Waveguide for TV Broadcast

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***Abstract*—Properties of circular waveguide are discussed with application to UHF TV broadcast systems. Mode filtering pins are introduced to eliminate cross-polar and higher order modes.**

***Index Terms*—Broadcast Systems, circular waveguide, mode filters.**

I. INTRODUCTION

Circular waveguide has been used successfully in high power UHF broadcast television since 1984 [1]. AT&T has also used it as a standard for long distance telephone traffic, with more than 15,000 installations throughout the United States. It became popular because it has some very useful electrical properties. Circular waveguide offers lower attenuation than alternative waveguides and is capable of providing dual polarized operation. Since circular waveguide typically operates above the cutoff frequency of at least one of the higher order modes, these properties are only beneficial if the circular waveguide is made very accurately.

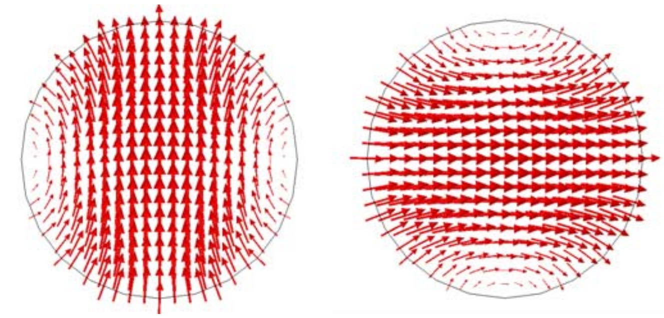
High power broadcasting, however, requires only one of these attributes, and that is low loss. The second, polarization benefit of circular waveguide is not useful. In fact, removing the second polarization has required field alignment and external loads attached to the tower. With this in mind, a type of circular waveguide, called GUIDELine has been, designed which eliminates one polarization and takes advantage of single-polarized operation to simplify field installation. This is accomplished by adding a series of conducting pins to the circular waveguide to produce a stop band filter effect for the unwanted polarization.

II. CIRCULAR WAVEGUIDE THEORY

Circular waveguide is basically a circular conducting tube with a diameter chosen to propagate power in the TE_{11}, and TM_{01} modes. The TE_{21} and all other higher order modes are cut off and do not propagate power.

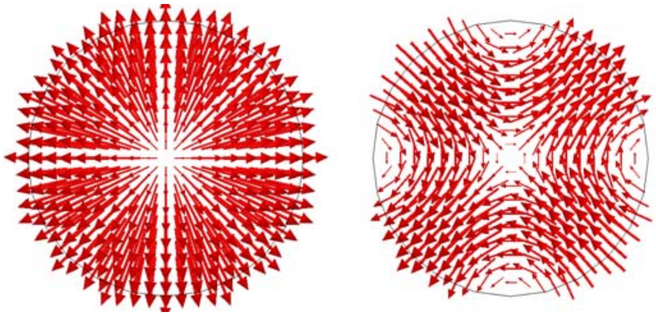
The TE_{11} mode has two independent orientations in the circular waveguide. These two orientations have identical electric and magnetic field configurations that are rotated 90 degrees azimuthally from each other as shown in Figure 1. Each orientation has all the properties of an independent mode and they are called the TE_{11} copolar mode and the TE_{11} crosspolar mode to distinguish them. Circular waveguide for broadcast systems uses only one of these modes -- the TE_{11} copolar mode. The TE_{11} crosspolar mode, the TM_{01} mode, and the TE_{21} mode, also shown in Figure 1, are undesired modes.

The desired operation of circular waveguide consists of launching the TE_{11} copolar mode at the bottom of the waveguide run (bottom of the tower) and extracting the TE_{11} copolar mode at the top of the waveguide run (top of the tower) as shown in Figure 2a. The only power lost is in the form of heat due to currents flowing in the resistive walls of the metal tube. This resistance is a property of the metal used to construct the tube. The currents in the tube are a function of electric and magnetic field structure inside the tube. Therefore, whenever the tube material is known, and the current is known, the amount of power lost to heat is known. This lost power is called attenuation. If this power loss is calculated for various types of waveguides (rectangular, elliptical, truncated, etc.) for the same type of wall material, circular waveguide is found to have lower attenuation than all other types of waveguide and significantly lower attenuation than some [2].



