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Circular Waveguide Components at 10 GHz

Most amateurs acquire only short lengths of rectangular waveguide purchased at prices ranging between £1 and £8 per foot. Whilst long lengths of waveguide are not needed for portable operation, they are often required for setting up fixed stations with roof-mounted antennas. At these prices WG16 proves rather expensive. However, a cheap and very effective alternative exists by way of conventional copper water pipe. This article describes the use of copper water pipe as circular waveguide. The author has installed such a system at his QTH and has made a variety of waveguide components using copper tube. Both 22 mm outer diameter (20 mm inner diameter) and 28 mm od (26 mm id) tubing may be used to carry 10 GHz radiation, provided the correct mode is used.

1. TE11 MODE IN CIRCULAR WAVEGUIDE

20 mm id (22 mm od) tube will carry 10 GHz radiation, provided mode TE11 is excited. TE11 is analogous to TE10 in rectangular waveguide. The modes TE10 and TE11 are shown diagramatically in **figures 1 and 2** respectively.

20 mm id tube operating in TE11 mode has the following characteristics: –

Cutoff frequency = 8.67 GHz
Cutoff wavelength = 3.46 cm

At 10.350 GHz the guide wavelength is 5.4827 cm. Formulae are given in Appendix 1.

In a rectangular waveguide the electric field is constrained to stay in one direction by the physical dimensions of the waveguide. However, in circular waveguide operating in TE11 mode, the electric field is not constrained and tends to rotate, owing to small discontinuities in the waveguide surface such as joints and bends. This is no problem if a rotatable joint is included somewhere in the system to correct for the rotational shift. The joint is rotated for maximum power and then soldered in this position. In this position the electric field will be in the correct orientation to excite the rectangular guide in TE10 mode. (Note, however, that if the waveguide is distorted or its length altered, the angular shift may need resetting.)

1.1. TE11 Circular Waveguide to TE10 Converter

Although circular waveguide is satisfactory for the main transmission runs, it is still preferable to originate or deliver the microwave radiation in rectangular waveguide for signal processing. The construction of a converter takes only about

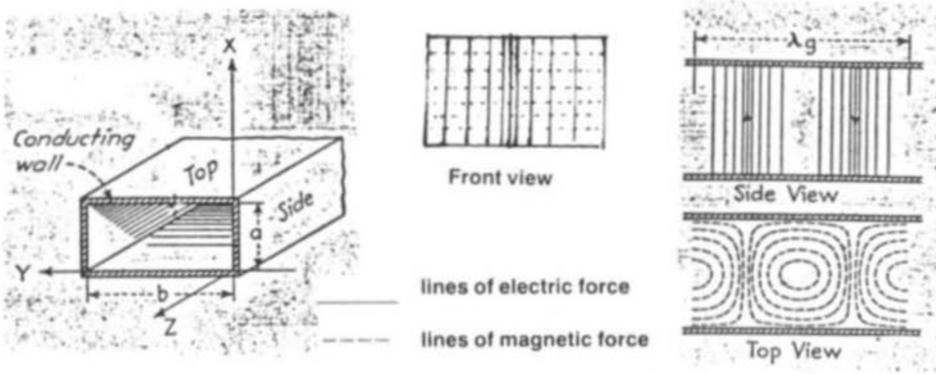

Fig. 1: TE10 mode in rectangular guide

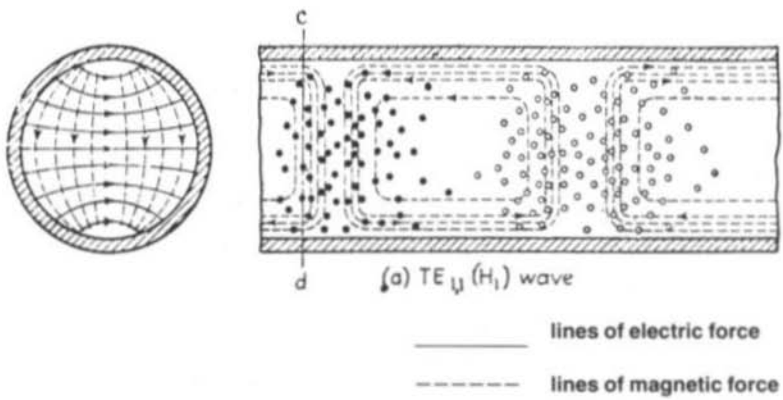

Fig. 2: TE11 mode in circular guide

30 minutes with simple hand tools. A photograph of this converter is shown in **figure 3**.

