About this Article

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Microwave Transmission Lines

In the previous two columns, we talked about some microwave antennas: horns and dishes. Now we need to get the antennas up in the air and radiating so that we can make contacts. Microwaves don't travel through obstructions very well—trees are great absorbers—so we must get the antenna in the clear and give our signal a good launch. In the clear is relative; a mountain isn't necessary, just a good start toward the horizon. A small tripod standing on a beach looking over the water can be better than a high hill covered with trees.

For most home stations, a tower or other structure is typically required to get up in the clear, above local trees and structures. With the antennas at the top of the tower and the station at the bottom, transmission lines are required to get the signal to the antenna. The only good transmission lines for microwaves are coaxial lines and waveguides. Open wire lines (twinlead or ladder line) are good for HF, but only work when the spacing between wires is much less than a wavelength.

Coax

Coaxial lines are lossy, even at HF, and the loss increases with frequency. Common coax, like RG-8, can be used for short runs at microwave frequencies, while smaller diameters, like RG-58, are only useful for short jumpers—long lengths make good dummy loads! Lower loss coax is available; Heliax (a cable with foam dielectric and helical corrugated outer conductor) is popular for the lower microwave bands, and larger diameters have lower loss (but higher cost). Connectors can also be a problem: good quality Type N and TNC connectors will work up perhaps 12 GHz, and good quality Type SMA connectors to 24 GHz, if properly installed. The exotic types of coax also need special connectors and installation procedures. Fortunately, most of this stuff is available through surplus channels.

Semi-rigid coax, with an outer conductor of solid copper tubing, is popular for microwave work. The most common size, UT-141, 0.141 inch in diameter, works to beyond 24 GHz, and a smaller size, UT-85, 0.085 inch in diameter, works to even higher frequencies, beyond 47 GHz. SMA connectors are readily available for both sizes and aren't hard to install. However, losses can be significant, as shown in Figure 1. Typical loss for an 18 inch length of UT-141 with connectors is around one dB. Larger sizes of semi-rigid coax are available, but connectors are hard to come by.

Waveguide

At the higher microwave frequencies, we must consider waveguides; small diameter coax is prohibitively lossy, and large coax starts to exhibit waveguide behavior. A waveguide is simply a hollow metal pipe that guides a radio wave; with no physical conductor and no leakage, loss is very low. Any hollow pipe with a big enough dimension for the wave to propagate, or travel, will work. Big enough for rectangular pipe is greater than ½ wavelength in the large dimension, while circular pipe must have a diameter greater than about 0.59 wavelength. Thus, common ¾ inch copper water pipe can be used as waveguide at 10 GHz. The minimum frequency that will propagate through a given size waveguide is called the cutoff frequency.

Below the cutoff frequency, attenuation is extremely high, so waveguide is a natural high-pass filter—one obvious advantage is eliminating IF leakthrough.

To use a waveguide as a transmission line, we must generate an electric and magnetic field traveling along the length of the pipe. These fields have different patterns, called *modes*, inside the waveguide. The electric field for the lowest frequency mode, or dominant mode, is shown in Figure 2. Other modes require larger dimensions (in wavelengths) to propagate—the next higher frequency mode requires a minimum dimension of one wavelength in rectangular guide or 0.77 wavelength in circular pipe—so if we pick a waveguide size carefully, only the dominant mode will propagate. Other modes, called higher-order modes, will suffer extremely high attenuation.