TE_{11} Copolar Mode

TE_{11} Crosspolar Mode

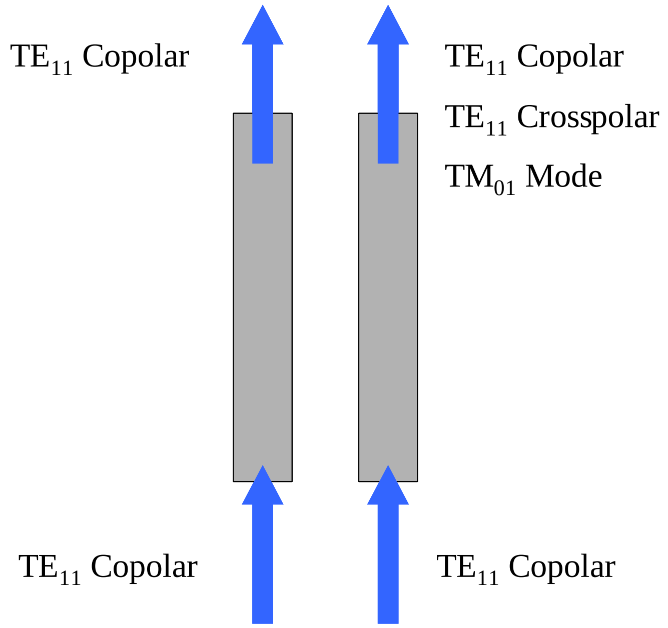


TM_{01} Mode

TE_{21} Mode

Figure 1: Lowest Order Modes in Circular Waveguide

To attain the desired operation, however, requires some care in manufacturing. When circular waveguide is not perfectly constructed, power launched into the TE_{11} copolar mode at the bottom of the circular waveguide run will come out the top of the run not only in the TE_{11} copolar mode, but also in the TE_{11} crosspolar mode and the TM_{01} mode as indicated in Figure 2b. Two problems arise from this situation. First, since power is present in the undesired modes, it must have been lost from the TE_{11} copolar mode. This appears as increased attenuation. Second, the power in the undesired modes must eventually be dissipated. This power can dissipate due to resistive loss in the circular waveguide wall, or the power can reconverted to the TE_{11} copolar mode at a later time and be radiated at the top by the antenna. If the time delay is long enough, and the power is high enough, the time-delayed signal can produce a ghost. The amplitude of the delayed power is called "reconverted mode level", or RML, and is expressed in dB below the TE_{11} copolar mode level.



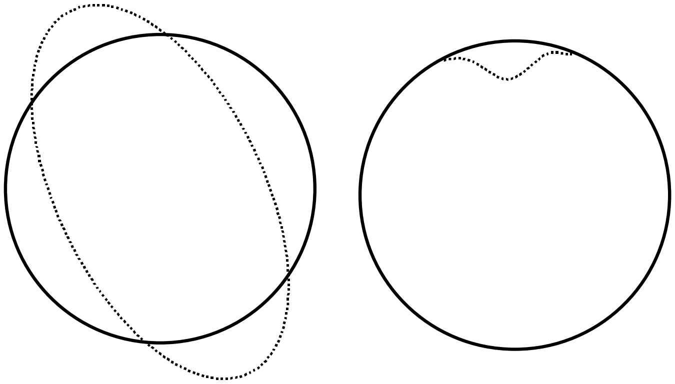
(a) Desired (b) Actual

Figure 2: Circular Waveguide Operation

Imperfections in circular waveguide are of various types. The worst is non-circularity as indicated in Figure 3a. A circular waveguide can never be made perfectly round. This problem results in power being coupled into the TE_{11} crosspolar mode. Under the right conditions of a fixed amount of non-circularity over a long distance, all of the power could be coupled from the TE_{11} copolar mode to the TE_{11} crosspolar mode. This is rarely the case. However, the TE_{11} crosspolar mode power could be only 10dB below the TE_{11} copolar mode power.

