RADIO ENGINEERING
MICROWAVE RADIO
WAVEGUIDE SYSTEMS
DESIGN CONSIDERATIONS

CONTENTS PAGE

1. GENERAL

1.01 This section discusses the principal transmission considerations in engineering waveguide systems for microwave radio stations operating in one or more of the 4-, 6-, or 11-GHz common carrier radio bands.

1.02 A complete waveguide system consists of four separate, but closely associated, elements or components:

(a) The antenna itself

(b) Waveguide from antenna to base of tower

(c) Waveguide from base of tower to equipment

(d) Combining network if more than one frequency band or more than one polarization is to be used. With horn-reflector antennas, the combining network is placed on the lower part of the antenna supporting tower. With parabolic antennas, the combining network is at the antenna, usually an integral part of the waveguide feed assembly mounted on the antenna itself.

1.03 The application and transmission characteristics of various antennas and the design layout of combining networks are described in other sections of the 940-3 layer. This section primarily concerns the waveguide runs themselves, together with the influence of connected antennas, networks, and radio equipment.

2. BROAD OBJECTIVES

2.01 In the past few years there has been a continuing need to improve the channel capacity or bandwidth as well as the transmission quality of microwave radio systems. To meet this need it has been necessary to improve both design, and installation and maintenance techniques of the various components of the systems, including the waveguide and its associated elements, such as antenna feed, combining networks, transducers, filters, and terminations. The need for properly designed waveguide runs cannot be overemphasized.

2.02 The most obvious consideration is signal attenuation, since failure to meet design signal level objectives on any single hop will cause an increase in both idle-circuit and intermodulation noise contributed by that hop to the system total.

2.03 More significant at the present state of the art, as well as more difficult to identify and alleviate, is intermodulation caused by echoes. Installations using parabolic antennas have a separate waveguide run of dominant mode rectangular guide for each polarization of each frequency band. In these systems, the currently recommended antennas include filters in the feed assembly to attenuate all signals of undesired frequency, mode, or polarization. In effect, the separation (or combining) network to provide isolation between separate radio systems is within the antenna itself.

2.04 In systems using horn-reflector antennas, a single, wideband, circular waveguide is used to provide relatively low-loss transmission, without polarization discrimination, on the 4-, 6-, and 11-GHz frequency bands. This guide will readily pass three modes in the 4-GHz band, six modes in the 6-GHz band, and 22 modes in the 11-GHz band. Mode conversions, like reflections, can occur whenever an impedance irregularity exists. In horn-reflector installations this condition exists:

(a) At the antenna, due to misaiming, reflections in the path or variations of bending of this signal path through space, causing off-axis reception at the antenna.

(b) At the transition from the antenna through its feedhorn to the circular waveguide.

(c) Within the uppermost section of waveguide, where a section of flexible or rigid curved guide connects the vertical run to the feedhorn.

(d) At each joint in the vertical waveguide run if the inner walls are not properly aligned and the flange bolts are not adequately tightened.

(e) At each component of the combining network at the bottom of the circular waveguide run, where directional couplers and transducers are cascaded. From time to time pratically every item in the combining network has been superseded by one or more improved units.

(f) At waveguide deformations, such as slight ellipticity of circular sections, slight twists in square transducers or spacers, and bends. In both circular and square components, the deformation may be either actual or effective and may vary with frequency. Its effect on cross polarization discrimination (XPD) is corrected by an adjustable axial ratio compensator on circular guide for the 4-GHz band, and if necessary by a 4-A clamp or a 35-A square transducer adjusted for optimum polarization on 6 or 11 GHz. The higher order modes generated by any of the above impedance irregularities, however, cannot be eliminated by the adjustable compensator or 4-A clamp.

3. DESIGN CRITERIA

3.01 Based on the performance characteristics outlined in Part 2, the engineering of a new installation or upgrading of an existing installation should recognize the following guidelines.

(a) Keep all waveguide runs as short as possible.

(b) Avoid any flexible wideband circular (2.812 inches) waveguide. Use a minimum of other flexible types.

(c) Avoid use of waveguide bends and twists as much as possible.

(d) Use longer lengths of circular sections to reduce the number of flange-joints required.

(e) Use combining networks for only the frequency bands and polarizations required initially, using square waveguide spacers for the combiners which may be required later for growth.

(f) Ensure that all network components are the latest type for the particular function to be performed.

