IV-5. E and H-Plane Bends for High-Power Oversized Rectangular Waveguide

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This paper presents the results of a study of bends for oversized rectangular waveguide having cross-sectional dimensions in the range between 1.5 and 2.5 free-space wavelengths. It is expected that waveguide having these dimensions will be able to transmit 50 to 100 kw of average power at *X*-band without water cooling. The transmission of at least 5.0 megawatts of peak power at *X*-band without pressurization is also a design objective.

The practical realization of reliable oversized waveguide systems for high-power applications depends on the development of components having low energy conversion to spurious propagating modes. An important advantage of rectangular waveguide in the design of components such as bends is the absence of modes which are degenerate with the desired TE_{10} mode. The bend study reported in this paper is part of a general study to develop a whole family of components for oversized rectangular waveguide.

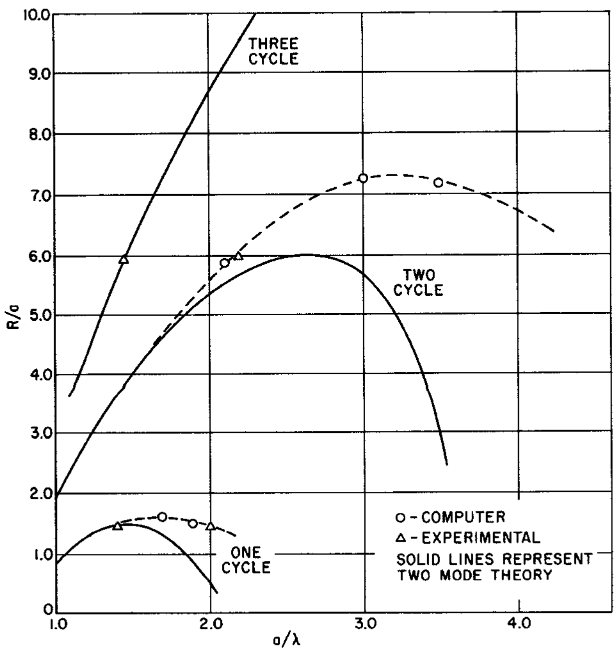

Fig. 1 Corrected design data for TE_{10} mode cyclic *H*-plane bends.

Two approaches to the bend design problems will be described. In the first approach, low mode conversion loss is obtained by employing the principle of "cyclic power transfer" between propagating modes[1] in bends having constant curvature. Thus, bend dimensions can be adjusted so that power that is incident in the desired TE_{10} mode couples over to some degree to a spurious mode, and then couples back to the TE_{10} mode. Similarly, several cycles of power transfer can be obtained between modes. Such bends are termed "cyclic" bends.

Figure 1 shows theoretical and experimental data for 90° H-plane cyclic bends. These curves give the value of the center line radius, R which results in zero power in the TE_{20} mode at the bend output with a TE_{10} mode incident at the bend input. The solid curves represent the first-order closed-form approximation obtained by assuming that only the TE_{10} and TE_{20} modes have significant power. The computer results consider the effect of all forward propagating modes. Since the required value of R/a first increases and then decreases with increasing a/λ, it can be seen that for