A length of 20 mm id copper tube which is at least 6 cm longer than the required length is selected. One end of this tube must be stretched slightly along its circumference and re-formed into rectangular cross section identical with WG16. This end will be forced through a WG16 flange. The flange is of the type such that WG 16 would normally go right through it.

First of all one end of the tube is squeezed in a vice which clamps the tube rididly. The other end of the tube is stretched by gently hammering two cold (stone working) chisels down into the tube – the broad faces of the chisels against each other. This has the effect of both stretching the circumference and forming a rough rectangular shape. Once the circumference is large enough, a better rectangular shape is formed by squashing in a vice and hitting it with a small hammer. The above stages are repeated until the end will fit into, and just through, a WG16 flange. A little persuasion with a small hammer may be needed to actually get the end of the tube right through to the far side of the flange.

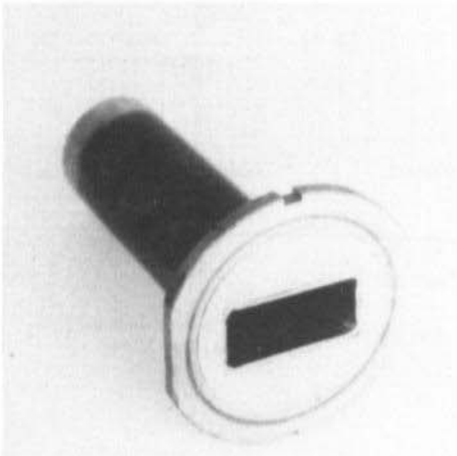

Fig. 3: TE10 to TE11 converter

Once the copper pipe has been forced through the flange, an old flat-ended file is used as a blunt chisel to form the copper close to the walls of the WG16 flange. This is especially required in the corners. The two chisels pushing against each other may also be able to achieve this, depending on their size.

Excess copper is then carefully filed off taking care not to damage the flange. The process is completed by rubbing the flange, with copper tube inserted, face down on a sheet of fine abrasive paper which is face up on a good flat surface.

The converter is now ready to be soldered. Normal soft solder was used as the solder is not in the path of RF. More than normal solder will probably be needed to ensure the joint is water proof if the converter is to be used outside. Once soldered the surface of the flange should again be cleaned with abrasive paper as described above. Finally a short length of tubing will have been damaged by clamping and hammering at the round end – this will need to be removed.

1.2. Jointing in TE11 Mode

Conventional 22 mm straight water pipe jointing sections may be used, provided care is taken when the joint is soldered. These sections sometimes come with solder rings already inside them but this type tends to have too much solder in them for our application and the excess tends to run out into the waveguide which adds to the

