutical technology in 1982. For more than 30 years, he worked in the biomedical industry, initially as a lab manager, and later as a director of R&D. Now retired, Guenther spends most of his time in 3D CAD mechanical engineering and building his homebrewed equipment. You can contact Guenther at **dk6et@darc.de**.

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