If the TE_{11} crosspolar mode power were only 10dB below the TE_{11} copolar mode power level, a 120 kW system could couple 12 kW to the TE_{11} crosspolar mode and a 10% power loss would be the result. The problem of non-circularity can be solved, however, by making the circular waveguide appear electrically round again. This is accomplished by compensating or "squeezing" the circular waveguide once it has been installed on the tower. If the circular waveguide has been made circular enough in the manufacturing stage, the process works quite well and can reduce the TE_{11} crosspolar power to 30 to 35 dB below the TE_{11} copolar mode level. This is a loss of less than 0.1% of the power. The TE_{11} crosspolar power can and does increase under severe mechanical loading due to the wind and ice and the circular waveguide will show more power loss under bad weather conditions. This power must be absorbed to prevent ghosting. External loads are normally provided to dissipate this power. Note that safety factors must be built into these loads to allow for temporary weather conditions.

The other types of distortion represented in Figure 3b, are less significant but still important and consist of misaligned flanges, non-concentric transitions, dents and periodic discontinuities (mainly related to the length of the waveguide sections). These contribute in a much smaller way to the power lost from the TE_{11} copolar mode, generating TM_{01} and TE_{11} crosspolar power levels typically 40 dB below the TE_{11} copolar mode, causing a 0.01% power loss. The TE_{11} crosspolar mode is absorbed, as above, by the external loads required to absorb power due to non-circularity. The TM_{01} mode power is, in general, low enough to ignore it were not for the resonant cavity effect of circular waveguide. The TM_{01} power is trapped in circular waveguide due to the type of transitions used to couple to the TE_{11} copolar mode. This means that at certain frequencies where the waveguide system is some number of half TM_{01} guide wavelengths long, the circular waveguide becomes a resonator. Since a resonant waveguide can cause ghosting, a load must be provided to absorb the TM_{01} mode power.