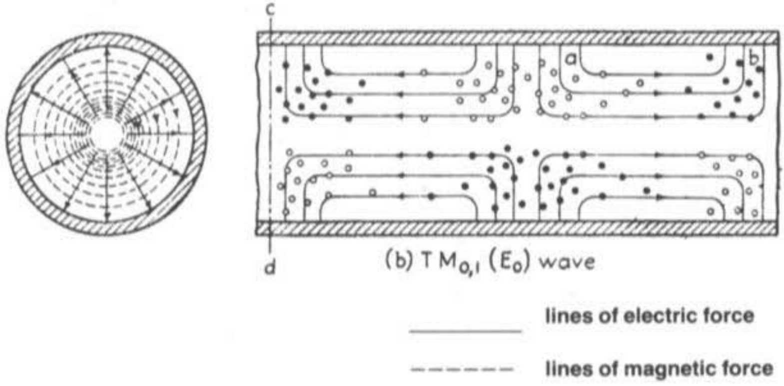

Fig. 4: TM01 mode in circular guide

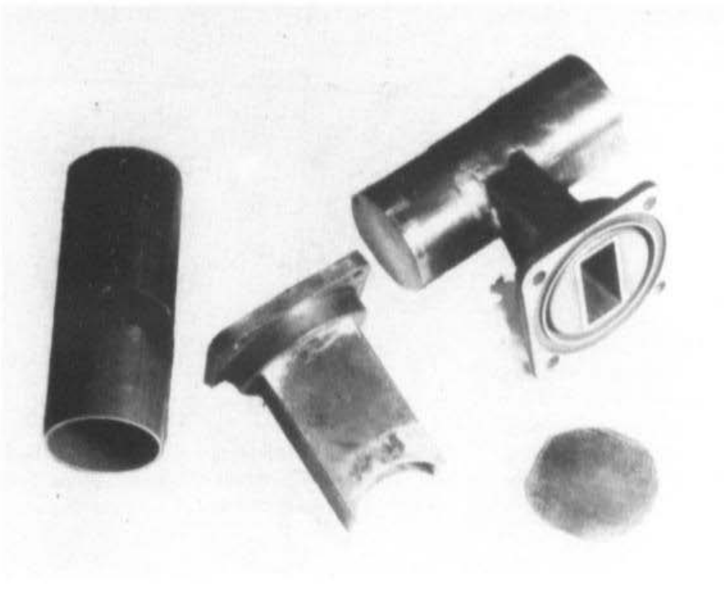

Fig. 5: TE10 to TM01 converter

waveguide losses. The type with no solder in is to be prefered. When soldering this latter type of joint, apply just enough solder to make the joint air-tight.

Slow 90 degree bends can also be used but the electric field will be rotated by this joint.

2. TM01 MODE IN CIRCULAR WAVEGUIDE

The disadvantage of using the TE11 mode described above is the somewhat un-predictable rotation of the electric field. However, by using the TM01 mode this particular problem is overcome. **Figure 4** shows how the electric and magnetic fields occupy the waveguide in TM01 mode. The advantage with this mode is that the electric field radiates from the centre to the inner surface of the tube; thus it is symmetrical about the centre axis (a bit like a coaxial cable) and orientation is insignificant. In order to propagate 10 GHz in this mode. 26 mm id (28 mm od) copper tubing is used.

26 mm id tube in TM01 mode has the following characteristics: –

Cutoff frequency 8.8385 GHz
Cutoff wavelength 3.393 cm

The guide wavelength at 10.350 GHz is 5.56 cm. Formulae are given in Appendix 1.

There is one disadvantage in using TM01, namely that the mode of propagation does tend to revert back to TE11 if sharp bends or discontinuities are introduced into the waveguide. This can be understood if a sharp right angle bend is compared with the converter described below – the main difference being that the distance from the shorted end to the centre of the rectangular hole is zero.

2.1. Rectangular TE10 to Circular TM01 Converter

A photograph of this converter (1) is shown in **figure 5**. It is merely the intersection of WG16 and 26 mm id tube. The distance from the centre of the rectangular hole in the copper tube to the inner surface of the shorted end is important, it should be three quarters of the TE11 wavelength. This puts a large series reactance for mode TE11 at the exit of the WG16 so this mode is not excited in the circular guide. The internal diameter (26 mm) is chosen to be approximately half the TM01 wavelength.

2.2. Circular TE11 to Circular TM01 Converter

This is very much like the converter described above except that the 20 mm id tube takes the place of the WG16. In fact a ready made plumbing "T" joint with 28 mm od along the top and 22 mm od down has been modified to act as a converter. However, the orientation of the electric field as it enters the 28 mm tube is important so a rotating joint of some description would be necessary.

