Design and Build a Dummy Antenna

A 40W, 50 ohm RF dummy load with a VSWR of 1.3:1 at 500 MHz.

by Geoff Koehler VE5ZE

A dummy antenna is one of the most basic and essential pieces of test gear in the ham shack. A good dummy antenna must meet two requirements. First, the dummy must be resistive and not reactive at the frequency of the transmitter. The impedance of most military and amateur transmission lines and equipment is 50 ohms, so it is most useful to build a dummy with a 50 ohm impedance. A 50 ohm dummy must present this impedance to the transmitter for maximum transfer of power and proper tuning of the transmitter. Moreover, to be versatile the dummy should not change impedance significantly as a function of frequency. Second, the dummy must be able to safely dissipate the RF energy supplied by the transmitter as heat, and not radiate RF.

The purpose of this article is to describe the design and testing of two simply-built dummy loads that maintain a more-or-less constant impedance at VHF frequencies, and are able to dissipate the power of hand-held amateur radios or low-power mobile rigs. In addition, comparisons are made to the performance of a few commercially available dummy loads, one of which was measured (the MFJ-264 dry dummy).

Back to Basics: The Smith Chart

Basically, the Smith chart is a circular graph (Figure 1) where circles of constant resistance and constant reactance form the grid. The only straight line on the chart is the axis of reals, marked "resistance component," along which are centered the circles of constant resistance (Figure 1a). All the points on a circle of constant resistance have an equal value to where they intersect the axis of reals and represent the resistive component of a complex impedance. Constant resistance circles are tangent to the edge of the chart at the infinite resistance point.

Superimposed on these circles are partial circles of constant reactance (Figure 1b) whose centers lie on a line normal to the axis of reals and are tangent to the axis of reals at the edge of the chart. The layout of the chart allows a complex impedance to be plotted in its two components, a resistive component and a reactive component.

Finally, radial scales complete the Smith chart (Figure 1c). Two scales are calibrated in terms of wavelength, and form the outer ring of the Smith chart. One is measured as "wavelengths toward generator," and the other "wavelengths toward load." The entire circumference of the chart represents one-half wavelength.

All Smith charts have a characteristic impedance of 1 ohm, and are normalized to the characteristic impedance of the system that you are working with. For example, a 50 ohm transmission line has a normalized value of Z/Zo $(50/50) = 1$. On this scale a resistive 120 ohm load would have a resistive component of $120/50 = 2.4$ ohms. In this way, the same chart can be used for any characteristic impedance.

Any impedance, regardless of value, can be plotted on the Smith chart. Impedances can be generally broken down into two components: a resistive component and a reactive component (either capacitive or inductive). These usually take the form of a complex number: $Za = Ra + jXa$, where R represents the resistive (real) component and X represents the reactive (imaginary) component. The sign of the reactive component determines whether the reactance is capacitive (negative) or inductive (positive). The completed Smith chart is shown on Figure 1d. Smith charts are also available in expanded form, which is useful when measured impedances all plot close to the center of the chart, or are already normalized to 50 ohms.

The primary use of the Smith chart in this article is to display graphically the complex impedances measured in the dummy loads at VHF frequencies, and convert these impedances to a more familiar form, the calculated VSWR at the transmitter. A good article on the various uses of the Smith chart, written by Jim Fisk W1DTY, appeared in the November 1970 issue of *Ham Radio* magazine (see "References" at the end of this article).

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Dummy Load Design

Two dummy loads of different design are considered (Figure 2). While a simple carbon resistor remains resistive to several hundred MHz, a dummy capable of dissipating more than about 2 watts must be built from a number of resistors. At VHF frequencies, most multi-resistor dummies become reactive, as well as simply resistive. Therefore, as the frequency increases the design of the dummy load becomes important.

Both dummies are constructed from about 20 2 watt carbon resistors, some double-sided copper-clad board, and an RF connector. I used a type-N connector, but a BNC connector will work, too. UHF connectors should work up to about 150 MHz, but at higher frequencies these connectors may compromise the performance of the dummy. All other things being equal, UHF connectors should not be used, although they are the most common on amateur equipment. It is also important to use only carbon and not wire-wound resistors because wire-wound resistors will become reactive at high frequencies. One dummy, which I call the DIP dummy, consists of a dual-inline arrangement of resistors, while the other is of radial design.