(g) Mount the horizontal rectangular guide with the short dimension horizontal.

(h) Stagger joints where possible.

3.02 On heavily-loaded or long-haul routes, requiring a large number of channels and minimum degradation of signals, economics usually dictate the use of horn-reflector type antennas with a single waveguide run on the tower or supporting structure. To keep signal attenuation low and flat as possible over the entire range of frequencies involved, circular waveguide must be used, with a transducer at each end to convert the circular field modes to suitable square or rectangular modes. At the antenna end the antenna feedhorn makes a flared transition from the circular throat to a square mouth which in turn connects directly to the horn-reflector structure. In effect, the side and rear surfaces of the antenna are a smooth continuation of the guide and feedhorn walls, approximately an impedance matching section to the reflecting surface and to space. At the bottom end of the circular run a fairly long transducer makes a more gradual transition from the circular to square shape, providing a very smooth change over the entire frequency range. At both ends the signal fields in the circular section must be precisely oriented with respect to the plane surfaces of the transducing component. If they are not, the signal will be constrained to the new boundaries, and may give up part of its energy to the generation of new modes, which will appear as intermodulation noise in the same radio frequency band as the signal from which they were derived. As previously mentioned, circular guide must not be bent except at a large radius of curvature to prevent impedance mismatching and reflections. Slight ellipticity, either real or effective, will not usually be detectable by the eye, but may alter polarization and moding. The effect of this on cross polarization discrimination can be eliminated or minimized with an adjustable axial ratio compensator. This is an adjustable clamp to deliberately squeeze a small section of circular guide in the proper plane and by the proper amount to "balance out" or compensate for the inherent ellipticity of the total vertical run.

3.03 Directional couplers are used to combine or separate microwave channels at different frequency bands or of opposite polarizations. A typical coupler consists of two pieces of waveguide having a common wall in which holes or slots provide coupling ports between the two. Figure 1 shows two such arrangements. The exact number, size, shape and spacing of the ports determine the frequency, bandwidth, mode, and polarization which will be coupled efficiently. In many cases small wires may be added in or near the ports, as shown in Fig. 2. These tend to reject signals of a higher freqency band and also improve the linearity of coupling across the desired band. The size, shape, and position of these wires are quite critical for proper operation, and are adjusted at the factory.

3.04 In multiband waveguide systems, it is often necessary to make a transition from one size waveguide to another. Here again, the principal objective is to maintain a smooth impedance characteristic over the range of frequencies to be passed and it is accomplished by making a gradual transition from one size to the other, with smoothly tapered inner surfaces in the transducer. In some older type units the inner wall (and the outer surface) had a series of successively smaller dimensions, reducing size in small but discrete steps. This type of unit is not recommended for new applications. Figure 3 shows examples of typical transducers.

3.05 The various types of waveguide transducers, couplers, and filters are used primarily in system combining networks or within the radio equipment. Section 940-340-132 describes the engineering of combining networks, and sections on the individual radio equipments describe filters and networks used within specific units or assemblies.

3.06 The velocity of propagation in a waveguide varies with the relationship of the signal frequency and mode to its cutoff frequency. The closer it is to cutoff, the slower the velocity, and as it approaches cutoff the velocity decreases very