2.3. TM01 Matching Sections

In rectangular guide operating in TE10 mode, the length of the guide can be electrically altered by inserting matching screws into the electric field from the broad face of the waveguide. However, this is not possible in circular mode TM01. Instead, a series of short sections of waveguide were made. The length increased in increments of 5 mm and ranged from 80 mm to 115 mm, including a joint at one end. These were then inserted in sequence into the system until the best match was found. (Fine adjustment can be made by not quite pushing the joint home.)

2.4. A Simple TM01 Slot Radiator in Circular Waveguide

A slot whose length approximates to half the wavelength in air will radiate if it traverses to an electric field. Therefore at 10.350 GHz a slot of length 14.5 mm around the circumference of the tube will radiate. (**It is important to attenuate the signal to a safe intensity before taking measurements close to any radiator.**) The matching section on the top of the antenna is tuned for maximum radiated or received power. In practice it has been found preferable to make matching sections rather then purchase the plumbing part. To make one of these a standard straight joint is cut in half and then a brass disc is silver-soldered to one end.

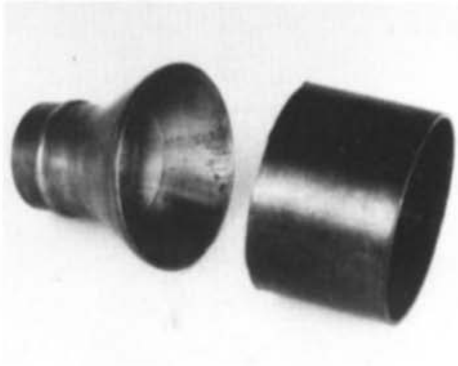

Fig. 6: A small horn antenna

2.5. A Small 26 mm Conical Horn Antenna

A straight plumbing joint which allows a pipe of 28 mm od to join a pipe of 52 mm od was sucessfully modified to work as a horn. **Figure 6** shows a photograph of the joint just after it was cut with a hack saw. The only modification was to remove all of the 52 mm pipe and bevel the outer edge of the resulting conical horn, as is shown in the photograph.

2.6. A TM01 to 'N' Type Transition

Figure 7 shows a TM01 to 'N' type transition. A brass disc is first drilled to take the 'N' type chassis-mounting socket and then the disc is silver-soldered to the copper tube. A short length of 6BA studding is then screwed into a 6BA brass hexagonal pillar and silver-soldered into place. This merely blanks off one end of the pillar. The length of the pillar is then adjusted to the dimensions shown in figure 7. The open end of the pillar is finally drilled out to be a tight fit with the 'N' socket and then soft-soldered onto the 'N' type connector.

The length of the inner piston has been adjusted experimentally to yield approximately 50 Ω at 10.350 GHz. Regrettably lack of test equipment made it impossible to improve on this design.

3. USEFUL HINTS

3.1. Preparation of Copper Tube

The author has learnt by experience that it is best to see and select the length of tube rather than be handed a length over the counter. Tubes sometimes contain grease and other dirt which is very difficult to clean out, and occasionally they have a few minor dents. All tubing should be cleaned as thoroughly as possible before use.

Cleaning can be carried out by pushing a cork in one end, pouring a good solvent into the tube, followed by small pieces of metal such as nuts or ball bearings, and then placing a cork in the other end. The tube is then rotated end over end for a few minutes, preferable outdoors in case one of the corks drops out!

3.2. Useful Tools

Plumbers use a tool known as a pipe cutter. This tool cuts all pipe sizes in the range 6 mm to 28 mm. In the UK the price of these range from about £10 to £20 but if a significant amount of tube work is to be undertaken, the purchase of one of these is recommended as cutting a pipe takes seconds and the cut is perpendicular. Their principle of operation is that a cutting edge is rotated accurately around the outside of the tube several times and eventually cuts through it. The inner edge usually needs a little deburring after cutting. This is either performed with the