(a) Inherent Non-Circularity Due to Normal Manufacturing Processes

(b) Non-Symmetrical, Random Distortion

Figure 3: Typical Distortions in Actual Waveguide Section

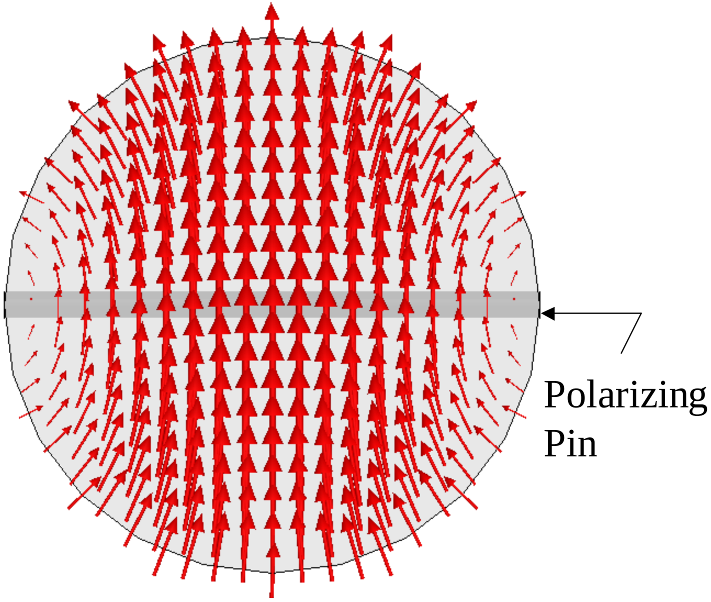


Figure 4: Alignment of TE_{11} Copolar Mode to Pins in GUIDELine

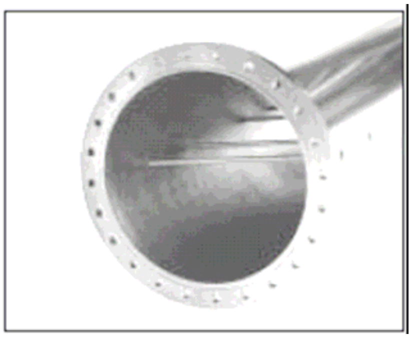


Figure 5: Typical GUIDELine Waveguide Section

III. GUIDELINE OPERATION

GUIDELine is an improved circular waveguide for broadcast applications. The major problem with circular waveguide is the TE_{11} crosspolar mode driven by the non-circularity of the waveguide. GUIDELine eliminates the TE_{11} crosspolar mode. This is accomplished by placing a sequence of metallic pins along the center of the circular waveguide parallel to the electric field of the TE_{11} crosspolar mode as shown in Figure 4. Figure 5 shows a picture of a GUIDELine waveguide section. The pins are spaced along the circular waveguide to act as a stop-band filter for the TE_{11} crosspolar mode and as a passband filter for the TE_{11} copolar mode.

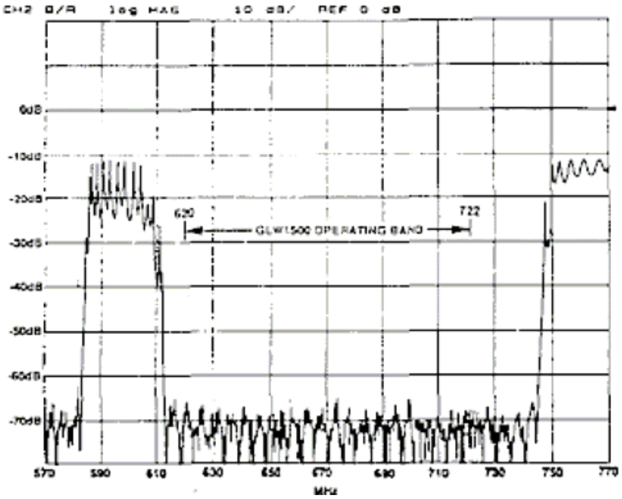


Figure 6: Transmission Loss; TE_{11} Crosspolar Mode GLW1500

Figure 6 shows the transmission loss measured for two sections of GUIDELine for the TE_{11} crosspolar mode. No transmitted signal in the operating band is visible above the noise level, which is 65 dB below the incident signal level. In fact, calculations show the level to be much lower than the measured values. Figure 7 shows VSWR for the TE_{11} crosspolar mode for the same two sections. The VSWR is infinite across the operating band for GLW1500. Again, no power can be coupled into the TE_{11} crosspolar mode. No matter how non-circular the circular waveguide is, no power is coupled to the TE_{11} crosspolar mode and there is no power loss associated with it. The TE_{11} crosspolar loads are no longer needed, and can be eliminated. No field compensation is needed and therefore, no associated technician or sophisticated test equipment is required.