To build the DIP dummy, 22 1.5k 2W resistors and two pieces of double-sided copper-clad fiberboard are needed (Figure 2a). Both are about 5/8" wide; the top board is 5" long, and the bottom board is 6-3/4" long with a tapered end. For the resistors, a total of 22 small holes are drilled in two rows of 11, about 3/8" apart. Solder the resistors between the two boards. You will have to solder all the resistors on one board first, and then fit the other board onto the resistor leads, and solder. Make sure to use a hefty soldering iron, because good solder joints are important. Mount the RF connector in the aluminum box, and solder the tapered end of the bottom plate directly to the center conductor of the RF connector. The top plate is grounded to the box by a sheet of copper foil which can either be soldered directly onto the top plate or bolted through with 4-40 machine screws. The purpose of the tapered bottom plate and the copper foil is to decrease, as much as possible, lead inductance in the dummy. Finally, mount the bottom plate on an insulating stand-off to the bottom of the aluminum box.

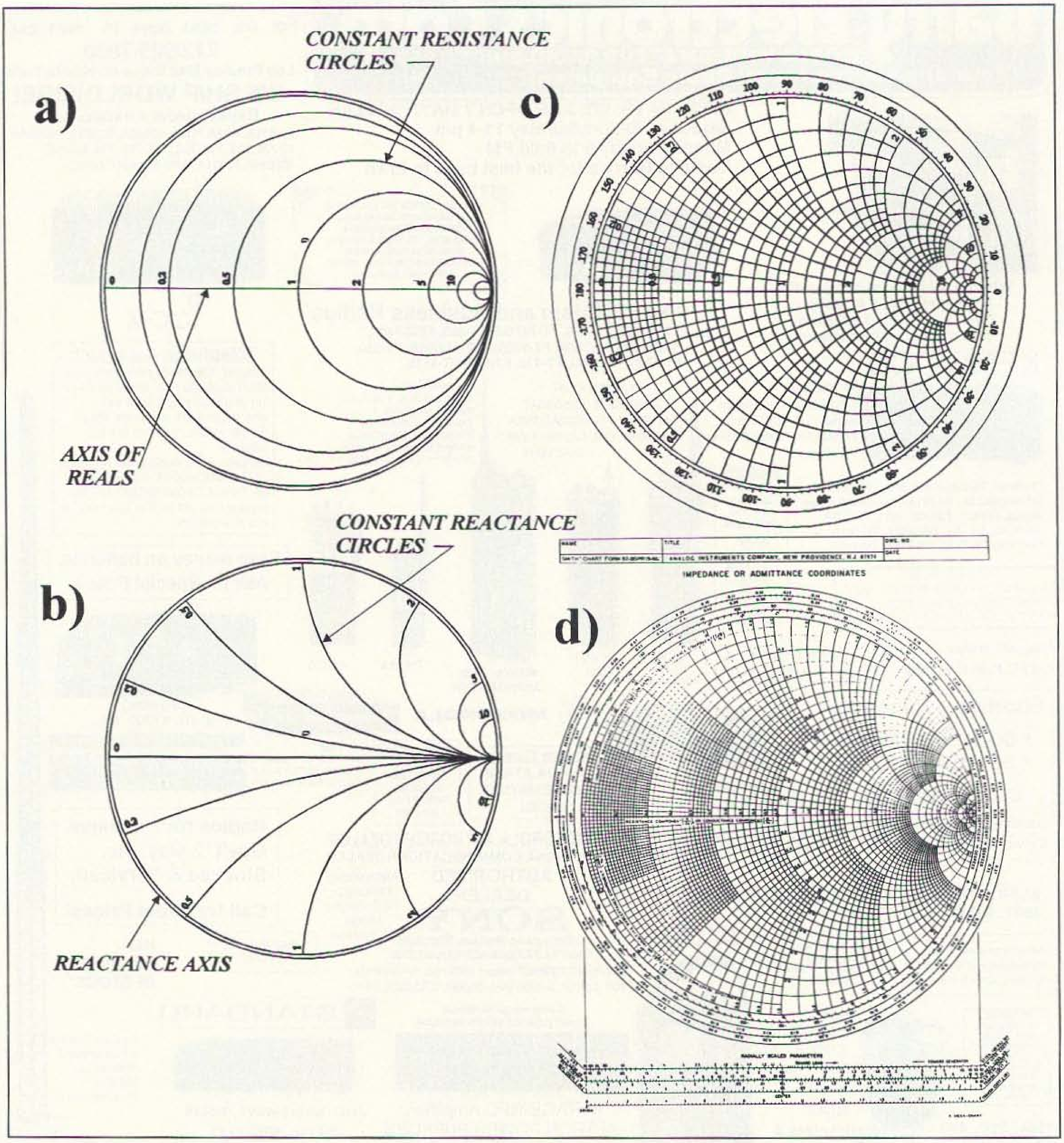

Figure 1. Construction of the Smith chart: a) constant resistance circles; b) partial circles of constant reactance; c) radial scales; d) completed Smith chart. Modified after Fisk, 1970.

