H_{01} MODE CIRCULAR WAVEGUIDE COMPONENTS *

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Summary

A convenient method of launching the H_{01} mode in round waveguide is described. Four resonant slots are employed in a compact end-feed transition design. Construction details and performance curves are given. Also described is a developmental bend which avoids the H_{01}-E_{11} mode degeneracy problem by employing a superimposed pair of "E" and "H" plane rectangular waveguide bends. A mode absorber is described which is capable of reducing the mode impurities inherent in the transition design to a level of less than 0.1% of the emerging H_{01} mode power. Other possible applications of the H_{01} wave to problems other than low loss microwave transmission are briefly considered.

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Introduction

It has been established that low loss transmission in the millimeter wave region can be achieved by employing the circular electric mode of round waveguide. Losses as low as 3 db per mile have been reported.[1] For radar systems work in the millimeter wave region, the use of H_{01} mode circular waveguide permits a wide separation between antenna and transmitter-receiver units. This paper will summarize briefly some results of a project aimed toward establishing design procedures for circular waveguide components in the millimeter region. The three components to be discussed are a transition from rectangular to round waveguide, a mode absorber, and a ninety degree bend.

Transition

By far, the component requiring the most amount of attention has been the transition. It was pre-supposed that such a unit would be reasonably compact and thus easily scaled to wavelengths as long as 3.5 cm. In addition, a useable bandwidth of 6% was required along with a mode purity of 99 per cent or better in the output guide.

Various methods of launching the H_{01} mode in round guide have been proposed. The problem is mainly one of selecting a feed arrangement that at least suppresses all modes having a cut-off wavelength greater than the desired H_{01} mode. One or two higher modes must also be suppressed, if a useable bandwidth is to be obtained. We chose to use only four feeds, since this would permit sufficient mode discrimination without unduly complicating the problem of power division in the rectangular waveguide.

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Fig. 1 shows how four sources of microwave energy of proper phase and amplitude may be obtained from rectangular waveguide. The top half of the rectangular waveguide section has been omitted to show the correct placement of a four-slot feed arrangement. Power enters through a convention "E"-plane power divider terminated by a shorting plate. A disk, shown above the waveguide, contains four resonant slots, each of which couples out one fourth of the total available power. The half wavelength spacing of the slots accomplishes two functions. First, it provides equal division of power between the two slots in each half of the "E"-plane power divider. Second, it provides the necessary phase reversal needed to favor H_{01} mode propagation in round guide. The four vectors shown above the slots represent the relative phases and polarizations of the field existing in each slot. They are of equal magnitude.

The H_{01} mode maximum current line is indicated in the upper right portion of the figure. It can be seen that this array of four resonant slots in the end plate of a circular guide should produce this mode. Also, referring to the mode picture for the H_{21} mode, one of the lower undesired modes, it can be seen that at least one pair of maximum current lines is in opposition with the fields radiated by the slots. This results in the suppression of this mode. Other undesired modes are also suppressed by a combination of suitable end-plate geometry and slot excitation.

Fig. 2 shows a complete transition designed for the 8.6 mm. region. It is designed to mate with RG-96/U rectangular waveguide. The circular waveguide portion has an inside diameter of one-half inch. This is sufficiently small to prevent higher mode propagation, but is not large enough to make good use of the low loss property of oversize H_{01} mode round guide. Low loss transmission is made possible by tapering to larger diameter waveguide beyond the transition.

Fig. 3 consists of curves of mode purity and voltage standing wave ratio as a function of frequency for the transition just described. The bandwidth for a maximum V.S.W.R. of 1.2:1 is approximately 7% and the mode purity over this range exceeds 15 db or 97%. Total insertion loss of this transition is less than 1/4 db. over the same band.

The power handling capacity of this design is not as high as one might prefer. The present 8.6 mm. transition breaks down at power levels of approximately 20 kilowatts. A similar transition designed for 3.2 cm. operation breaks down at power levels of approximately 200 kilowatts. R.F. breakdown occurs across the centers of the resonant slots in both cases. High-power handling capacity of the transition was not a specific objective of the project, but some progress is being made to improve the present design. One alternative consists of reshaping the slots to lengthen the R.F. breakdown path.

