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ABSTRACT

Waveguide components designed specifically for transmitting power into PDX for electron cyclotron heating (ECH) at 60 GHz are described. These include mode converters from the circular electric TE01 mode to the polarized HE11 mode, compact corrugated waveguide bends with a hyperbolic secant curvature variation, compact corrugated waveguide diameter tapers with a parabolic profile, and a high voltage DC break incorporating a section of dielectric waveguide, all designed for low-loss HE11 propagation. Optimization of the corrugation depth and curvature for bends propagating TE01 is also discussed.

III. INTRODUCTION

The two gyrotrons used on PDX generate the TE02 mode near 60 GHz in 2.5-inch waveguide. Since TE02 has both a poor radiation pattern and relatively high waveguide loss, we quickly tapered down to smaller waveguide where low-loss mode converters can be made in reasonable lengths. The smaller diameter also allows reasonably short low-loss bends to be made. In Table I we show the sequence of components and waveguide modes used between the gyrotrons and PDX. The TE02 and TE01 components and corrugated waveguide for bends in these modes were supplied by GA Technologies, Inc., San Diego, California.

Designing bends for TE01 is particularly tricky, since the corrugation depth must be large enough to split the propagation constant degeneracy with TM11 but small enough to avoid indirect coupling to HE21 (see Fig. 1). In contrast, bends propagating HE11 can be made much shorter than those with TE01, since there is no mode close to degeneracy with HE11 at reasonable corrugation depths.

Due to cramped space near PDX and a desire to obtain a polarized mode with a good radiation pattern, mode converters were used near PDX to convert TE01 into HE11. To use a commercial high-power waveguide window and to reduce the antenna beam width, the waveguide was finally tapered up to 2.5 inches and the HE11 mode was radiated from open-ended corrugated waveguide into PDX.

We first consider the TE01-HE11 converters, and then the HE11 bends. Discussion of the theoretically more complex TE01 bends follows. We then discuss the HE11 taper to 2.5 inches and a high voltage DC break. Finally, we consider the overall transmission system performance.

II. TE01 to HE11 MODE CONVERTERS

A schematic of the converters used at PPPL is shown in Fig. 2 [1]. Curvature continuously couples power from TE01 to TM11, which in smooth waveguide is degenerate (propagation constant is identical) with TE01. A constant radius bend of angle θ_c will ideally convert all the power from one mode to the other if

$$\theta_c = \frac{X\lambda}{2\sqrt{2}\, P^2 a}\,, \tag{1}$$

where $$P = \beta_z/k = \left[1 - X^2/(k^2a^2)\right]^{1/2}, \tag{2}$$

X = 3.8317 is the Bessel function root for TE01 and TM11, a is the waveguide radius, and $\lambda = 2\pi/k$ is the free space wavelength. (The factor P^2 in (2) is a small correction to the expressions found in the literature [2]; see the derivation in [3].) The bend must be long enough to avoid unwanted mode conversion to modes such as TE11 and TE21 but as short as possible to minimize ohmic (wall) loss from the high-loss TM11 mode.

The second converter "adiabatically" converts TM11 to HE11 by increasing the corrugation depth gradually from zero to something approaching $\lambda/4$. The properties of the HE11 mode are quite well-established in highly overmoded waveguide at considerably smaller corrugation (slot) depths, as might be concluded from the behavior of β_z shown in Fig. 1. The converter must only be long enough to suppress the "branch hopping," principally to the TE11-EH11 branch, that accompanies an abrupt change in corrugation depth. The HE11 is polarized perpendicular to the plane of the bend.

The TE01-TM11 converter was fabricated by annealing a 57-inch piece of commercially available WC109 (1.094-inch I.D.) waveguide in a vacuum furnace and then bending it in a pre-assembled frame with a form defining the curve. The anneal made the waveguide easy to bend by hand, and the side walls of the frame kept the waveguide from becoming significantly elliptic in the plane perpendicular to the bend. An actual bend arc length of 48 inches for $\theta_c \approx 28$ degrees was adequate to reduce the unwanted mode conversion between 59 and 60 GHz to 1% while keeping the ohmic loss down to about 3% [1].

