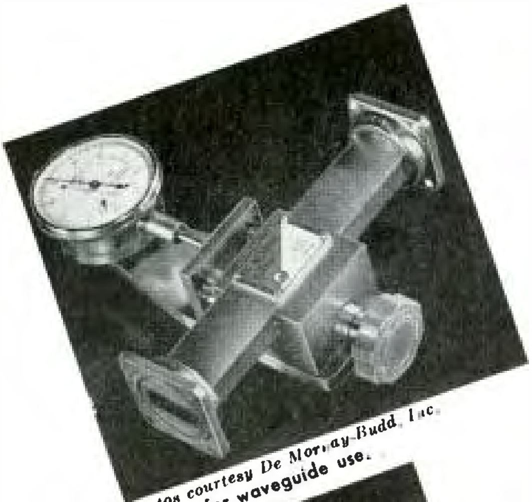
MICROWAVES

PART I—How radio waves can be transmitted inside pieces of pipe

By C. W. PALMER



Photos courtesy De Mor.ay-Budd, Inc.

A variable attenuator for waveguide use.

Waveguides may be tuned with this device.

WAVEGUIDES and waveguide techniques have developed so rapidly as a result of wartime use in radar, point-to-point communication, and other ultra-high-frequency radio systems that the average radioman has not had time to acquaint himself with their principles, understand their advantages in u.h.f. applications, or to learn how to use them. Technical publications have devoted considerable space to waveguide techniques during the past year or two, but usually in language which presupposes some familiarity with the subject and considerable engineering training.

It is important that the practical radioman get a thorough understanding of waveguides and their use. With color television in the offing, and with ham radio (particularly narrow-band FM) looking to higher frequencies in the u.h.f. spectrum, "radio plumbing" (as the guides are affectionately called) will become increasingly common in the next few years.

First of all, what is a waveguide and how does it differ from the parallel-wire and co-axial transmission lines that have become second nature to the ham and the television and FM experimenter? It is a simple hollow tube, usually made of metal, having no central conductor or wire. It is essentially a means of restricting ultra-high-frequency waves within its walls so that they may be transferred from one place to another.

Waveguides are used mostly for conducting the waves generated by a u.h.f. oscillator to the antenna, for conducting the waves picked up at a receiving antenna to the converter or detector, and for mixing or combining several u.h.f. waves. Waveguides also provide a convenient method for measurement of frequency, power, and similar characteristics in the u.h.f. spectrum.

Waveguides may be rectangular, circular, or oval, though most of the present-day applications use the rectangular guide because it has been found easier to fabricate than the other two shapes.

Losses in waveguides are relatively low since the waves bounce off or are reflected by the inner metallic walls of the guide but otherwise travel much the same as radio waves in free space. The guides may be bent around corners, carrying the waves with them. (The action here is similar to the transmission of light waves through lucite or fused quartz rods. As a matter of fact waveguides can be made of solid dielectric rods. The waves will follow along just as the light waves do in the lucite rod. The losses are higher than in hollow metallic waveguides, however, which explains why dielectric rods are seldom used.)

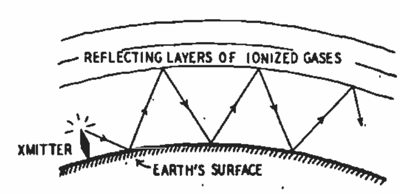


Fig. 1—The oldest and best-known waveguide.

Propagation in wave guides

So much for a general explanation of what constitutes a waveguide. To understand how high-frequency radio waves travel in a guide, let's look at Fig. 1. This picture is familiar to most radiomen and is often used to explain dx transmission. A few miles above the earth's surface, there are accumulations or layers of ionized air or gases that act as a reflecting plate or mirror, bouncing the waves back toward the earth's surface, where they are again reflected by the surface of the earth. Thus the waves are bounced back and forth to appear in receiving antennas thousands of miles away from the transmitter.

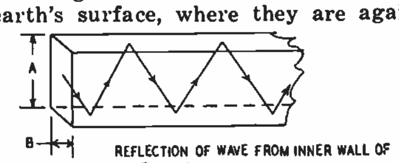


Fig. 2—The waves bounce off the metal walls.

In a like manner, the u.h.f. waves bounce back and forth from opposite sides of the waveguide as shown in Fig. 2. The only restriction is that distance A must be greater than a half-wave-

We present here the first article of a series on microwave propagation and waveguide equipment. Since waveguides are the only practical means for propagating and controlling waves across a wide band of frequencies in what is becoming a highly important part of the radio spectrum, the up-to-date radioman must master waveguide technique.

length or the waves bounce back and forth from directly opposite points and do not advance through the guide. The frequency at which A is half a wavelength is known as the cutoff frequency of the guide.