R.F. power breakdown in the circular guide is quite interesting to observe. The discharge follows a circular path which coincides with the circle of maximum electric field for the H_{01} mode. This has been verified by inserting a gas-filled tube into the circular guide of a transition operating at moderately high power. Peaks in the standing wave pattern then appear as a series of luminous rings extending along the axis of the tube.

The radiation from H_{01} mode circular guide has been shown to behave in a similar manner. The radiation pattern is nearly conical in shape with a null on center. It is quite possible that this property may prove useful in future microwave antenna applications. Also, the field configuration within the guide is useful in some forms of omni-directional slot antennas.

Mode Absorbers

The 15 db mode purity that is obtained from this transition is not considered entirely adequate for certain applications, although this figure amounts to only a 3% loss in power transfer. If extraneous modes are allowed to propagate in a microwave transmission line, they may give rise to false echoes, in the case of radar, or produce other undesirable effects in other systems. Usually, these spurious modes would die out, over a long run of line, since they do not possess the low loss property of the H_{01} mode. However, in short runs of transmission line, a mode absorbing device of some sort would have to be used. This, in theory, would absorb all unwanted modes without introducing any additional losses in the system.

The next sketch, Fig. 4, shows a mode absorber designed to attenuate all modes other than the H_o family. Operation is based on the fact that H_o modes are not affected by a series of narrow, transverse gaps in the waveguide wall. All other modes are coupled out to some extent since they contain longitudinal components of wall current. Various devices based on this principle have been described in the past.[2]

This particular design has an inner round waveguide containing a number of transverse slots. The small connecting links are part of the original brass tube and therefore, maintain precise alignment and spacing of the assembly. The next layer consists of a cylinder of lossy absorbing material, such as synthane, Grade L-564. This layer is enclosed by a weatherproof brass outer shell.

Fig. 5 shows some results obtained with a combination of mode absorber and transition at "X" band. The two upper curves illustrate the degree of mode purity improvement obtained by adding a mode absorber to the transition. In this case, spurious modes have been attenuated approximately 10 db. The lower curve represents the combined V.S.W.R. of transition and mode absorber when terminated in a matched load. A similar curve was obtained without the mode absorber, indicating a very low standing wave for this unit. The insertion loss of this mode absorber was less than 1/8 db for the H_{01} mode over the 6% frequency range shown in the figure. This value probably holds true for a much wider range of frequencies.

A systematic study of the mode absorber problem would have required a mode launching device for each of the modes to be suppressed. This could not be done in the allotted time. However, we did obtain a curve of mode absorber loss for the dominant (H_{11}) mode, which was readily obtainable. This curve is shown in Fig. 6. It can be seen that at least 15 db attenuation is obtained for this mode.

Bends

The bend problem in circular waveguide is complicated by the presence of another mode having identical phase velocity as the H_{01} mode. It is known as E_{11} mode. Useful energy is lost to this mode whenever an H_{01} waveguide bend is attempted, regardless of how gradual the bend is made.[1,2] Additional spurious modes are also created if a very small bending radius is attempted.

Our goal has been to achieve a 90° bend having a radius on the order of one foot or less. This was thought to be a reasonable requirement for systems work. We therefore chose to avoid the H_{01}-E_{11} mode degeneracy problem by investigating several mode conversion devices that might be useful in a bend. The most obvious of these, of course, consists of using a pair of transitions and a rectangular waveguide bend of conventional design. Another alternative consists of employing a special waveguide cross-section in the bend proper, and transforming to the H_{01} mode at each end of the bend.

One of the latter type bends has shown considerable promise and is currently being studied. This bend, as shown in Fig. 7, consists of a cross-shaped waveguide bend terminating in tapers to round waveguide. The desired mode transformation is shown in the upper portion of the figure. The required mode in the bend cross section is similar to the H_{20} mode of rectangular waveguide and has been so designated in the figure.

A bend of this type has been constructed for the 8.6 mm. region. Its radius is 3 inches, dimension "A" is .500 inch and dimension "B" is .100 inch. The tapered sections end in half-inch diameter waveguide. The cut-off wavelength for the indicated bend mode is 1.16 cm. as determined experimentally.

The performance of this bend is illustrated in Fig. 8. The lower curve of voltage standing wave ratio includes the effects of a transition through which the measurements were made. This transition had a maximum V.S.W.R. of 1.2:1 over the indicated range. The middle curve is the mode purity at the output of the bend using an incident mode purity of approximately 15 db. The upper curve is mode purity obtained by adding a mode absorber at the output of the bend.