Why do we worry about different modes in waveguide? Because different modes have different wavelengths in the guide, so

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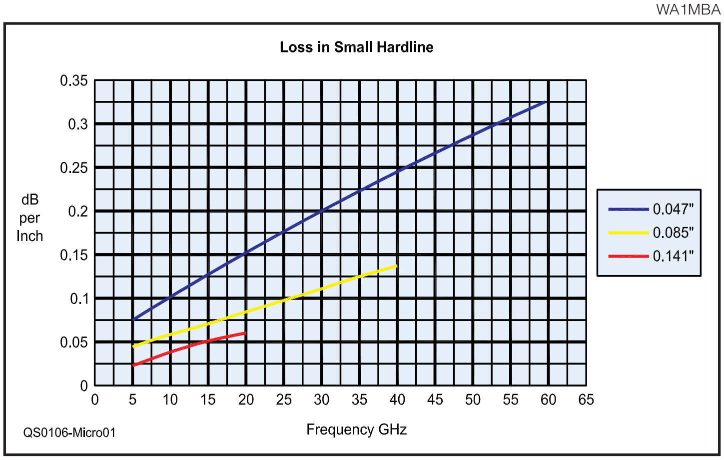

Figure 1—Loss in small semi-rigid coaxial line.

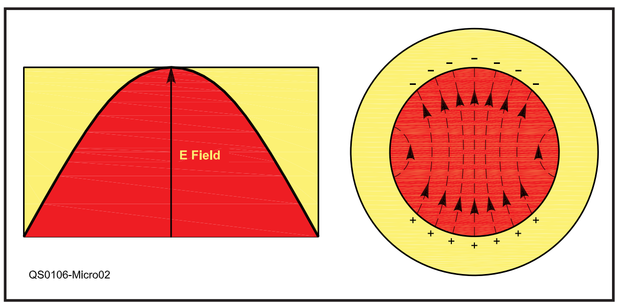

Figure 2—Electric field of dominant mode in rectangular and round waveguide. Arrows show polarization of field, and red area in rectangular shows relative intensity.

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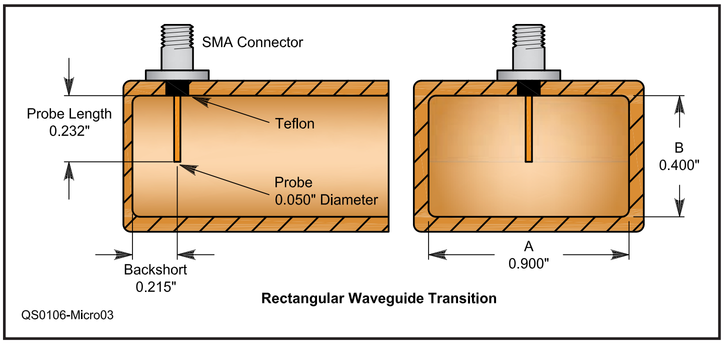

Figure 3—Sketch of rectangular waveguide transition. Dimensions shown are optimum for WR-90 at 10.368 GHZ.

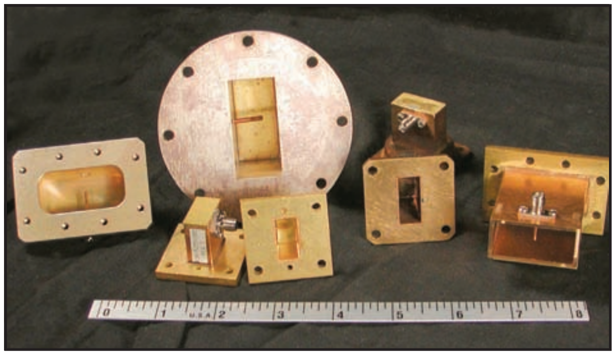

Figure 4—Homebrew transitions in several sizes of waveguide.

energy in different modes will not all arrive in phase at the far end. Energy arriving in different phases tend to cancel rather than be delivered, so energy is lost. Thus, it is difficult to have a low-loss transmission line carrying multiple modes.

Standard waveguide sizes have recommended operating frequencies, from a minimum somewhat above the cutoff frequency to a maximum frequency somewhat below the frequency where additional modes may occur. For instance, WR-90 waveguide, 0.9×0.4 inch inside, is recommended for operation at 8 to 12.4 GHz. In amateur use, we sometimes stretch the frequency range a bit to make use of available parts, but never below the cutoff frequency—a real physical limit. Most amateur microwave bands fall within or very close to the recommended frequency range for two or three standard waveguide sizes.