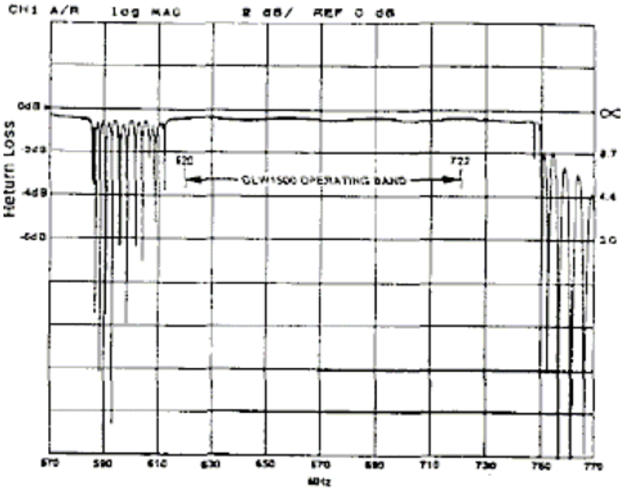


Figure 7: Return Loss; TE_{11} Crosspolar Mode GLW1500

The TE_{11} copolar mode has its electric field normal to the pins and effectively does not see them. Since no current flows in the pins, there is no associated resistive loss and therefore no increase in attenuation due to the pins. The VSWR of the TE_{11} copolar mode is unaffected by the pins for the same reason. The power rating of GUIDELine is unchanged from that of circular waveguide. Since there is no change in the current flowing in the TE_{11} copolar mode, there is no increase in loss in the metallic walls and no increased heat to dissipate. Also, there is no increase in voltage in the transmission line system so that voltage breakdown and peak power ratings are not affected. The TM_{01} mode produces very small currents in the pins and is therefore still present in the waveguide as before. Loads must be provided to remove any TM_{01} power in the system to prevent low level ghosting. The power level is very low, however, (more than 30 dB below the TE_{11}, copolar power level) so for a 120 kW system, about 120 watt loads are needed.

IV. MECHANICAL ADVANTAGES

Circular waveguide has two distinct mechanical advantages over non-circular waveguides, They produce lower wind load on the tower and they have the ability to withstand 2 to 3 lb/in2 pressurization. GUIDELine waveguide has both of these advantages.

Tower wind load is generally proportional to the largest cross section that an object such as waveguide projects to the wind. Circular objects, however, present lower drag than objects with other shapes. Circular waveguides produce Only two-thirds the wind load on the tower compared with any other object with the same projected area.

Pressurization is sometimes overlooked as a potential problem in waveguides. A waveguide should be pressurized to approximately 2psi to prevent the entry of water through the flange seals in the event of a weather front passing the tower Site. A weather front can cause the pressure inside the waveguide to be lower than the outside pressure, and moisture can literally be pulled into the waveguide system. With falling temperatures, the moisture can condense causing potentially serious degradation of attenuation and VSWR characteristics of the system. Circular waveguide can easily withstand the pressure necessary to prevent system pressure from dropping below atmospheric pressure.

V. TEST RESULTS

A 1000 foot test run of GUIDELine waveguide GLW1500 (15 inch inside diameter), considered to be representative of a typical UHF waveguide system, was built. UHF circular waveguide has been in production at ERI for several years, and the process of making the waveguide itself is well proven. The test program was developed and all quantities which were considered to be pertinent to performance in UHF television broadcast systems were measured.

The tests included system VSWR of TE_{11}, copolar mode, attenuation of TE_{11} copolar mode, RML due to TM_{01} mode and power level into TM_{01} mode loads. Attenuation of TE_{11} crosspolar mode power and VSWR of TE_{11} crosspolar mode were measured on short runs in our lab and are shown in Figures 6 and 7. When these tests were finished, a pulse test was performed on the complete system.

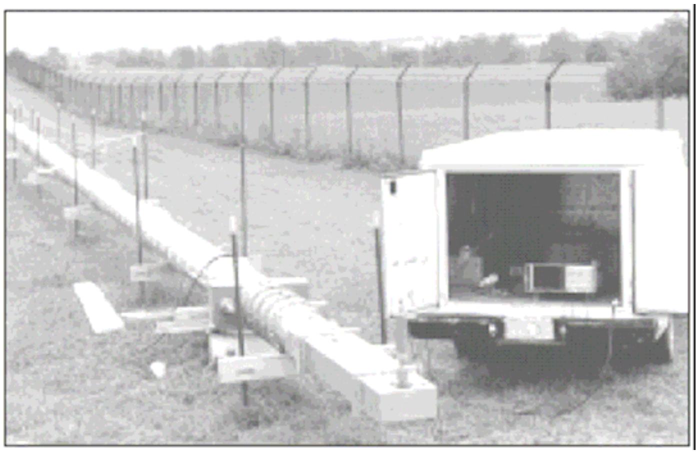


Figure 8: 1000 Foot GLW 1500 System Under Test

The GLWl500 was set up as shown in Figure 8. Since the ground contour is not perfectly flat in this location, the support stands were built in varying heights to approximately level the waveguide. However, the test run was deliberately allowed to deviate from straight in order to simulate tower tolerances and wind loading. The line was assembled and pins aligned In the same way that it would be aligned on a tower. The assembly was done by factory personnel and no technicians were required.

