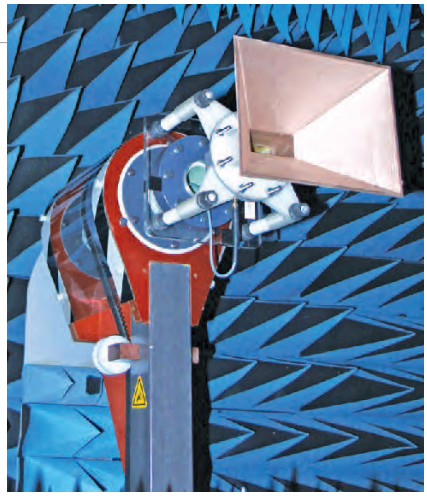
Paul Wade, W1GHZ, w1ghz@arrl.org

Microwavelengths

3D-Printed Antennas



A 3D-printed horn antenna for S-band use under test in an anechoic chamber. [Glenn Robb, KS4VA, photo]

3D printers have become quite inexpensive, and many hams have acquired one. Printing hard-to-machine horn and feed antennas for microwaves is a natural task for 3D printers. With extremely low costs and the ability to quickly iterate designs, there is little reason not to embrace this technique. But the inexpensive printers only print plastic, so the plastic must somehow be coated with metal. John Ishham, AA1I, printed a horn of "conductive" plastic that proved essentially transparent to RF, like most plastics, so it did not work as an antenna.

Several hams have tried different metallization techniques, but it is hard to tell how well they work. Recently, I heard from Glenn Robb, KS4VA, an RF engineer and founder of the Antenna Test Lab Co., a commercial antenna evaluation laboratory. Using their anechoic chamber and laboratory equipment, Glenn refined and proved out a process for printing and metalizing fully functioning horn antennas. I'll turn the rest of the column over to Glenn as guest author.

Rough Beginnings

In the spirit of true science, I wanted to create plastic horns that could be tested against their commercial all-metal counterparts. So, I 3D-printed copies of 15 dBi standard gain horns from 2 to 40 GHz, ranging from salad-bowl-sized horns to palm-sized antennas.

I chose MG Chemicals® shielding spray paints for metallization because they are easy to buy (available on Amazon). Their 843AR Super Shield™ Silver Coated Copper worked flawlessly. While I did try several coatings, I'll focus on the one that worked the best.

My first test antenna was an **x**-band horn with an expected gain of 15 dBi. The shiny horn looked awesome, and I had high expectations. However, testing results from the anechoic chamber were terrible. Gain was only about 5 dBi. But I did notice something promising — the antenna had 15 dB of directivity. Since its VSWR was great (better than 1.2 across the band), the only explanation was loss within the horn stealing its gain.

After lots of experimenting, and a trash can full of horns, I did find the culprit. The raw 3D-printed surfaces were to blame — the coatings are highly conductive, but apparently not over rough surfaces. Smoothing the surface proved to be the key to removing this loss and achieving the expected 15 dBi gain, as shown in Figure 1.

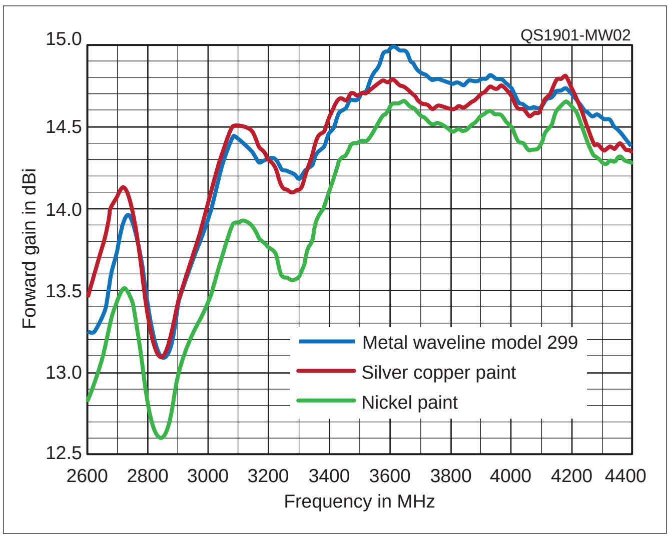


Figure 1 — Measured gain of 3D-printed horn antennas for S-band with silver-copper paint and with nickel paint compared to commercial metal horn.

Pre-Testing with VSWR

I devised a simple bench test to prove this theory and to pre-test antennas. This is an excellent way to verify your antenna prints. We often check for low VSWR because we all know this indicates a good antenna, but this assumes your antenna's internal losses are low. Paradoxically, even a bad lossy antenna has great VSWR.