The radial dummy is built in a similar manner, except that the RF connector is bolted directly to the ground plate, with the center conductor soldered to the back plate with a piece of large (less inductance) hookup wire (Figure 2b). Twenty 1k resistors are arranged around a 1-1/2" circle. As with the DIP dummy, it would be a good idea to mount the dummy in an aluminum box to help shield the dummy and prevent any grounded surface from contacting the back plate of this dummy, where there will be RF voltage.

Measurement of Complex Impedance

Measurement of complex impedances can be performed with an impedance bridge and a signal generator. An impedance bridge that, with careful attention to construction, should work at VHF frequencies is described by Henry Keen W2CTK. For the dummy antennas in this article, I used an alternate setup which consisted of a Hewlett Packard 608A Signal Generator, a power divider, a couple of 10 dB pads, and a Hewlett Packard 8405A Vector Voltmeter (Figure 3).

In this setup, V_A represents the incident voltage only, because the end is terminated in a purely resistive 50 ohm load and therefore there is no reflection. V_B, however, will represent the vector sum of the incident voltage and the reflected voltage. The ratio

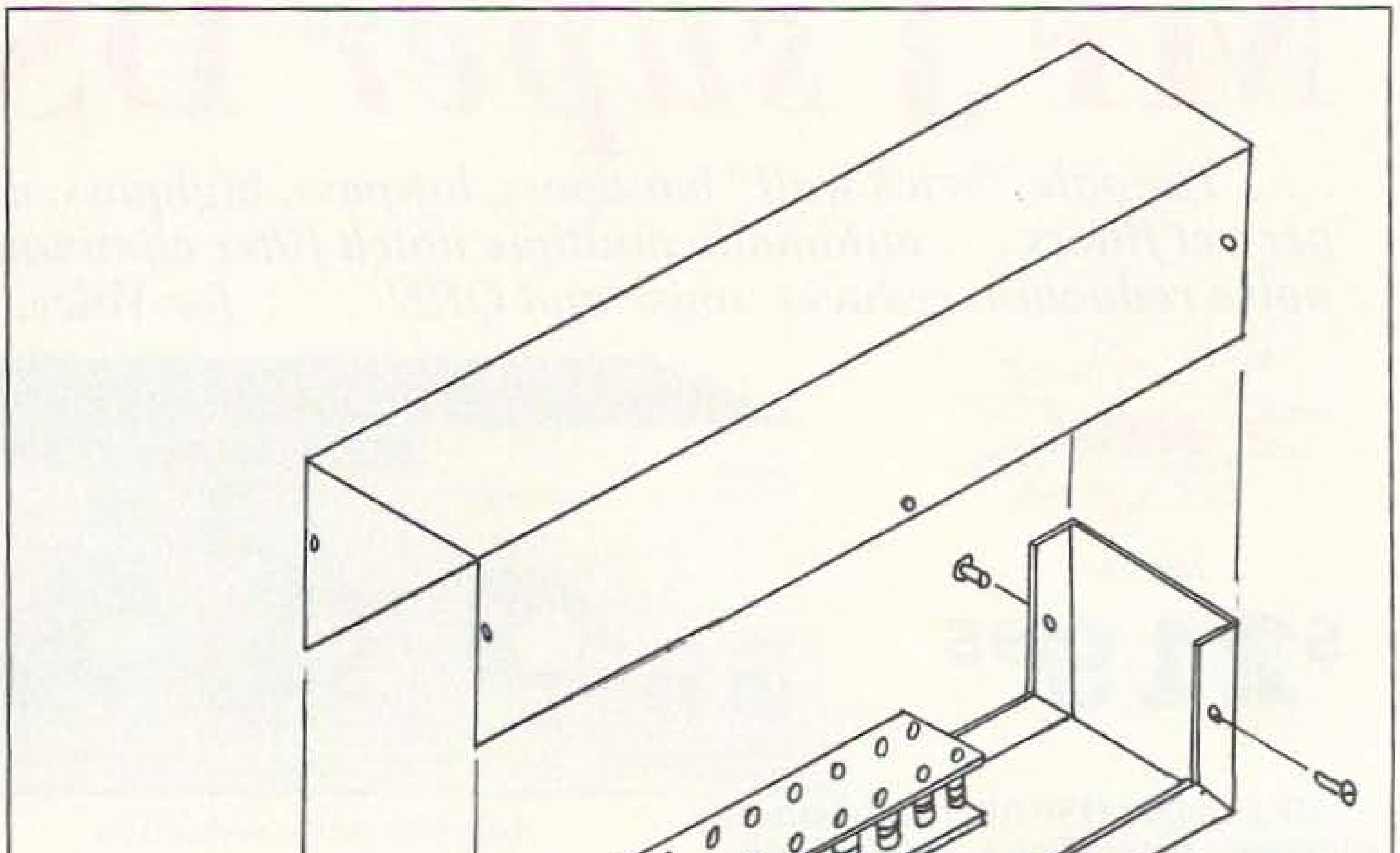

Figure 2 (a). Construction detail of the "DIP" dummy.

