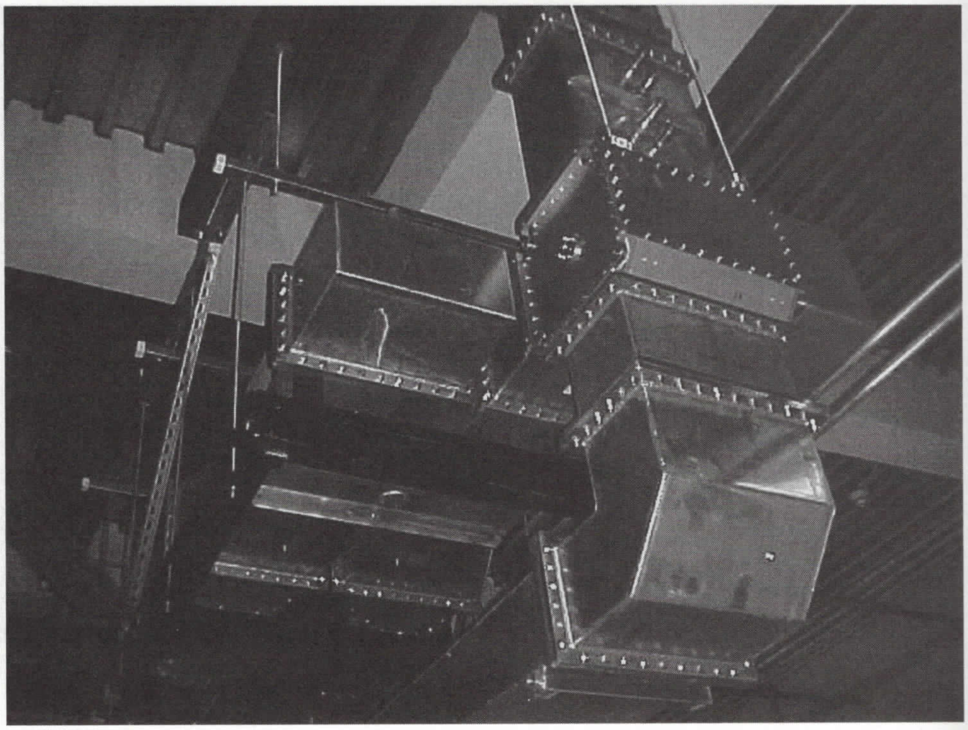

Figure 13.25 Square waveguide.

is 35 ns. The velocity of propagation is based on the ratio between the lower cutoff frequency and the actual frequency. A typical lower cutoff frequency would be around 460 MHz. A $1^5/_8$-in waveguide has a loss of 2.3 dB/300 ft.

The disadvantage of waveguide is that it is generally wider than coax, which increases wind loading. Also, waveguide has limited bandwidth. The group delay is greater in waveguide than coax. The disadvantage of coax is that the bullets need to be replaced every 10 years, and there is also a greater chance of burnout (Fig. 13.26).

In a comparison of rectangular to circular waveguide, rectangular waveguide has higher wind loading, more group delay, and is more expensive. However, when compared to circular waveguide, it has lower loss and can handle higher power. Circular waveguide has slightly less wind load than rectangular waveguide and is less expensive, but transitions to other lines can be tricky.

13.3.3 Antennas

Like everything else, antenna selection involves a number of trade-offs. High-gain antennas (rf propagation limited to desired directions only) allow less transmit power. However, the higher the gain of an antenna, the larger its size and the narrower its vertical pattern.