Total insertion loss of this bend varies from 1/2 to 3/4 db over the 6% frequency range of the transition with which it was tested. Recent reworking of the tapered sections of the bend has reduced the voltage standing wave ratio to negligible proportions. A scaled version of this design, intended for 3.2 cm. operation, had an insertion loss of less than 1/8 db and had excellent mode purity.[3]

Fig. 9 illustrates a possible millimeter wave transmission system using circular waveguide components. If a rotary joint should be required, it is merely necessary to provide for a small gap in the transmission line at a convenient location. Sliding contacts or choke joints are not required to maintain electrical continuity in the H_0 mode and spacings on the order of one-quarter wavelength may be tolerated providing that good axial alignment is maintained.

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References

1. S. E. Miller and A. C. Beck, "Low Loss Waveguide Transmission," Proc. I.R.E.; March, 1953.
2. S. E. Miller, "Notes on Methods of Transmitting the Circular Electric Wave Around Bends," Proc. I.R.E.; September, 1952.
3. "Design Criteria, Circular Waveguide Components," Final Report, dated March, 1954, S.C.E.L., Sig. Corps, U.S. Army, Contract No. DA-36-039-SC-5518 (Microwave Associates, Inc.).

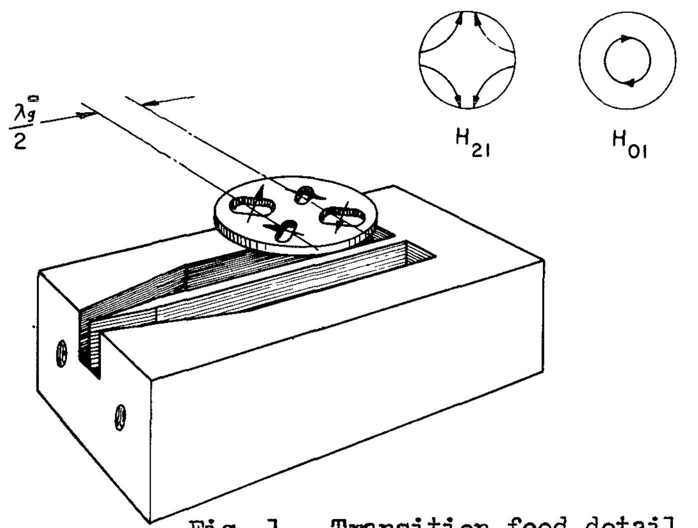

Fig. 1 - Transition feed detail.

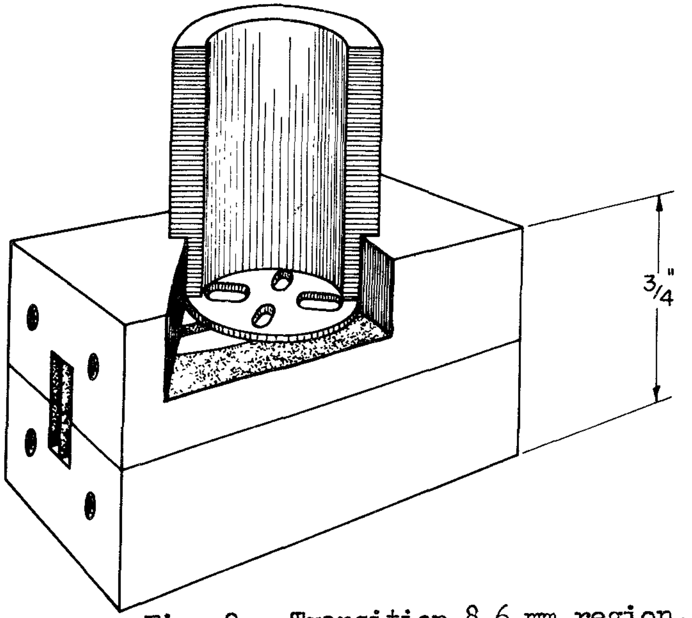

Fig. 2 - Transition 8.6 mm region.