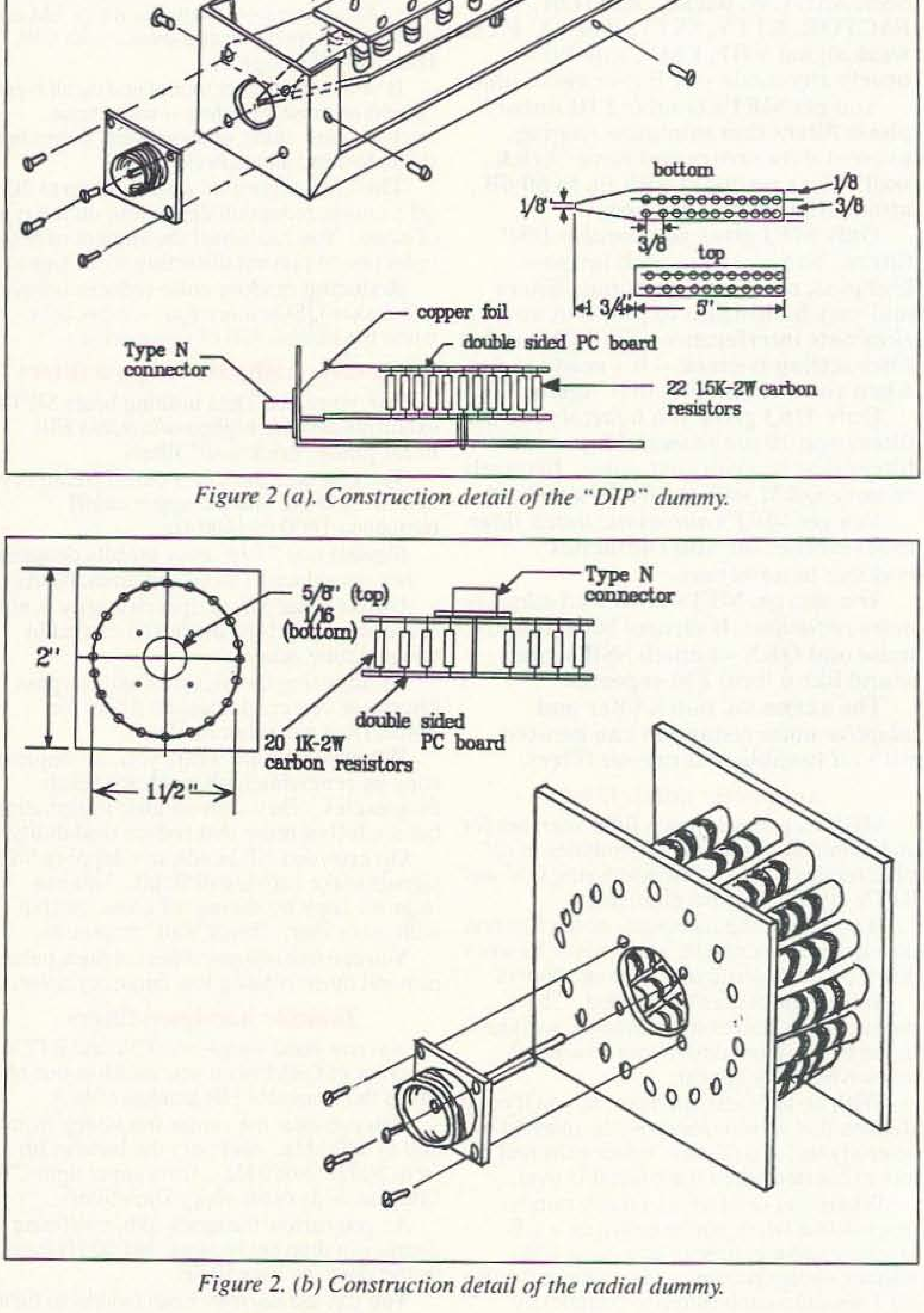

Figure 2. (b) Construction detail of the radial dummy.