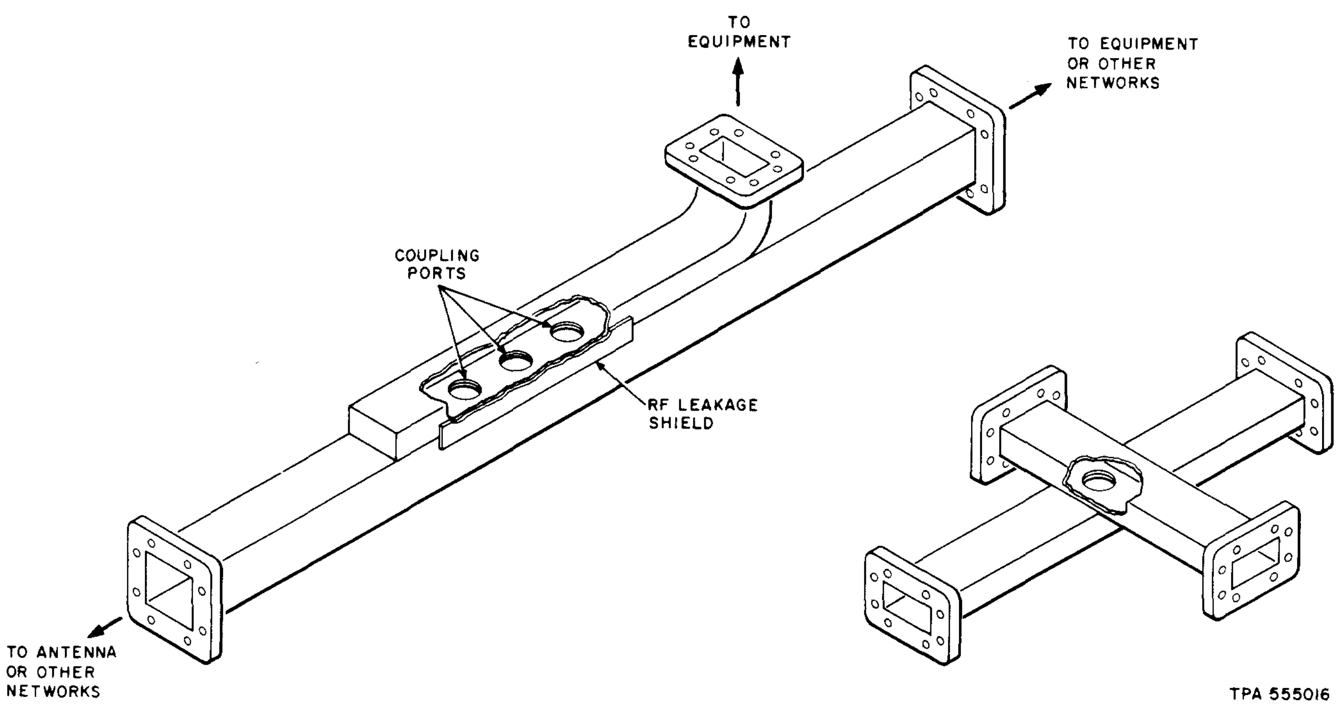

Fig. 1—Typical Coupling Between Two Waveguides

rapidly. Since the higher-order modes have a higher cutoff frequency, their velocity will be lower, or their delay greater, than the dominant mode or any other mode of lower order. Table A shows the propagation time of a few selected frequencies and modes in two commonly used sizes of waveguide to indicate the magnitude of the variations.

3.07 The echo paths illustrated in Fig. 4 are representative of situations often encountered in a typical field installation. Figure 4 (a) shows a differential echo, in which the absolute delay of the echo relative to the primary signal results from the propagation time differential between dominant and higher-order modes traveling in the same direction in the same waveguide run. The higher-order mode is assumed to be excited in the antenna by the incoming signal and is converted back to the dominant mode by components of the combining network near the bottom of the vertical run. Figure 4 (b) illustrates a round-trip echo, so called because the echo path loops back on itself to a point at or near the point of initial excitation. Echoes of this type have longer delays and therefore tend to produce transmission amplitude and delay ripples with closer frequency spacings. Theoretically,