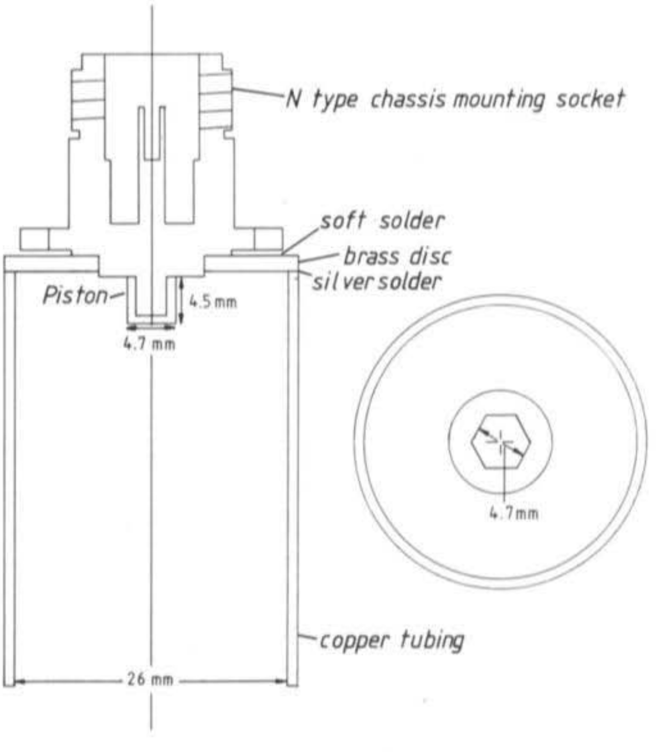

Fig. 7: TM01 to 'N' type transition

blunt knife often attached to the pipe cutter or a round file. The pipe cutter may also be used to scribe a line around the circumference of the tube prior to filing slots etc.

A cheap oxygen torch has been found invaluable for silver-soldering, experience having shown that some blow-lamps will not quite attain a high enough temperature.

3.3. Acknowledgements

I would like to thank G 3 VMW, GW Ø FJV and G 8 MXI for their help during this project.

4. REFERENCES

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5. APPENDIX I

5.1. Rectangular Guides

a = transverse dimension of guide, x dimension.
b = transverse dimension of guide, y dimension.
f = frequency, in Hz.
$\omega = 2\pi f$, angular velocity, radians per sec.
β = phase constant, radians per cm, based on phase velocity.
λ = wave length, cm (in free space).
c = velocity of light, 3×10^{10} cm per sec.

Operating Characteristics Common to All Rectangular Modes

Wave length in guide:

$$\lambda_g = 2\pi/\beta$$

Wave length in free space:

$$\lambda = c/f$$

Phase velocity:

$$v_p = \omega/\beta$$

Group velocity:

$$v_g = d\omega/d\beta = c^2/v_p$$

Mode	Cutoff frequency, f_o	Cutoff wave length, λ_o	Phase constant, β
$TE_{1,0}(H_{1,0})$	$c/2b$	$2b$	$\frac{2\pi}{\lambda}\left[1-\left(\frac{\lambda}{2b}\right)^2\right]^{1/2}$

5.2. Circular Guides

a = guide radius, cm.
f = frequency, in Hz.
$\omega = 2\pi f$, angular velocity, radians per sec.
β = phase constant, radians per cm, based on phase velocity.
λ = wave length, cm (in free space).
c = velocity of light, 3×10^{10} cm per sec.

Operating Characteristics Common to All Cylindrical Modes

Wave length in guide:

$$\lambda_g = 2\pi/\beta$$

Wave length in free space:

$$\lambda = c/f$$

Phase velocity:

$$v_p = \omega/\beta$$

Group velocity:

$$v_g = d\omega/d\beta = \frac{c^2}{v_p}$$

Mode	Cutoff frequency, f_o	Cutoff wave length, λ_o	Phase constant, β
$TM_{0,1}$ (E_0)	$0.383\frac{c}{a}$	$2.61a$	$\left[\left(\frac{2\pi}{\lambda}\right)^2 - \left(\frac{2.405}{a}\right)^2\right]^{1/2}$
$TE_{1,1}$ (H_1)	$0.289\frac{c}{a}$	$3.46a$	$\left[\left(\frac{2\pi}{\lambda}\right)^2 - \left(\frac{1.84}{a}\right)^2\right]^{1/2}$