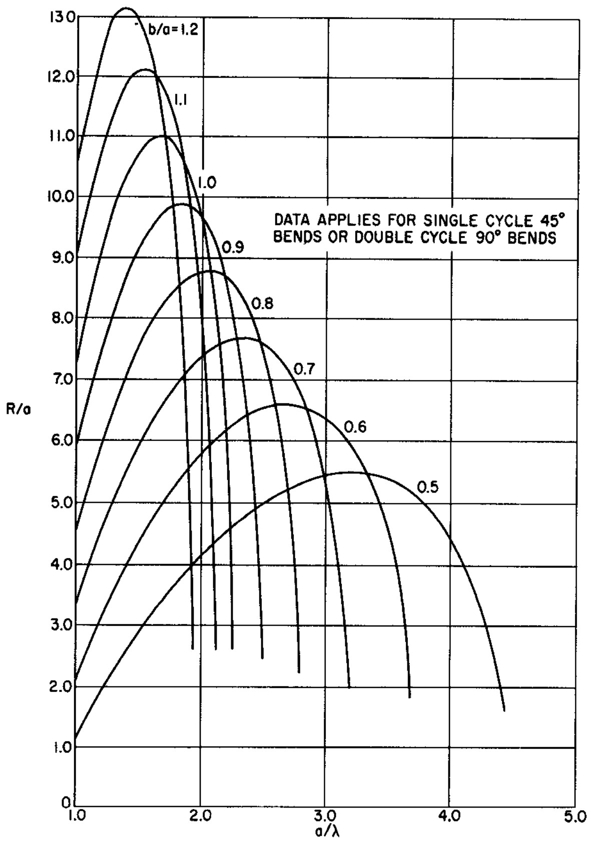

Fig. 2 Dimensions for TE_{10} mode single-cycle 45° (or double-cycle 90°) E-plane bends.

some values of R/a there can be two values of a/λ for which the power in the TE_{20} mode is zero. Measured data and computer calculations indicate that the power in all spurious propagating modes at the bend output is low for the dimensions given in Fig. 1, provided a/λ is less than about 2.25.

Figure 2 shows first-order data for constant curvature E-plane cyclic bends. In this case, the bend dimensions are adjusted to give zero output power in the TE_{11}, TM_{11} degenerate mode pair.

Figure 3 shows data measured at X-band for an experimental H-plane cyclic bend. In this case, the width, a, was 2.25 inches, and the height, b,

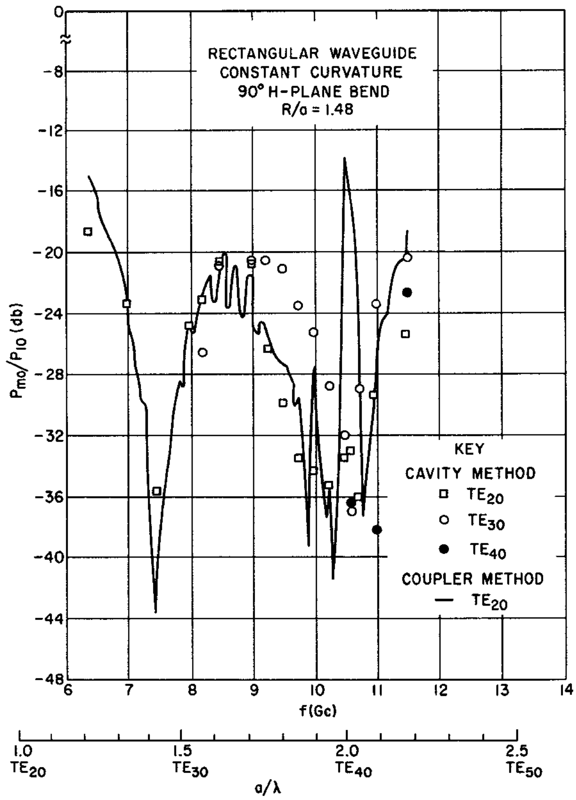

Fig. 3 Experimental results for H-plane bend #1.

was 0.497 inches. The results, however, apply for any other value of b. The ordinate, P_{mo}/P_{10} represents the ratio of the power in the TE_{mo} mode at the bend output to the power in the incident TE_{10} mode.

Mode conversion loss to each of the propagating modes in the bend was measured by a cavity method due to Klinger.[2] As a check on the cavity measurements the mode conversion to the TE_{20} mode was also measured by a coupler method, and these data are shown as a solid line in Fig. 3. Good agreement between the two methods is indicated at all frequencies except near 10 Gc, where a TE_{40} mode load resonance occurred with the coupler method. The data of Fig. 3 show the broad frequency bandwidth predicted by the one-cycle curve of Fig. 1. Very low mode conversion loss was measured at frequencies near 7.5 Gc and 10.5 Gc, and these results provide the two experimental points for the one-cycle curve of Fig. 1.

A second experimental *H*-plane cyclic bend was also tested. In this case, the value of R/a was made equal to 5.95, so as to obtain operation near the maximum of the first-order two-cycle curve of Fig. 1. Measured mode conversion loss for this bend was very low for all spurious modes at the two values of a/λ indicated by the experimental points on the three and two-cycle curves of Fig. 1. The good agreement between the experimental and computer data plotted in Fig. 1 indicates that accurate results can be expected with the coupled transmission line equations, provided all forward propagating modes are considered.