Test transitions were designed and built to test the GUIDELine waveguide test run. These transitions were designed to transform from WR1500 standard rectangular waveguide to GLW1500 GUIDELine waveguide. The transition is made using a quarter wavelength step transformer with a shape that is intermediate between a rectangle and a circle. The step is used in order to broaden the bandwidth of the transition and to make tuning the transition easier.

A TM_{01} mode transducer is built into the circular portion of these transitions and consists of a pair of circumferential cavity backed slots coupled to coaxial lines that contain loads. The loads are used to attenuate the small amount of TM_{01} power generated by non-symmetries in the system. Transitions for the actual system are more sophisticated and are discussed below.

The tests were started by attaching the test transitions to two 12-foot sections of GLW1500. The transitions were connected to Type N transitions on both ends via WR1500 to coaxial adapters. A 6- foot WR1500 slotted line was also included in the transmit end. The transitions were pre-tuned in this configuration for channels 45 through 50 (656-692 MHz) so that the VSWR of the whole system was about 1.02. The transitions were then placed back-to-back by removing the two 12-foot sections. The attenuation of the transitions was measured in this configuration by placing a shorting plate at the WR1500 output flange in place of the WR1500 to coaxial adapter and measuring the VSWR using the WR1500 slotted line. The attenuation of the transitions was subtracted from the test run attenuation to obtain actual GUIDELine waveguide attenuation.

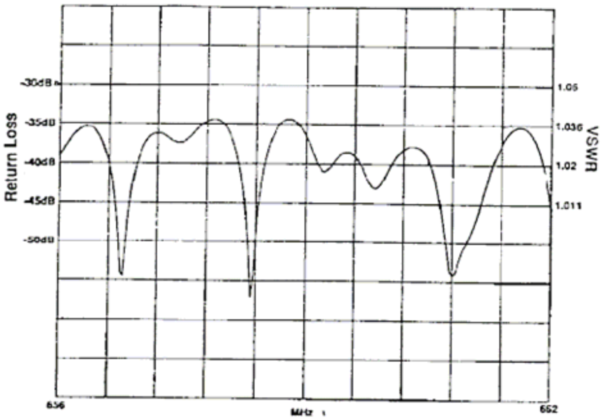


Figure 9: Channel 45 System Return Loss for GLW1500 Waveguide

The transitions were then attached to the main run of GLW1500 at the test site. The VSWR, attenuation, RML and TM_{01} mode level of the run were measured for the region where the transitions were tuned. The data is presented here as the performance of a typical single channel. The VSWR curve of channel 45 is shown in Figure 9. The table below summarizes the measurements. Finally, the system was pulse tested. Figure 10 shows the measured results from the pulse test for channel 45.

GLW1500 Typical Performance, Channel 45	
VSWR	1.05 Maximum
Insertion Loss	0.0445 dB/100ft
Power in TM_{01} Mode	-34 dB below
RML	TE_{11}
TE_{11} Crossover Level	Undetected
TE_{11} Crosspolar Mode	Infinite