Waveguide action cannot be fully understood in terms of transmission-line theory, though there are some similarities between them. Waveguides must be approached from the viewpoint of *radiation of electromagnetic waves* instead of that of conduction.

However, since most radiomen are familiar to some extent with transmission lines, they provide a jumping-off point. Let us examine Fig. 3-a. This shows a section of two-wire transmission line with a quarter-wave stub across it. The open ends of a quarter-wave stub present a high impedance across the line and do not short circuit it. As a result, the addition of the stub has very little effect on radio currents flowing in the transmission line. Now if we add an infinite number of quarter-wave stubs, as in Fig. 3-b, we will have a continuous rectangular pipe (3-c) or one type of waveguide. In this guide,

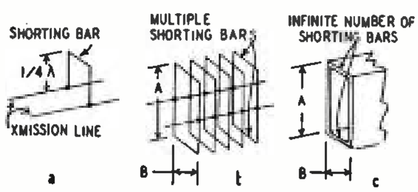


Fig. 3—How a waveguide might have evolved.

dimension A must be at least a half-wavelength but may be larger. (If it were smaller, the waves would be below the cutoff frequency of the waveguide.)

In considering the transmission of r.f. energy in waveguides, a new term, *mode*, has been applied. If we examine a cross section of co-axial transmission line, where there is a central conducting wire surrounded by a metal tube or shield but insulated from it, we find that there are two fields, a magnetic

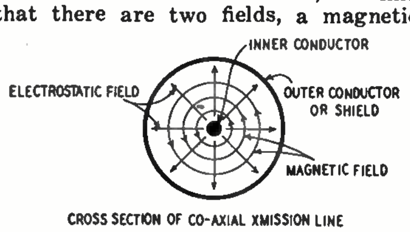


Fig. 4—Energy in co-axial transmission line.

field and an electrostatic field, resulting from the conduction of r.f. current through the transmission line. This is illustrated in simplified form in Fig. 4.

Similarly, in a waveguide, electrostatic and magnetic fields are built up due to the propagation of r.f. current. These can be seen for one mode or orientation of fields, called the TE_{01} mode, in a rectangular waveguide in Fig. 5-a. The magnetic lines of force can be likened to whirlpools when looking down on the top of the waveguide. These whirlpools travel down the tube in the direction of propagation. The electrostatic lines of

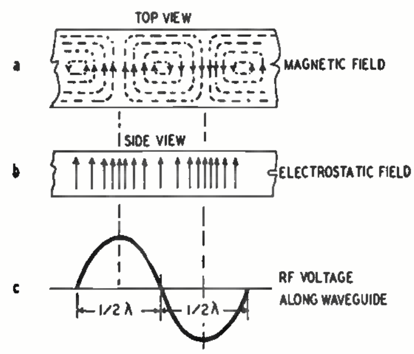


Fig. 5—Energy in a rectangular waveguide.

force are at right angles to the magnetic ones and are shown in the side view of the waveguide in Fig. 5-b. The corresponding instantaneous r.f. potential along the guide is shown at c.

There are numerous modes, identified by the letters TM for transverse magnetic and the letters TE for transverse electrostatic modes, one of the most commonly used one being the TE_{01}.

The subscripts refer to the number of waves which travel down the guide at one time. A TE_{02} wave, for example, would have two waves traveling down the waveguide side by side, much as if a vertical partition were running down the center. A diagram of the TE_{02} mode is given in the article *Microwaveguides* in last December's issue. The question of modes will be covered in greater detail in a future article.

The modes are determined or selected by the type and placement of the coupling device from the source of r.f. energy. Usually r.f. power is introduced into or extracted from a waveguide by means of a quarter-wave dipole, probe, or coupling loop. Two of these are shown in Fig. 6. In the case of the TE_{01} mode the probe is introduced at the center of the A dimension and at a point of maximum electrostatic field. When a loop is used, it must be introduced in the B dimension at a point where the magnetic field is greatest.

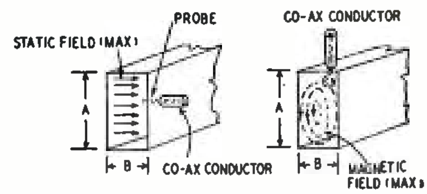


Fig. 6—Getting energy in and out of guides.