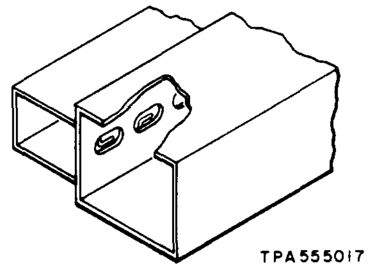

Fig. 2—Waveguide Slot Coupling with Tuned Wire Inserts

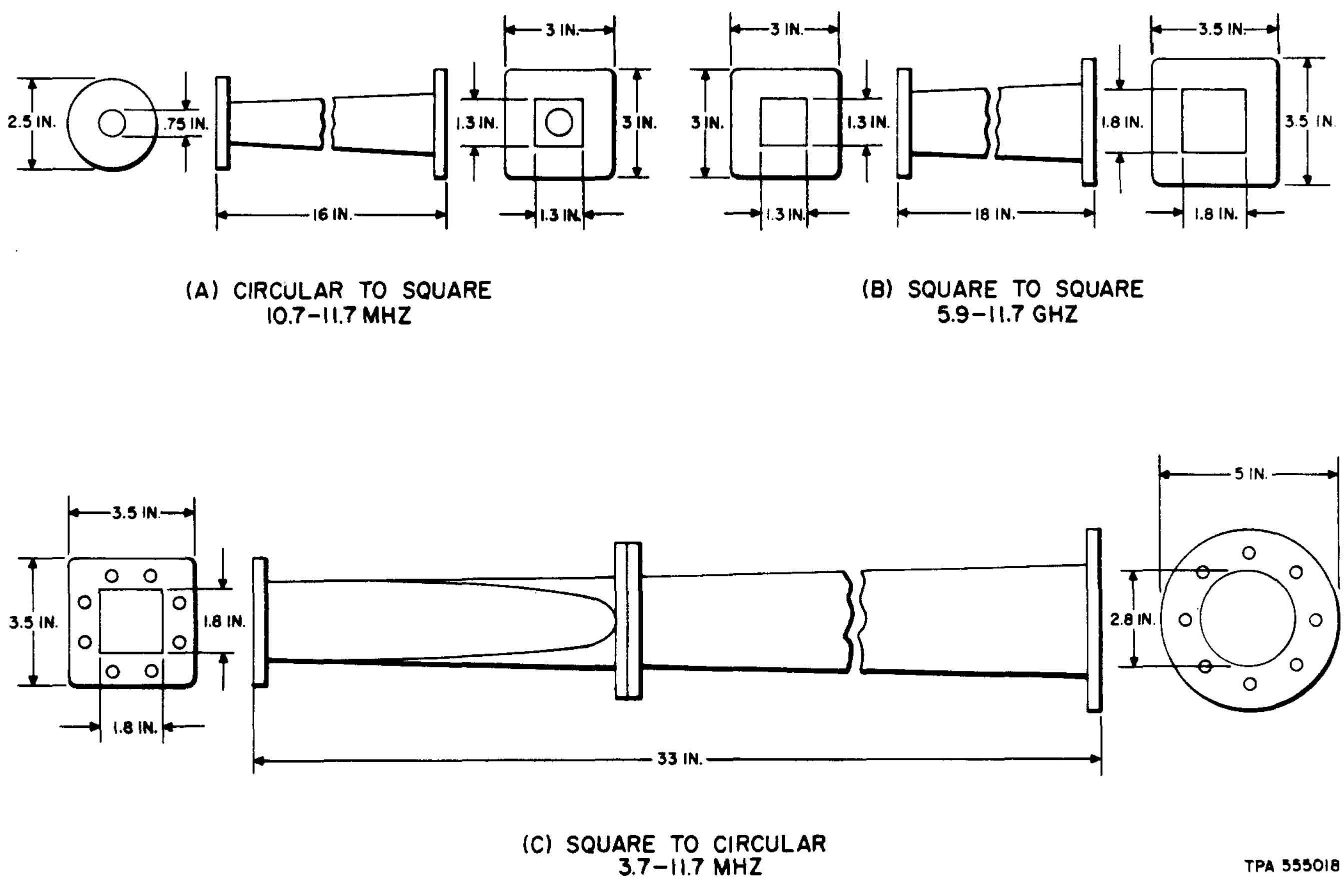

Fig. 3—Typical Waveguide Transducers

TABLE A

PROPAGATION TIME IN NANOSECONDS PER 100 FEET				
WAVEGUIDE	MODE	FREQUENCY MHz		
		4.0	6.0	11.0
Circular 2.8″	TE_{11}	129	111	104
	TM_{01}	171	120	106
	TE_{21}	1040*	139	110
	TM_{11}, TE_{01}	195	195	115
	TE_{31}	—	288	118
Square 1.79″	TE/M_{01}	180	122	107
	TE/M_{11}	—	162	112
	TE/M_{02}	—	—	127
	TE/M_{03}	—	—	233

— Indicates frequency is below cutoff in this mode

* At 4.10 MHz. This mode has a cutoff frequency of 4.08 MHz

given the ripple periods of a transmission characteristic, the mechanism producing them can be deduced. In practice, the identity of the individual components of a delay pattern is considerably obscured by the number of echoes appearing simultaneously. Often on a hop with horn-reflector antennas at each end, five or more echoes of varying absolute delay and amplitude will be found, making the job of mode identification difficult.

3.08 For modes inherently generated by a horn-reflector antenna, such as TM_{11}°, the resulting echo levels are the same for each antenna. The amount of intermodulation noise then depends on the length of the vertical run in which the higher order modes can propagate. The amount of noise produced in this manner can be computed for any one antenna waveguide installation. Combining the total of such noise from two or more systems in tandem, however, cannot readily be predicted because the length of successive waveguide runs are not usually equal. More significantly, even when the vertical runs are of the same nominal length, tolerance in the exact lengths and diameters of individual pieces of waveguides are sufficient to cause unpredictable variations in the relative phase of any two echos.