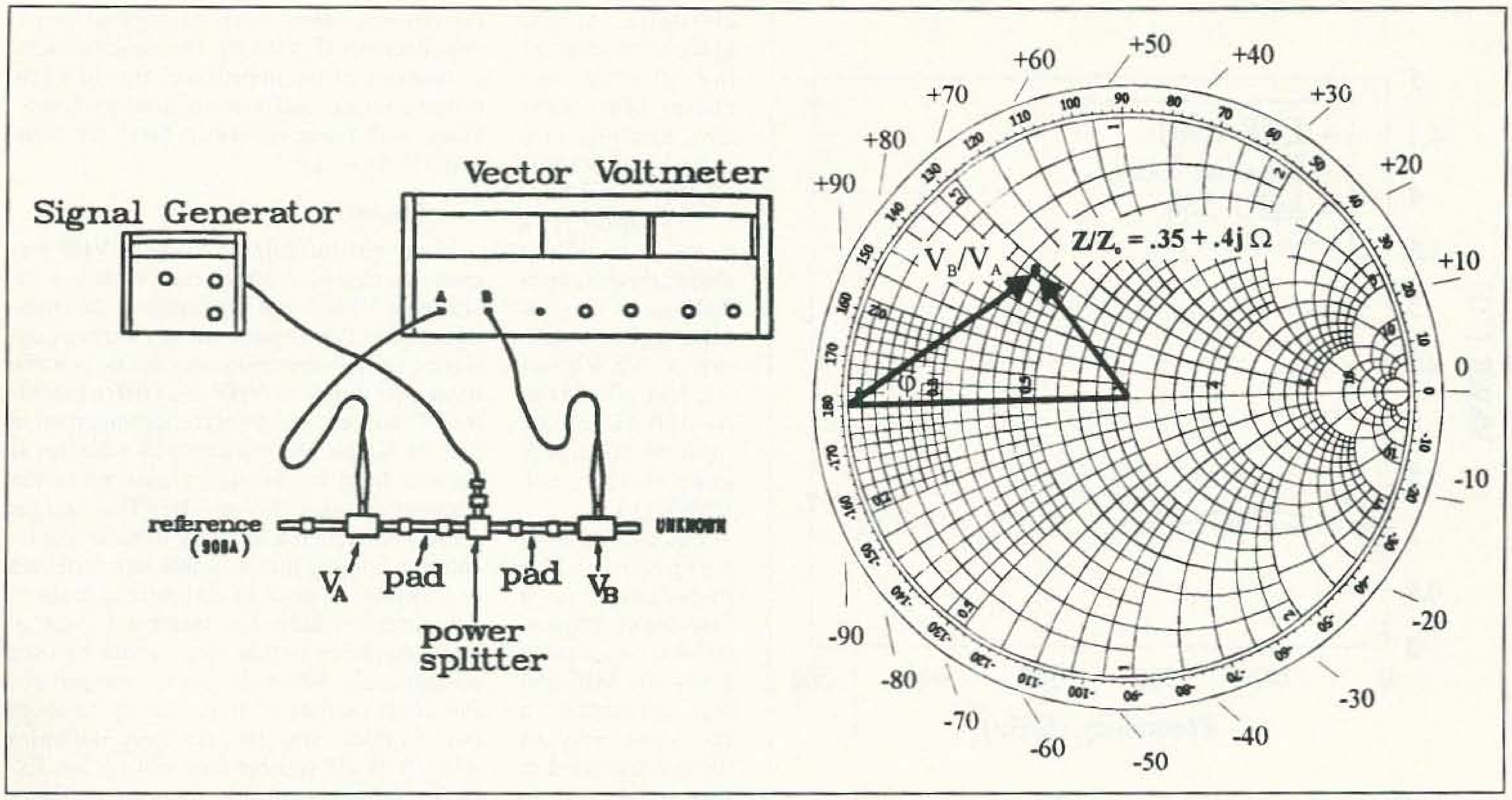

Figure 3. Complex impedance measurement using the Vector Voltmeter.

V_B/V_A is the vector voltage ratio between a 50 ohm resistive load and the load under test. This is the resistive (or real) component of the complex impedance of the load. To find the reactive component, the phase difference (m) between V_A and V_B are measured. If V_B lags V_A, the reactive (imaginary) component is capacitive and the phase difference is negative; if V_A leads V_B it is inductive and the phase difference is positive. These two measurements, V_B/V_A and øB-A, can be plotted on the Smith chart (Figure 3). This task is then repeated for a variety of frequencies to calculate the impedance of the load as a function of frequency.

Results

Measured complex impedances of these two loads are shown in Figures 4 and 5. The DIP load remains essentially resistive up to about 10 MHz, after which it becomes reactive to a maximum VSWR of 1.5:1 at 100 MHz. Because it has a DC resistance of 68 ohms, there is a small mismatch with 50 ohm equipment at low frequencies (VSWR = 1.4:1). The experimenter may be able to get better results at VHF frequencies by simply clipping off pairs of resistors with a pair of diagonal cutters. However, this will probably result in a higher VSWR at low frequencies. This aside, this dummy is surprisingly good, and should be usable up to about