Microwave testing equipment is usually arranged so that the coupling device can be shifted by means of a slot cut longitudinally in a length of waveguide. This allows the energy distribution to be examined continuously along the guide. There is a point of maximum energy, reversed in polarity from the previous maximum, at each half-wave point. This provides a convenient means of measuring wavelength or frequency and also *standing-wave ratio*, which will be discussed in detail in a later article.

Waveguide dimensions

A given size waveguide can carry u.h.f currents of any frequency higher than cutoff, but there is one optimum frequency that is carried best by a given size of guide. For this reason the radio industry has endeavored to standardize on the smallest number of sizes consistent with good performance. In the following list, dimensions are in inches and frequency in megacycles:

A dimension	B dimension	Cutoff freq.	Wall thickness
3	1½	2,080	.080
2	1	3,155	.064
1½	¾	4,305	.064
1¼	⅝	5,265	.064
1	½	6,772	.064
¾	⅜	9,495	.064
½	¼	14,060	.040
11/32	3/16	20,935	.031

Above 20,000 mc it has become the practice to use solid coin-silver waveguides or, in some cases, laminated guides, because of the difficulty of manufacturing hollow guides of constant size. The tentative outside dimensions of these are as follows:

A dimension (inches)	B dimension (inches)	Range (mc)
0.42	0.17	18,000–26,000
0.34	0.17	22,000–33,000
0.28	0.14	26,000–40,000
0.224	0.112	33,000–50,000
0.188	0.094	40,000–60,000
0.148	0.074	50,000–75,000
0.122	0.061	60,000–90,000

(Continued on following page)

Because of size and construction limitations, waveguides are not practical for frequencies higher than about 100,000 mc or lower than 3,000 mc. An idea of the relative efficiency of a given size

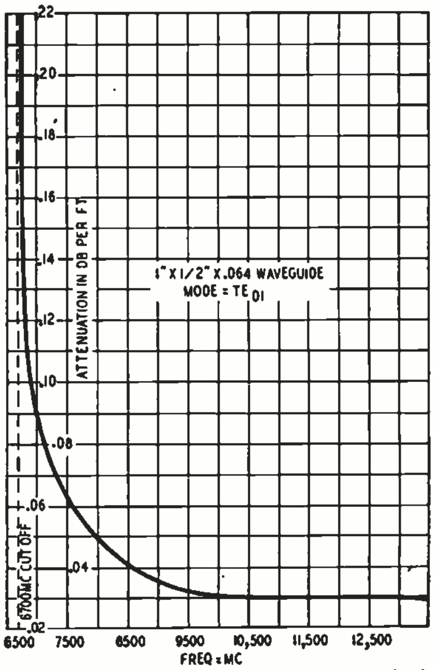


Fig. 7—Attenuation as cutoff is approached.

guide for a wide frequency spectrum can be seen in Fig. 7. Here, attenuation in decibels per foot of a piece of 1 x ½-inch waveguide is shown at various frequencies. The low-frequency cutoff at about 6,700 mc is quite evident in the greatly increased loss as this frequency is approached.

Special waveguide devices

Just as at lower frequencies, special devices for introducing inductance, capacitance, and resistance are available for waveguides, though they differ in shape and use from the familiar coils, capacitors, and resistors. For example, fixed or variable resistors in waveguide practice are strips of resistance material introduced longitudinally in the

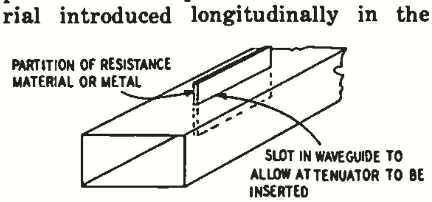
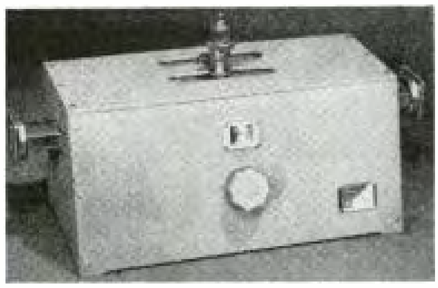


Fig. 8—Variable resistor, waveguide style.

guide as shown in Fig. 8. The further into the waveguide the resistor strip is lowered, the greater the attenuation. By adding a driving mechanism, we have a variable attenuator which can be calibrated.

A section of waveguide can be used as a tuned circuit or as a transformer, displaying both inductance and capacitance or, to be more exact, inductive and capacitive reactance. In Fig. 9 the u.h.f. voltage is introduced at point X. If the C dimensions are a quarter-wave each, reflections will occur and reinforce the voltage at X. (Dimensions C may also be multiples of a quarter-wavelength.)