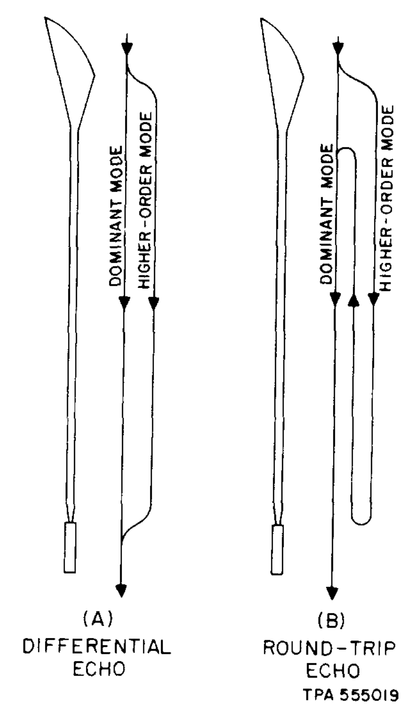

Fig. 4—Typical Delay or Echo Paths by Multi-Moding

3.09 For those modes not inherently generated by the antenna, such as TM_{01}^{o}, the echo levels are very much dependent on the degree of antenna misaiming, reflections in the path, and variations in beam bending with time. No meaningful estimates of noise due to these echoes can be made.

3.10 The principal points of mode conversion or generation are shown in Fig. 5. Each of the items shown represents a form of discontinuity or a departure from the conditions of a uniform waveguide of constant cross section, which is a necessary condition for mode conversion. A unique condition exists when a section of circular flexible guide is used. Trapping may occur when modes near cutoff are generated and able to propagate there, but not out of either end because of reduction of the ***effective*** guide size and a resulting increase in the cutoff frequency. The grooves on the flex-guide's inside walls make it appear to the trapped mode as a tubing slightly larger than the inside diameter of the abutting solid guide. Trapping of a particular mode can occur in the frequency range between the cutoff of that mode in the flex-guide and that in the solid circular guide. Mode trapping results in sharp amplitude notches and rapid phase variations with frequency. This condition can be alleviated by using rigid guide especially bent to join the vertical run to the antenna after the antenna has been precisely aligned, but the bends in the rigid guide will still cause some round trip echoes, and may alter polarization. Any change in the circular waveguide requires readjustment of the adjustable axial ratio compensator at the far (lower) end of the circular waveguide run.

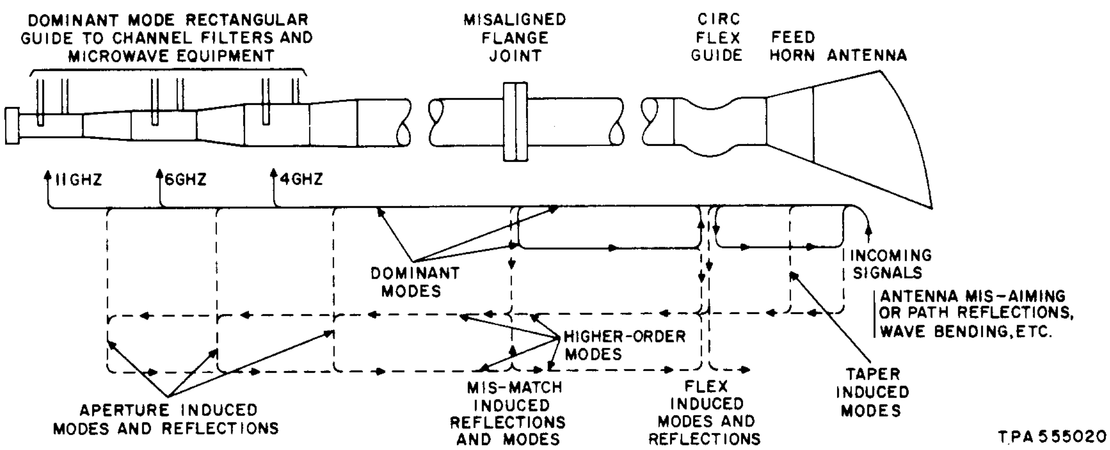

Fig. 5—Mode Generating Points and Echo Paths in Antenna Waveguide System