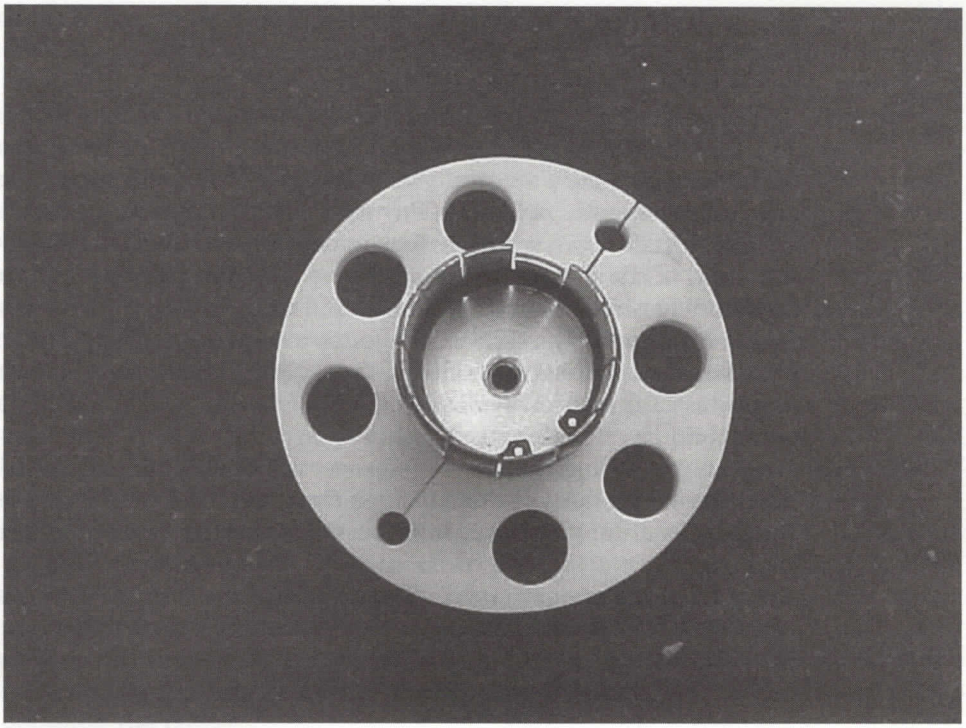

Figure 13.26 Bullet used for mating sections of rigid coax.

13.3.3.1 Propagation. In rf transmission systems two terms are often used to describe power. The first is TPO, that is, the total power out of the transmitter into the rf plumbing system. Between the transmitter and the antenna the rf power is attenuated by combining, filtering, and transmission/waveguide losses. These losses are known as the *line efficiency.* The power that is actually radiated by the antenna is known as the *effective radiated power* (ERP). Thus.

$$\text{ERP} = \text{transmitter power out} \times \text{line efficiency} \times \text{antenna gain}$$

The *directivity* of an antenna is its ability to concentrate radiated power in a particular direction. The *gain* of an antenna indicates its directivity. Antenna gain considerations are transmitter size and expense versus good coverage. Low gain means better coverage, but the transmitter needs more power out.

Tower-top pole-type antennas can be classified into two categories:

1. Resonant dipoles and slots
2. Multiwavelength traveling wave elements

RF waves are comprised of transverse electromagnetic (TEM) waves. A TEM wave has E (electrostatic) and H (magnetic) waves transverse (or normal, 90°) to the direction of propagation. Maxwell's equations indicate that changing electrostatic fields create magnetic fields and vice versa. Once created, they therefore sustain each other. E fields are much stronger than H. E fields generally induce currents into receive antennas.

With regard to antennas, near fields versus far fields are often mentioned. In a near field E is based on a Poynting vector and a dielectric constant, along with distance. The Poynting vector is a power density vector associated with an electromagnetic field. The Poynting vector points towards the source. The surface integral (an envelope encompassing all the radiating surface of the antenna) of the Poynting vectors over a closed surface equals the power leaving the enclosed volume. This is referred to as Poynting's theorem. In far fields H and E are mainly based on the antenna current and the distance. The ratio between E and H becomes a constant. Near fields are where the distance is much less than the wavelength. Far fields are where the distance is much more than the wavelength.

When computing the coverage properties of an antenna, the distance to the radio horizon is usually done using a chart with the earth's radius that is four-thirds the actual size to account for atmospheric refraction effects.

13.3.3.2 Radiation resistance. The *radiation resistance* of an antenna is the ratio of voltage at any point on an antenna to the current flowing at that point ($R = E/I$). Since current decreases toward the ends of the antenna and voltage increases, R increases toward the antenna's ends.

13.3.3.3 Polarization. The orientation of the E field can be in one of three directions: (1) vertically polarized (AM transmission is vertically polarized), (2) horizontally polarized (such as FM and most of television), or (3) circularly polarized (used by some FM and UHF TV).

Many natural, along with a wide selection of synthetic, obstacles produce shadows for broadcast signals. This situation has sometimes caused degradation of NTSC coverage. As has been widely publicized with the advent of DTV, gradual degradation of the signal should not occur in the digital domain. The baseband, modulated, and transmitted digital signal should be decoded perfectly by a receiver right up to the point where noise, reflections, and other factors swamp the error-correction system's ability to recover the data, that is, the well-known cliff effect. It has been determined from testing that error-free DTV reception can plummet to an almost one in two chance for errors with less than a 2-dB change in the signal-to-noise ratio.

Signal reflection or multipath problems, while annoying in NTSC, have been rumored to be lethal to ATSC signals. CP propagation has been employed by some broadcasters since the late 1970s to minimize ghosting. This is largely attributable to the fact that reflections off buildings and other objects tend to have the opposite polarization than what was transmitted. It has also been found that signal components in the H and V fields fade to a great extent, independent of each other. H seems to fade or be defracted off its axis to a greater degree over water than does V. Indeed, defraction off the

H axis has been evident since television's inception. Early CATV systems often mounted receive antennas in vertical orientations rather then horizontal for the strongest receive signal. Horizontally polarized *E* fields sometimes appear to be defracted by obstacles along the path and end up with vertical orientation.