The standing-wave detector, a device for exploring energy distribution in a waveguide.

By moving the closed ends, the guide can be tuned.

Open-ended or closed sections of waveguide can be used for switching u.h.f. currents from one waveguide path to another, without actually closing off the undesired path mechanically. Fig. 10 shows a small section of waveguide with two paths Y and Z and a short closed section U arranged with a mechanical flap that provides a short circuit at point A. When A is shorted, point X is effectively a solid wall and r.f. current can pass only through path Y. When the short at A is removed, current can pass both Y and Z paths. Many varied switching arrangements have been devised following this general scheme.

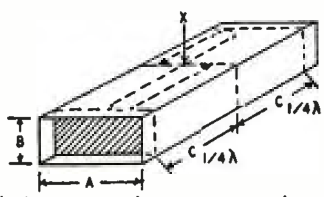


Fig. 9—The waveguide section may be made to act like an inductor or capacitor by making it less or more than a quarter wave long. See RADIO-ELECTRONICS, Dec. 1948, p. 24.

Impedance matching, usually done with transformers on lower frequencies, is accomplished in waveguides with shorting stubs. For instance in matching a waveguide section to a length of co-axial line, the characteristic impedance of the waveguide is higher than that of the co-axial line. The impedances are matched by introducing metal plates called matching stubs. They reduce the opening in the guide and reduce its impedance to match the co-axial line, which is coupled by means of a loop or dipole to the waveguide.

When two lengths of waveguide are coupled together, there is danger of leakage of the u.h.f. current at the junction, with resulting loss in efficiency. By

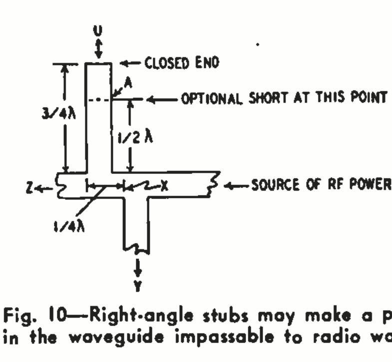


Fig. 10—Right-angle stubs may make a point in the waveguide impassable to radio waves.

cutting a slot approximately a quarter-wavelength deep in the junction plate of one of the pieces of waveguide, an r.f. choke is created at the junction (see Fig. 3-a); it effectively prevents high-frequency leakage. See Fig. 11. A straight junction is always butted against a choke or slotted junction in joining waveguide units.

From the few examples given above it can be seen that you can do anything with waveguides that can be done with the old familiar coils, capacitors, and

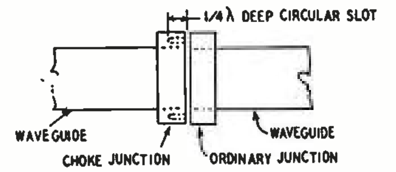
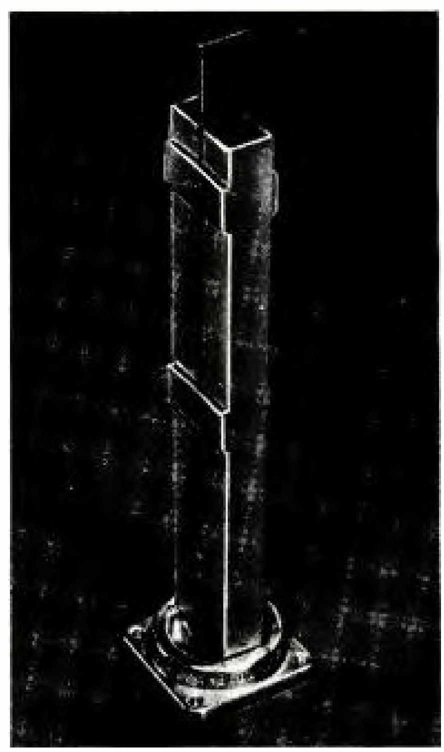


Fig. 11—A quarter-wave stub (slot in this case) is an efficient radio-frequency choke.

transmission lines. The only difference is in the mechanical form of the waveguide circuits. In further articles of this series, the use of waveguides as inductors, capacitors, and attenuators will be described. Setups for measuring frequency, generating power, and measuring standing-wave ratio will be shown, and the discussion of basic waveguide theory will be continued.

(Our next installment will discuss some of the things mentioned above in greater detail, paying special attention to standing waves and the standing-wave ratio, waveguide tuning, and resonant cavities, and will introduce some simple waveguide circuits.)



A terminating section, or piece of waveguide with an attenuating strip which presents to the waves the waveguide's characteristic impedance, terminating the line without causing reflections or setting up standing waves.