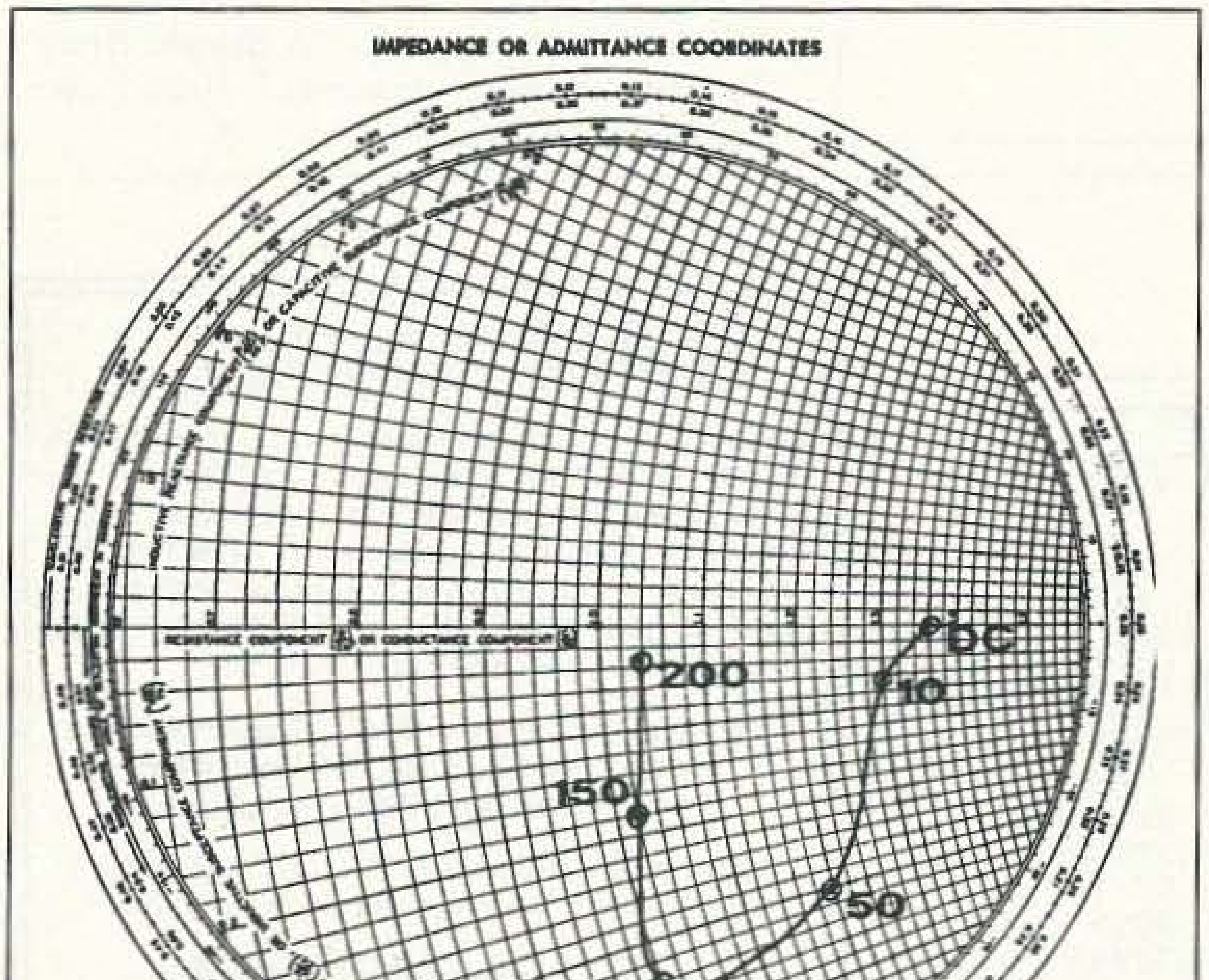

Figure 4. DIP dummy impedance from 0 to 200 MHz. The Smith chart is in expanded form.