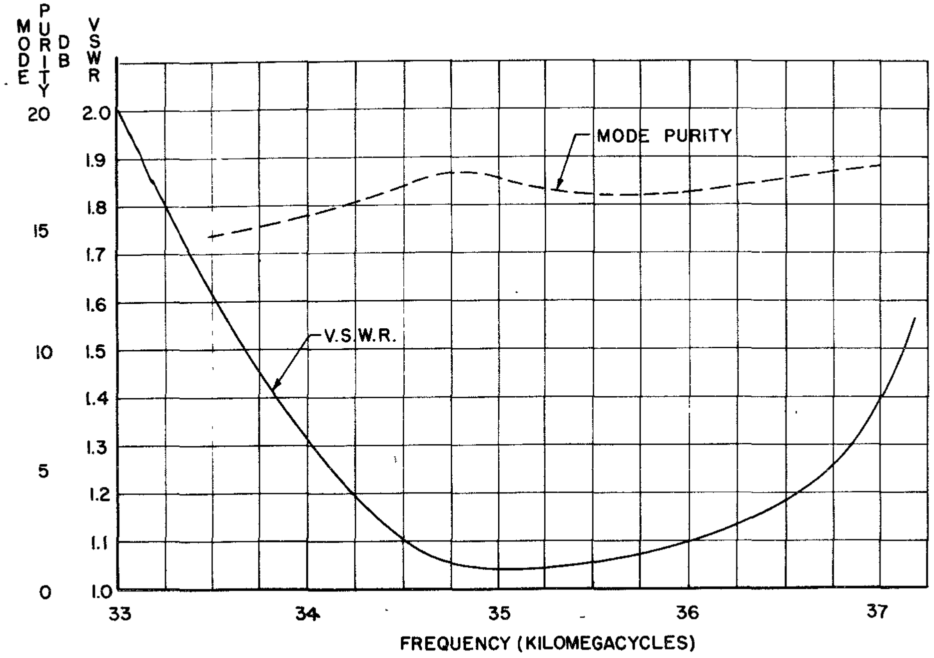

Fig. 3 - End feed transition results.

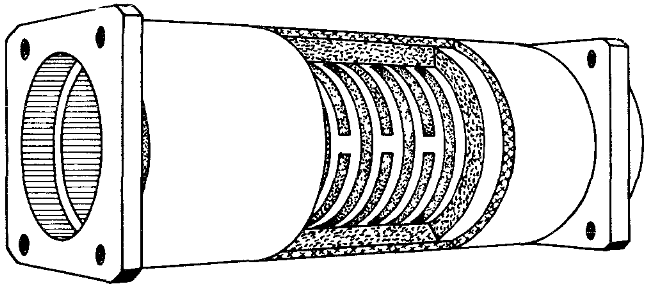

Fig. 4 - Mode absorber.