To look for loss within an antenna, you need the opposite approach. The return loss from a short circuit coax is close to zero (infinite VSWR), and the same is true for a good horn antenna when its aperture is shorted. So, I tested the return loss of horns

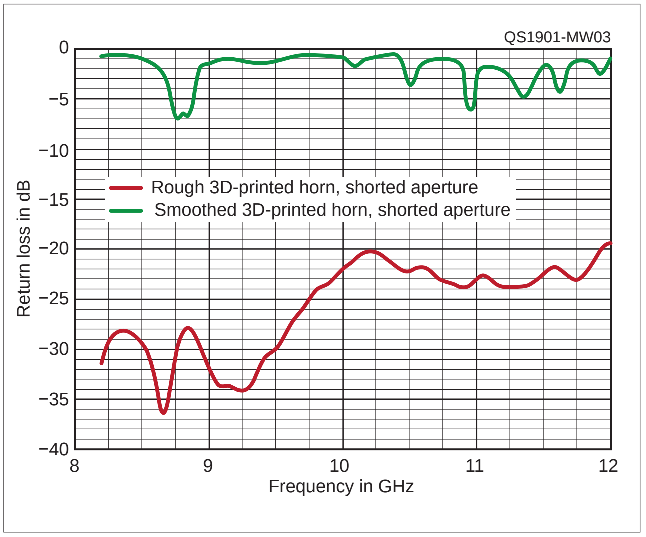


Figure 2 — Return loss test of 3D-printed horn antenna with shorted aperture, comparing rough and smooth surfaces.

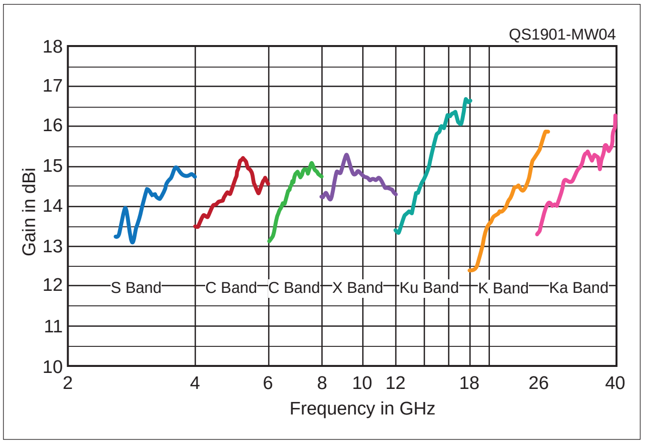


Figure 3 — Measured gain of 3D-printed horn antennas for frequencies from 2 to 40 GHz, showing performance comparable to commercial metal horns.

and launches with their apertures covered (shorted out) with aluminum cooking foil. In Figure 2, the shorted rough surface horn shows 20 dB of return loss (VSWR of about 1.2), proving that it has about 10 dB of internal loss (through the horn and then back from the cooking foil short). This accounts for the missing 10 dB of gain. You can see the dramatic difference in this graph between good and bad horns.

Surface Preparation

Sanding is an obvious way to smooth your 3D prints and it works perfectly fine. But it is hard to sand inside an enclosed space like a horn or wave-guide. I performed some experiments to verify two surface preparation processes.

I found that solvent smoothing was quick and easy on large horns. Acetone works well for ABS plastic prints, and dichloromethane (methylene chloride) is effective at softening and smoothing PLA plastic.

Both solvents are hazardous, but dichloromethane (the key ingredient in many paint strippers) is especially poisonous. Work outdoors with full-length chemical gloves and eye protection.

I simply poured solvent into a metal paint-roller tray, then brushed and scoured the surfaces of my antennas with steel wool. It takes only a minute to smooth the inside of even the largest horn if it is kept wet with solvent. A round bottle brush also easily scrubbed the wave-guide portion of the horns.

If you are assembling a larger antenna from smaller prints, now is the perfect time to solvent weld the softened parts.

A Less Toxic Approach

At Microwave Update 2018, Michelle Thompson, W5NYV, showed some 3D-printed antennas smoothed with a paint-on two-part epoxy coating. I tried “XTC-3D” from **smooth-on.com**, and it worked well for printed antennas from 2 to 18 GHz. Some pre-sanding before application removes large high spots from rough surfaces, and post-sanding is required to remove the high gloss from the finished surface. The cured shiny surface looks great but will not accept the metallized paint until lightly sanded. In horns from 18 to 40 GHz, the plastic features were just too small for the relatively thick coating. Critical dimensions were distorted, and holes and inside radiuses were starting to get filled in. However, antennas are quite tiny at these frequencies, and you can smooth them quickly with small hobby files.

Results

Figure 1 shows a detailed comparison of S-band horns. The blue and red curves compare a commercially made all-metal lab-grade horn antenna to a 3D-printed copy. Gain differences are less than ± 0.2 dB.

The smoothing process worked well up to 26 GHz. But my Ka-band horn only had 12 dBi of gain. This was fixed by filing the horn completely smooth with a tiny file. This extra smoothing step resulted in very high shorted-aperture VSWR on the bench and fully restored the expected 15 dBi gain in the anechoic chamber.

Figure 3 shows the measured gains versus frequency of my 3D-printed 15 dBi family of standard gain horns.

If you would like to experiment further, I have made the STL printable files and 3D models (made with *Sketchup Make*, a free 3D computer-aided design tool) available for download at **antennatestlab.com/3dprinting**.