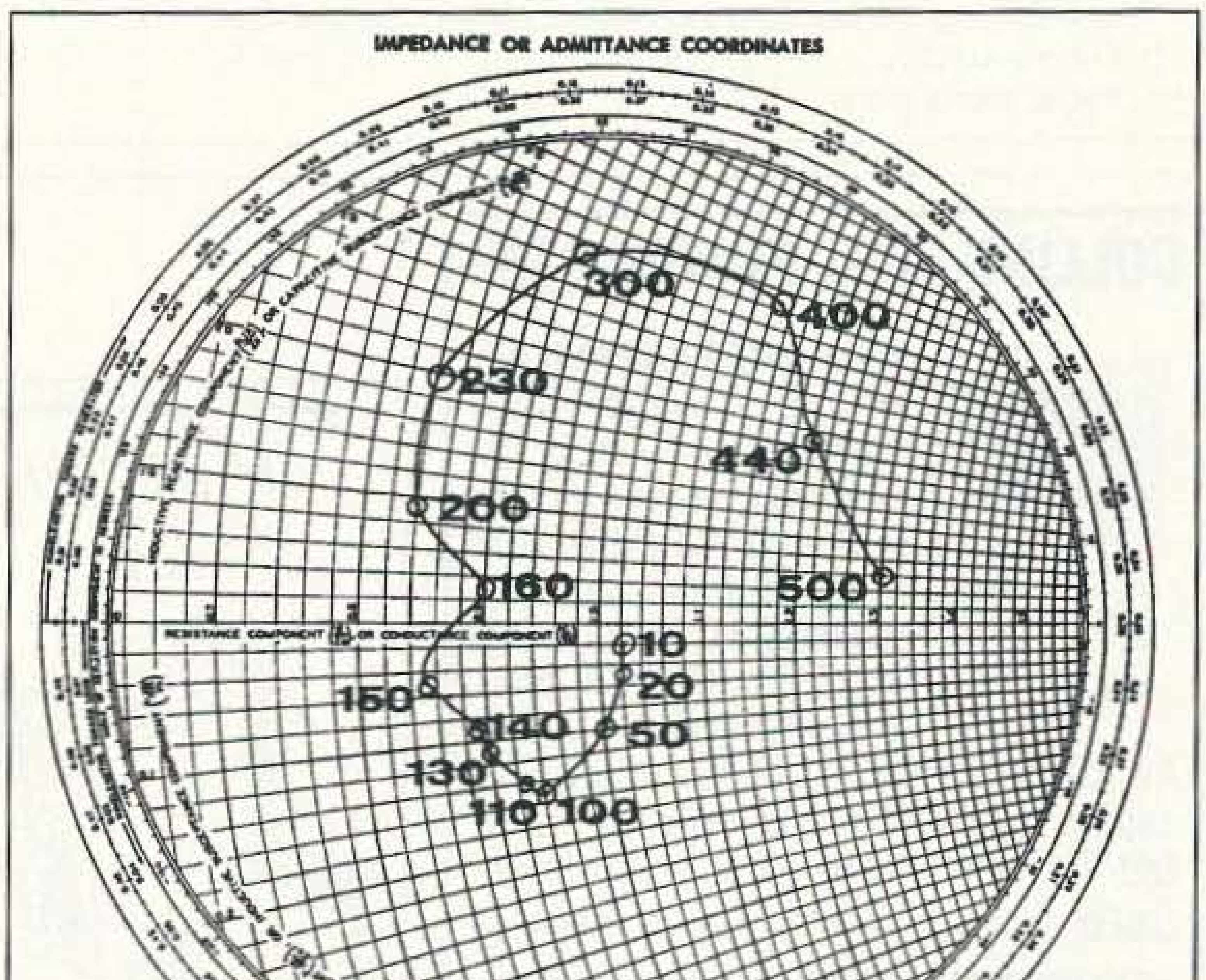

Figure 5. Radial dummy impedance from 10 to 500 MHz. The Smith chart is in expanded form.