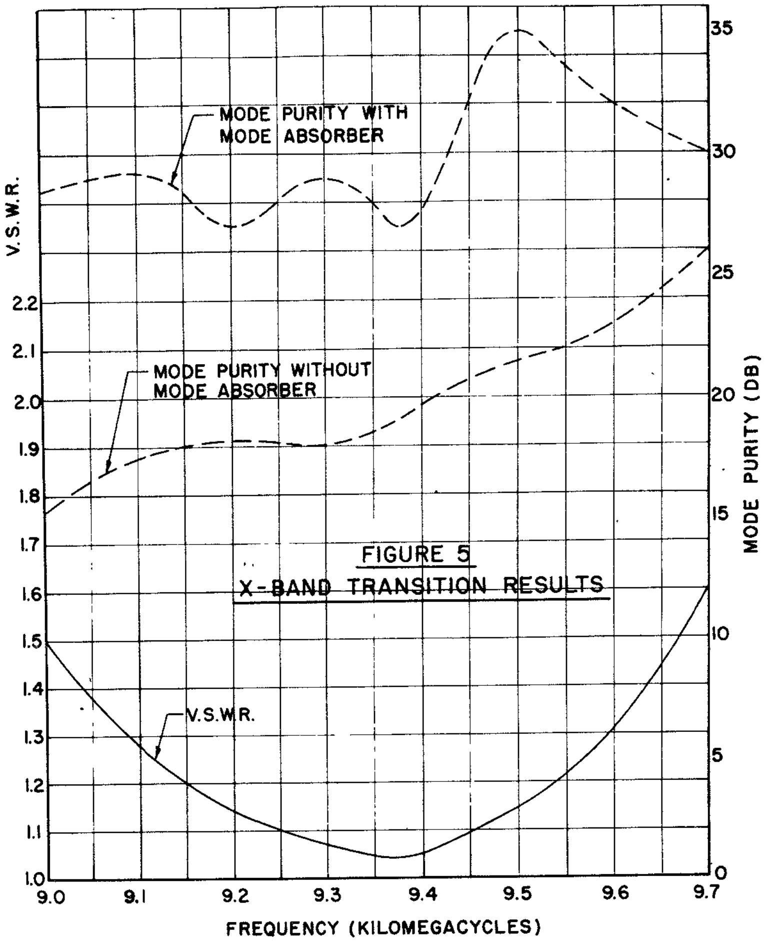

Fig. 5

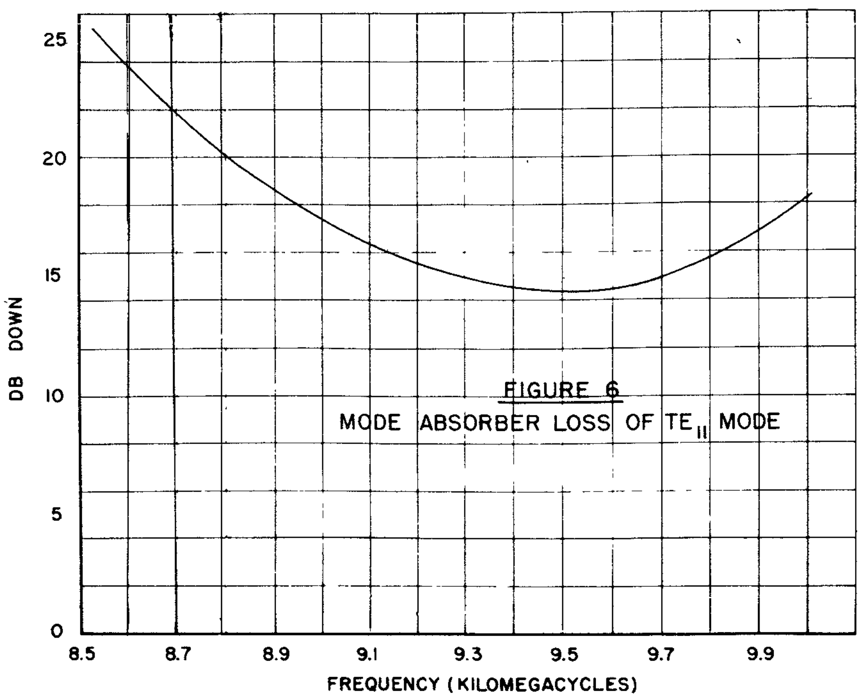

Fig. 6

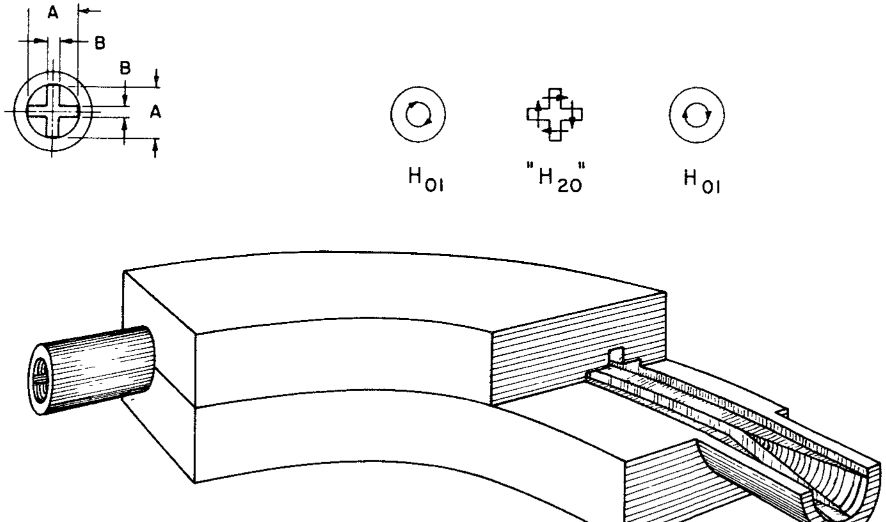

Fig. 7 - E-H bend.