A number of DTV receive attribute tests were conducted. One of the measured attributes concerned *H* versus CP polarization. Although the tests were inconclusive, hints that CP might add a degree of robustness to the propagated signal were apparent. One hint came from the DTV receiver. A parameter called *tap energy,* which is a measure of how hard the receiver's equalizer is working, was slightly lower with CP broadcasts than with *H*. A second hint was that the received signal strength indoors actually increased slightly with CP.

There are a number of disadvantages to using CP. Most center on cost. Although true circular polarization is nearly impossible, to approach it will mean doubling radiated power, with nearly equal vertical and horizontal *E* fields. Fairly high assigned radiated power, along with the desire for using a fairly low-gain antenna for a fat vertical pattern, means that it would take more rf cabinets if CP instead of *H* polarization were implemented. This equates into increased up-front costs and increased monthly costs, mainly for power. Doug Lung has stated that he believes only 25 percent vertical component might be necessary. This would obviously lower the power required. Some have stated that noteworthy diversity improvement can be obtained without doubling the power.

Another problem arising from using CP is that more tower reflections are possible from the vertical component. One of the advantages of using a panel antenna is that it produces minimal reflections from its support tower. Finally, at the receive end, antennas with poorly shielded downleads can have reflections induced into the received signal from the CP's *V* component.

For circular polarization the sense of rotation is determined using the right-hand rule. Point the thumb on the right hand toward the radiator and curl the fingers. Looking at the curled fingers from the index figure end of the hand represents the direction of polarization as seen by the receiver. The vertical radiation should not exceed the horizontal component. On side-mounted CP antennas, tower interaction, or reflections, will occur mainly in the *V* plane.

Some early CATV systems experimented with *H*- and *V*-mounted receive antennas which were combined. This was done long before there were any CP transmit stations. The vertical component of the signal was apparently generated through a diffraction process over obstacles along the path, and, as a result, the polarization diversity was site-specific. Due to reflection from non-vertical objects or to ionosphere contour, the polarization of a ground or sky wave may be twisted out of its original polarization. It has been found that *H* and *V* signals fade independently to a large extent. The main attribute of CP operation is ghost cancellation. Inherent CP reflection cancellation can reduce the equalization effort required of the ATV receiver's adaptive equalizer.

A common technique for producing circular polarization has been to place two linear dipoles at right angles in front of a reflecting screen and feed them with equal voltage magnitudes but with a 90° phase difference. However, the azimuth beam width for horizontal and vertical polarization is about 60° and 120°, respectively. Thus, the power ratio between the two planes is low only for directions near the normal to the reflective screen. Flat-crossed dipoles enclosed in a circular cavity are one technique for equalizing the azimuth beam's width for vertical and horizontal polarization.

13.3.3.4 Gain. The gain of an antenna is always specified relative to a one-half-wavelength dipole. The gain–beam width product of antennas is essentially a constant. The product for practical antennas varies from 50.8 to 68. This illustrates that as the gain increases, the beam width decreases.

13.3.3.5 Beam width. The approximate beam width of an antenna corresponds to 70.7 percent of the value of the field (50 percent of the power), or 3 dB below the maximum. Beam width is determined by the number of radiators, the distance between the radiators, and the frequency.

13.3.3.6 Beam tilt. The phasing of cables feeding various antenna elements will introduce beam tilt. Any specified beam tilting of the beam below the horizontal is easily achieved by progressively phase shifting the currents in each panel. Antenna beam steering changes with frequency.

13.3.3.7 Turnstile antennas. Turnstile, or bat-wing, antennas are the oldest type. Turnstiles are made of four bat-wing–shaped elements mounted on a vertical pole. The bat wings are, in effect, two dipoles that are fed in quadrature phase. The azimuthal field pattern is a function of the diameter of the support mask. Usually, there are six stacked turnstiles for channels 2 to 6 and 12 for channels 7 to 13.

Most existing VHF antennas are tuned to operate on specific channels and, therefore, are not suitable for multiplex operation. Bat-wing antennas can be used for $N + 1$ operation, and can be designed for multiplex VHF operation.

13.3.3.8 Slot antennas. The vast majority of UHF antennas currently used in NTSC service are slotted cylinder designs. They have excellent omnidirectional azimuth patterns, low wind loads, and smooth null fill. Most slotted cylinder antennas have diameters between 8 and 14 in. In addition to reducing wind loading, this also translates into a small electric radius (radius/λ) for the slot radiators, resulting in excellent circularity or azimuth pattern. Multislot antennas are available for channels 7 to 13, and these antennas are comprised of an array of axial slots on the outer surface of a coaxial transmission line. The slots are excited by an exponentially decaying traveling wave inside a slotted pole. The azimuthal pattern deviation is less than 5 percent. The antenna is generally approximately 15 wavelengths long.