In the second approach to the bend design problem, bends having a variable radius of curvature were investigated. The advantages of this approach have been previously demonstrated in the design of tapers for circular waveguides carrying the TE°_{01} mode.[3,4] In that case, the cone angle was varied gradually along the length of the taper. It was thought that by gradually varying the radius of curvature in the bend case, it might be possible to obtain very low mode conversion loss over wide frequency ranges, possibly at the cost of increased size compared with the cyclic bend design.

A computer program was developed for obtaining numerical solutions of the coupled line equations for the case in which the coupling coefficients are

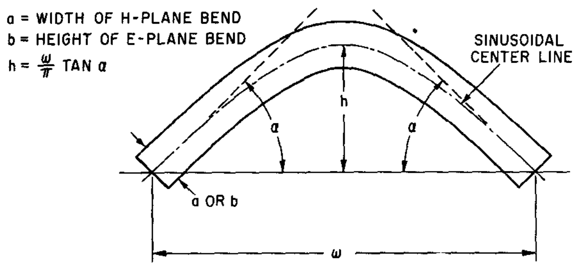

Fig. 4 Dimensions for sinusoidally shaped *H*-plane bends.

variables along the length of the bend. Figure 4 shows the important dimensions for sinusoidally shaped *E* or *H*-plane bends, and Tables I and II show the results of computer calculations for the normalized mode voltages at the bend output for unit power incident in the TE_{10} mode. Inspection of these data indicates that the "tapered mode" principle can be applied to bends, as expected, and that reasonably compact variable curvature *H*-plane bends can be designed. The dimensions for the *E*-plane bends are less compact because of the smaller difference in the propagation constants between the desired TE_{10} mode and the TE_{11}, TM_{11} spurious mode pair. The data in Table II for the *E*-plane bends were calculated for an infinite waveguide width. For a finite waveguide width the free-space wavelength, λ,should be replaced with λ_{10}, the wavelength of the TE_{10} mode. Note that in some cases the spurious mode voltages do not decrease steadily with increasing

TABLE I

Computer Calculations for Variable Curvature 90° *H*-Plane Bends

Mode Content at Bend Output*

$a/\lambda = 1.75$

ω/a	E_{10}	E_{20}	E_{30}	E_{40}	E_{50}
7.0	0.9985	0.0549	0.000759	–	–
8.0	0.9967	0.0815	0.000737	–	–

$a/\lambda = 2.25$

ω/a	E_{10}	E_{20}	E_{30}	E_{40}	E_{50}
4.4	0.9918	0.0536	0.116	0.00621	–
7.0	0.9914	0.129	0.0169	0.000230	–
8.0	0.9966	0.0821	0.00602	0.000101	–
8.88	0.9995	0.0297	0.00112	0.000173	–

$a/\lambda = 2.75$

ω/a	E_{10}	E_{20}	E_{30}	E_{40}	E_{50}
10	0.9872	0.159	0.0128	0.000146	0.00001103
12	0.9999	0.0109	0.000742	0.000115	0.000000856
15	0.9983	0.0591	0.00133	0.000115	0.00000545

*Mode Power is proportional to $|E_{mo}|^2$

TABLE II

Computer Calculations for Variable Curvature 90° *E*-Plane Bends

Mode Content at Bend Output*

$b/\lambda = 1.5$

ω/b	E_{00}	E_{01}	E_{02}	E_{03}
20	0.9999	0.0184	0.000121	–

$b/\lambda = 2.0$

ω/b	E_{00}	E_{01}	E_{02}	E_{03}
20	0.9981	0.0624	0.00885	0.000273
40	0.9983	0.0621	0.000131	0.0000383
60	0.9986	0.0253	0.0000265	0.0000163

*Mode Power is proportional to $|E_{on}|^2$

ω/a, indicating a residual cycling of power among modes. Computer calculations are under way for other bend shapes, and these may lead to more compact designs.

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