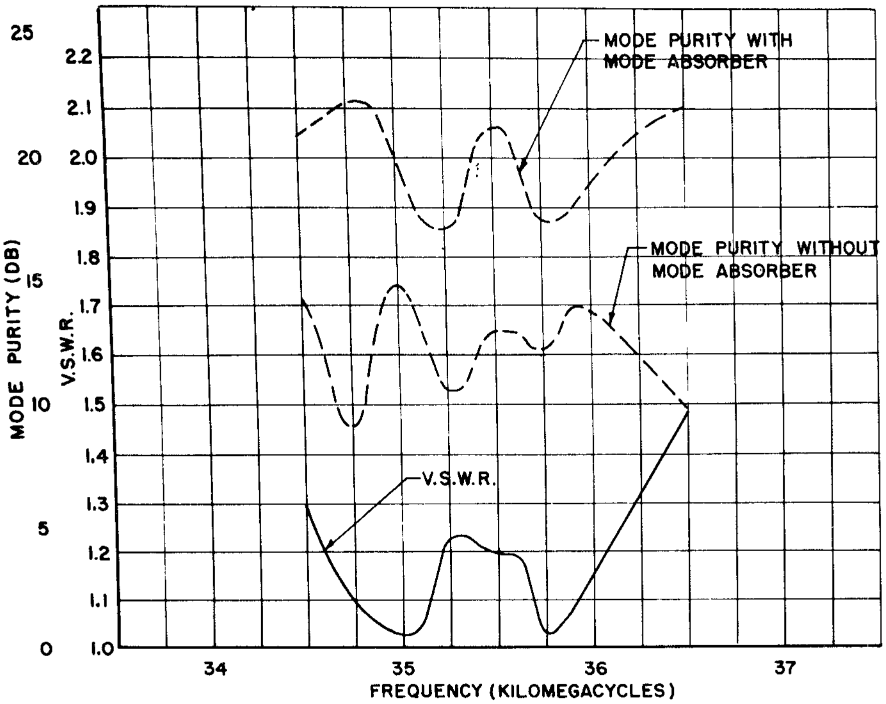

Fig. 8 - E-H bend results.

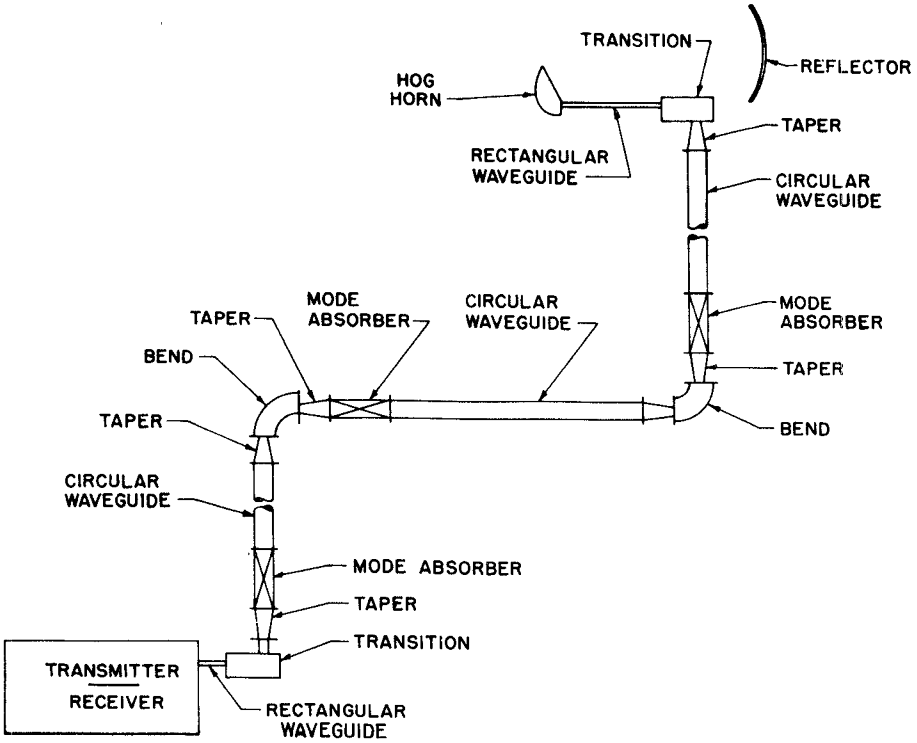

Fig. 9 - Circular waveguide transmission system.