The standard "WR" rectangular waveguide sizes are designated by the larger inner dimension in hundredths of an inch. For WR-90 that is 0.90 inch, WR-42 is 0.42 inch, and WR-229 is 2.29 inches. Since the large dimension is also a half-wavelength at the cutoff frequency, we can quickly estimate the minimum usable frequency for a waveguide.

If a coaxial line has inner dimensions larger than a half-wavelength, it can also support waveguide modes, increasing the loss of the line. So both small diameter and large diameter coaxial cable can have high losses at microwave frequencies.

Waveguide also has loss, though smaller than coax, since the metal walls are not perfect conductors. For WR-90, typical loss per 100 feet according to the handbooks is about 5.5 dB at 10 GHz; actual loss may be higher. Loss in the transmission line to the antenna reduces signal-to-noise ratio directly, so every dB hurts. Smaller waveguides at higher frequencies are even worse, while larger waveguides at lower frequencies have significantly lower loss. However, large waveguides are also heavy, and minimum surplus prices are based on the scrap value of the brass or copper walls.

Circular waveguide is slightly better. K2TXB measured 5.9 dB loss for 94 feet of ¾ inch copper water pipe at 10 GHz. However, bumps and bends in the circular guide may rotate the polarization of the electric wave, so the polarization of the output transition must be adjustable for maximum output.

A final problem with waveguide is condensation. Any humidity inside the guide will condense on the walls when the outside temperature drops below the dew point, increasing losses and starting corrosion. In commercial installations, waveguide is often pressurized with dry air or nitrogen.

Transitions

Whatever transmission line we use to get up the tower, a flexible section is needed to get around the rotator. Flexible waveguides are available, and some hams use them, but most use a flexible coax cable. Somehow, we must make the transition from waveguide to coax.

At the other end, almost all microwave equipment uses coaxial connectors, since it is extremely difficult to connect a transistor directly to a waveguide. To make a connection from coax or microstrip to waveguide, a transition is required, unless the equipment includes one internally.

Commercial transitions from coax to waveguide are available as surplus, but not often at reasonable prices. More important, many of them have optimum performance over some commercial microwave frequency band rather than the amateur band of interest. Fortunately, a good transition is not hard to homebrew from a scrap of waveguide.

Most transitions from coax to waveguide consist of a simple probe extending through the broad wall of the waveguide, with a closed end behind the probe acting as a short circuit (backshort), like Figure 3. There is a persistent myth from some old books that the backshort should be a quarter-wavelength behind the probe. For best performance, however, an optimum combination of backshort distance, probe length and probe diameter must be determined, either experimentally or by computer analysis using a 3D electromagnetic simulator program.

For circular waveguide, I described some experimental results in a *QEX* article.[1] Results for rectangular waveguide will be in an upcoming *QEX* article, but the optimum dimensions for a WR-90 waveguide to SMA transition are shown in Figure 3. To build one, cut off a short section of waveguide with a flange attached, file the end square, carefully measure, drill and tap the holes, then solder a flat metal plate to the open end. Trim the connector center conductor to the desired length for the probe and bolt the connector in place. Some of my homebrew transitions are shown in Figure 4.

The other transition problem is between different sizes of waveguide. Often, we find good surplus components that work on the same frequency but use different waveguide sizes. Commercial transitions typically have a linear taper section more than a wavelength long. Hams have made similar transitions using hobby brass, but excellent results are often obtained by simply butting the two flanges together and trying it out. If it works, the mounting holes can be filed out so that the two guides may be bolted together.

Alternatives

What we can conclude is that both coax and waveguide are lossy at microwave frequencies. Is there a better way to get a signal up to the antenna? Our next column will examine some alternative approaches.

More Information

A good source of information on waveguides, cables, and microwave connectors is **www.wa1mba.org**.

[1]"Understanding Circular Waveguide—Experimentally," *QEX*, Jan/Feb 2001, p 37.