Figure 9b: GLW Typical Performance

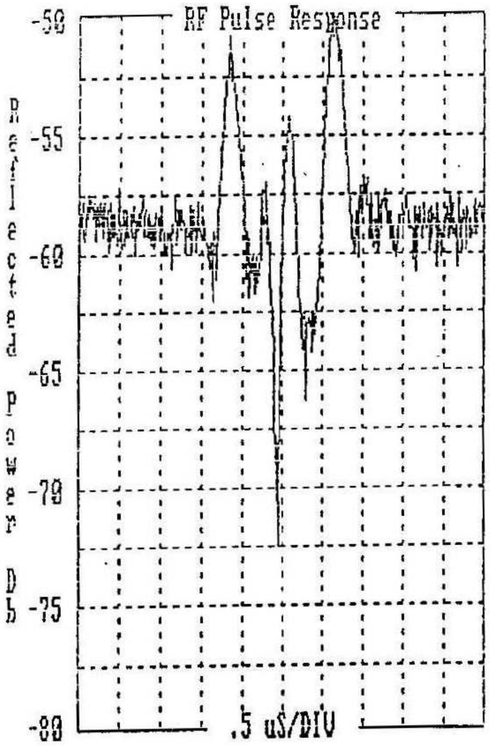


Figure 10: Channel 45 GLW1500 System Pulse Response

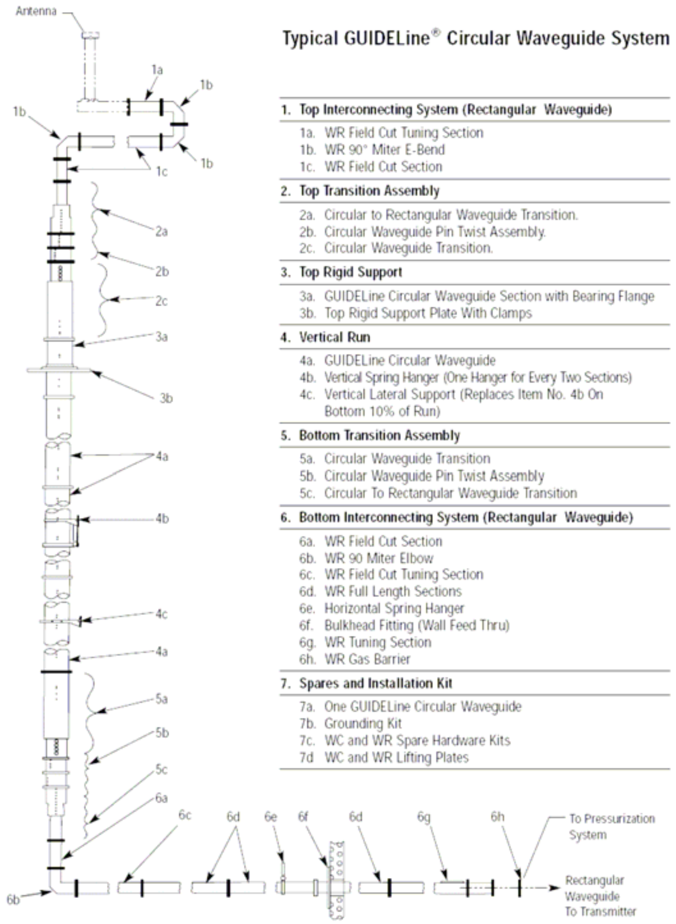


Figure 11: Typical GUIDELine Waveguide System Layout

GUIDELine waveguide can be configured into a transmission line system for use in high power UHF broadcasting. A typical system layout is shown in Figure 11. This system uses the same GUIDELine sections tested in the 1000-foot test run, except that a different type of transition is used at each end.

VI. CONCLUSION

GUIDELine Waveguide, a type of circular waveguide with mode filtering pins, has been designed, developed and tested for high-power broadcast television. GUIDELine waveguide retains all of the good properties of circular waveguide, while simplifying installation and eliminating crosspolar loads. These properties are: very low attenuation, very low wind load, very high power rating, pressurizable to 3 psi, superior VSWR performance, transitions with continuous angular alignment, TM_{01}, power levels less than 120W for a 120 kW system, and field compensation is not needed.

REFERENCES

[1] Wittaker, Jerry, ed., *NAB Engineering Handbook*, 9th *Edition*, Washingtion, DC, 1999

[2] G.W. Collins, *Fundamentals of Digital Television Transmission*, John Wiley & Sons, Inc., New York, 2001.

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