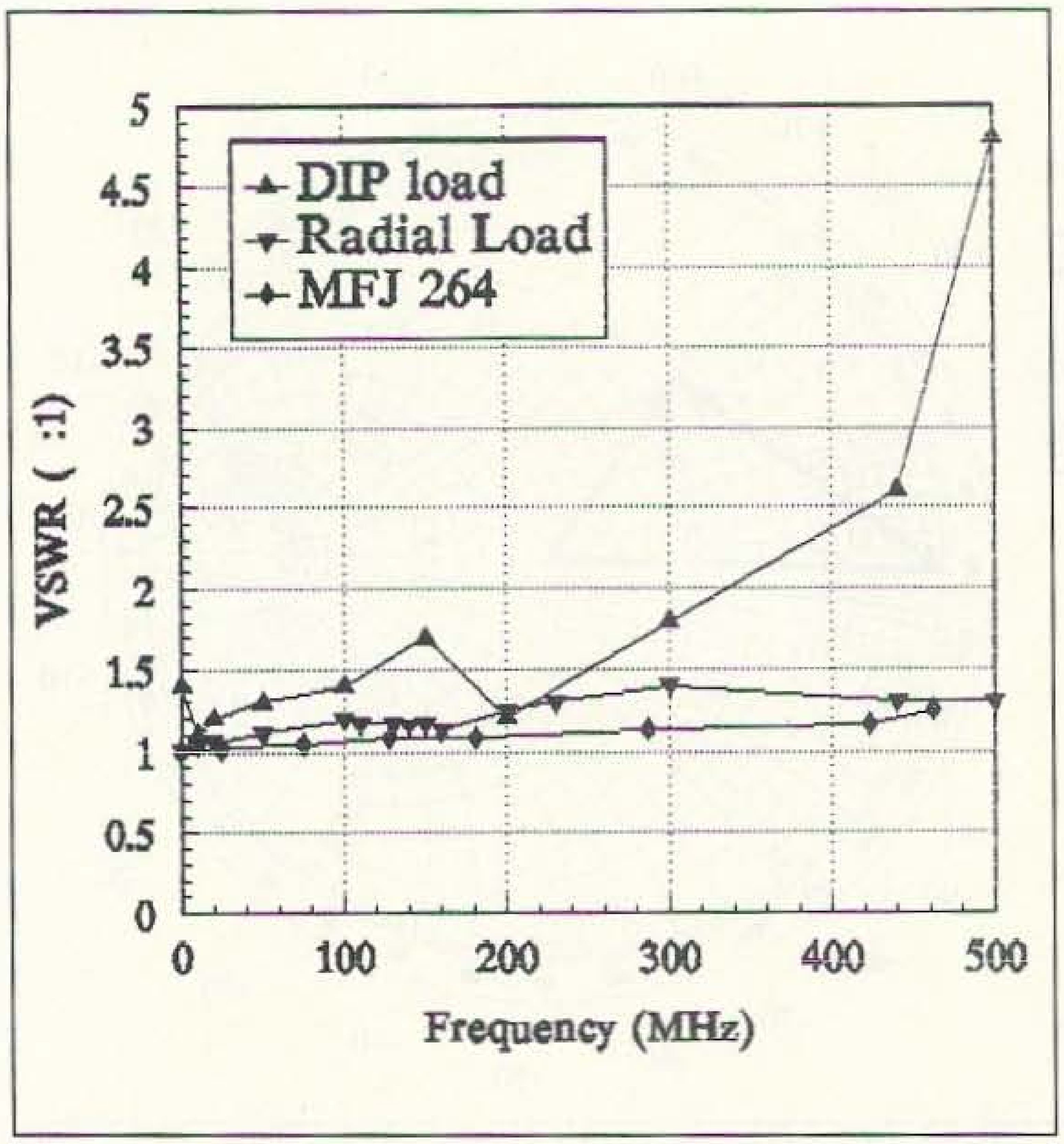

Figure 6. VSWR of dummy antennas at various frequencies. Included for comparison is the MFJ 264 dry dummy.

200 MHz. At 300 MHz (not shown) the dummy becomes very reactive, resulting in a calculated VSWR of greater than 4:1!

The radial load displays excellent characteristics, even well up to the 300 MHz region, reaching a VSWR of 1.2:1 at 300 MHz. At 500 MHz (the limit of my signal generator) the VSWR is 1.3:1.

For comparative purposes—the impedance as a function of frequency of a commercial load—the MFJ-264 was measured in the same way as those constructed in this article. Up to 500 MHz, the VSWR of this dummy remains below 1.3:1, as claimed by the manufacturer (Figure 6). For completeness, a summary of the impedance, etc., of a few other commercially-built dummy loads, along with those described here, are compared in Table 1.

Table 1. VSWR of Dummy Loads from 0-500 MHz

Dummy	0-100 MHz	200 MHz	500 MHz	Power**(W)	Price***
Ten Tec 239	1.1:1*	1.1:1*	2:1*	75	$60
MFJ 260 B	1.3:1*	1.5:1*	—	90	$30
MFJ 262	1.5:1*	—	—	200	$80
MFJ 264	1.1:1 (<1.3:1)	1.1:1 (<1.3:1)	1.3:1 (<1.3:1)	75	$60
DIP	1.3:1	1.1:1	5:1	40	$10
Radial	1.2:1	1.2:1	1.3:1	40	<$10

* Manufacturer's specifications: Where both manufacturers specifications and measured values are available, the manufacturer's values are shown in parentheses.

** Continuous duty.

*** Prices approximate.

Conclusions

Multi-resistor dummy loads at VHF frequencies can be reactive and result in considerable VSWR and mismatch to the transmitter. For this reason, those dummies designed for HF operation may not be suitable for proper tuning of VHF and UHF transmitters. Therefore, design becomes important in that the simple DC resistance of a dummy is not the total impedance presented to the transmitter, especially at VHF. Two designs are offered here that are easy to build and result in a dummy that is usable into VHF, are well below the price of commercial loads of comparable quality. The major drawback of these dummies is that they cannot be used continuously with high-power transmitters. For short periods of time, say up to about two minutes, you can use these dummies with 100W HF rigs but they will get hot. Experience has shown that about two minutes of keydown at 80W will melt the solder on the dummy!

Acknowledgments

I would like to thank the members of the Institute of Space and Atmospheric Studies at the University of Saskatchewan, who were nice enough to loan me their Vector Voltmeter, and always had the time to answer my questions. 73

References

Jim Fisk W1DTY, "How to Use the Smith Chart," *Ham Radio,* November 1970, p. 17.

Henry Keen W2CTK, "A Simple Bridge for Antenna Measurements," *Ham Radio,* September 1970, p.34.