The slotted cylinder antenna, commonly referred to as the pylon antenna, is the most popular top-mounted antenna for UHF applications. Horizontally polarized radiation is achieved using axial resonant slots on a cylinder to generate circumferential current around the outer surface of the cylinder. A good azimuthal pattern is achieved by exciting four columns of slots around the circumference of the cylinder, which is a structurally rigid coaxial transmission line. Slots along the pole are spaced approximately one wavelength per layer. Typical gains range from 20 to 40.

Helical and slotted traveling wave antennas have low wind loads, but they only radiate on a single channel. They have a limited number of azimuthal patterns, but can be used for ellipitcal polarization.

Branch feed–type antennas (such as turnstiles or panels) are assumed to have equal path lengths to each element, so that all elements receive the signal from the feed system at the same instant. In contrast, slots in a traveling wave antenna receive the input signal sequentially, not simultaneously. A traveling wave–type antenna is essentially a leaky transmission line. The traveling wave antenna has less gain than the branch feed antenna because the signal must propagate up the antenna to each radiating element. Slew rates are longer than branch feed types, since the first element is fed (gain of 1), then the second element (gain of 2), etc.

Bottom-fed slotted cylinder antennas have slots one wavelength apart (at a center frequency of interest). Therefore, the beam tilt of a slotted cylinder antenna varies with frequency, which means that, at the lower band edge, beam tilt is higher than desired and lower than expected at the upper edge of the band beam tilt. Beam tilt can be as high as ±2.5° (−0.75° is common).

An alternative feed design is to electrically center-feed the slotted antenna. A "T" is used on a side-mounted antenna, and a triaxial configuration is used for the bottom half of the antenna on a top-mounted antenna. Center feeding will cause the bottom and top halves of the antenna to have electric tilts in the opposite directions. This produces a constant electric beam tilt for the entire antenna.

Slotted antennas cannot be made to have low gain. These antennas are generally about 16 wavelengths long. Each slot, which is spaced about one wavelength apart, effects a gain of 4. For NTSC visual and aural carriers the wavelength is slightly different. Therefore, the amount of beam steering is different for each carrier. To minimize this difference, the antenna's slot spacing is usually a compromise between the two.

For UHF the antenna height is everything. UHF power cannot travel over the horizon; UHF signals cannot go around objects. Height is more important than power when dealing with UHF. The exception to this rule is if the audience is close in, then lower the gain of the antenna and increase power to better penetrate buildings.

13.3.3.9 Panel antennas. Although slotted antennas are not wideband devices, panels are, and DTV needs wideband antennas. Although panel antennas are fairly light, they produce much wind loading. Panels can't take high power; they are generally restricted to about 4 kW/panel, although some are now rated up to 8 to 10 kW.

Panel antennas are primarily used to control or minimize the reflections from the supporting structure. The simplest panel is either a horizontal dipole or, in the case of a CP antenna, two crossed dipoles in front of a reflector. The reflector is usually a wire grid for VHF and a solid sheet for UHF. For good omnidirectional patterns the tower width should not be greater than one wavelength.

Panel antennas can be used for multiplex operations, but are not suitable for $N + 1$ operation. Panels can achieve excellent pattern circularity.

13.3.4 Towers

Tower structural standards are 1949 RETMA TR-116, 1959 EIA RS-222, 1980 ANSI A58.1, and 1996 RS-222-F (also known as TIA/EIA RS-222-F). Electromagnetic radiation rules are covered in OET 65 (www.fcc.gov/oet/rfsafety).

An *appurtenance* is a thing added to a more important thing. This term is applied to things hung on a tower.

Terms important with tower loads are

Dead load. Antennas, transmission lines, waveguides, lighting systems, conduits and junction boxes, ladders, safety climbs, work platforms, guy wires, and elevators.

Wind load. Round members are more aerodynamic. Wind load increases with height.

Ice load. Ice is a leading cause of tower failure.

Seismic load.

Other tower loads. Bending moments, shear force, compression, tension, and axial load.

Several tower upgrade methods are

Leg member upgrades. Reduce the unbraced length of legs with added leg bracing. Fill legs with high-strength concrete or grout. Weld half-round sections of pipe to legs. Weld or bolt plates, angles, or channels to legs. Install additional horizontal bracing (Fig. 13.27).

Guy wire or anchor upgrades. Add additional guy level between existing guys. Add a star frame with torsional guys.

Reducing wind loads. Add antenna radomes, which reduces wind loads by as much as 45 percent. Hide coax and transmission lines.

Although towers can inflict heavy damage if they fail, tower insurance ranges from $5 to $10 million for general liability, as compared to $1 million for