The TM11-HE11 converter was fabricated by electroforming, using an aluminum mandrel machined on a numerically controlled lathe. The corrugation depth was made to increase slowest at shallow depths where the coupling coefficient for hopping to the TE11-EH11 branch is largest. The corrugation period and width must be less than λ and $\lambda/2$, respectively. Higher order modes in the corrugations are attenuated (as in cutoff waveguide) by as much as 12 and 26 dB in a depth of $\lambda/8$ when the corrugation width is $\lambda/4$ and $\lambda/8$, respectively. If significant TE11 (or TE21) is present at the converter input, the corrugation width and period should be reduced somewhat, since these modes turn into surface waves with guide wavelengths less than that of free space ($\lambda g \approx \lambda/\sqrt{2}$, for example, when the corrugation depth is $\lambda/8$). Measured overall TE01-HE11 conversion efficiency was about 92% near 59.5 GHz [1].

The HE11 mode may also be generated from TE01 using TE11 as the intermediate mode [4]-[6]. This scheme has the advantage that the converters can all be made without bends, and testing is made simpler because TE11 in circular waveguide can be generated quite conveniently directly from TE10 in single-mode rectangular waveguide. The TE11-HE11 converter may also be made somewhat shorter than the TM11-HE11 converter due to reduced coupling, and there is no danger of surface mode generation in the converter. The serpentine TE01-TE11 converter, however, must be made very long to suppress TE12 and also TE21, or else the waveguide diameter of the converters must be reduced. Due to the relatively large number of periods of the coupling, the TE01-TE11 converter bandwidth is likely to be inherently narrower than that of the TE01-TM11 converter. The TE11-HE11 converter bandwidth is also reduced relative to that of the TM11-HE11 converter by the need to start the corrugation depth at $\lambda/2$ in the former.

III. HE11 BENDS

The HE11 is well-suited for negotiating tight bends in corrugated waveguide, because its propagation constant β_z is well-separated from other modes and is not sensitive to charges in corrugation depth (Fig. 1). The primary coupling due to curvature is to TE01 and HE21; the (dimensionless) coupling coefficient K for coupling to either mode is about 4 for a waveguide inside diameter of 1.094 inches near 60 GHz [3]. Such a situation is particularly convenient for a low mode-conversion 90-degree bend using a hyperbolic secant curvature variation with arc length. The power lost to a single unwanted mode in such a bend is ideally [7]

$$P_\ell = \frac{\sin^2 K\theta}{\cosh^2\left(\Delta\beta R_o \theta/2\right)} , \qquad (3)$$

where $\Delta\beta$ is the difference in propagation constants of the two modes, R_o is the minimum radius of curvature (at the center of the bend), and it is assumed that the differential attenuation between modes is negligible in the bend (virtually always true in short bends). From Eq.(3), it is clear that when $\theta = \pi/2$ and X is even, the loss should vanish.

The actual loss in an HE11 bend is complicated by simultaneous coupling to both TE01 to HE31. A hyperbolic secant curvature must also be truncated at some finite length, producing a further departure from Eq. (3). Nevertheless, Fig. 3 shows the superiority of this type of curvature over other types in this application.

Due to the sensitivity of the mode conversion to the curvature variation in a sharp bend, a frame was constructed to restrain the flexible corrugated waveguide; the entire assembly is shown in Fig. 4. The bend arc length is 32 inches. In order to allow bending to a minimum radius of 8 inches at the bend center without fracture, the corrugations had to be rounded. The total length of the corrugated waveguide in Fig. 4 is 40 inches. The measured mode conversion between 59 and 60 GHz when this bend was used to propagate HE11 was less than 0.1 dB for both H-plane and E-plane orientations.

IV. TE01 BENDS

Mode conversion in bends propagating TE01 is much harder to prevent. If the corrugation depth is too small, then coupling similar to that in the TE01-TM11 converter predominates. If, on the other hand, the corrugation depth is too large, the HE21 mode becomes almost degenerate with TE01 (Fig. 1). In that case, even though there is no direct coupling between TE01 and HE21 in a bend, indirect coupling through HE11 can lead to disastrous results [8]. This sensitivity to corrugation depth is shown in Fig. 5, calculated from numerical integration of the coupled mode equations for a cosine curvature variation over a 72-inch arc length. For shorter bends the low-loss "window" becomes even narrower.

The cosine curvature variation exhibits the widest window in corrugation depth for this application. Results of numerical integrations for a 60-inch arc length are shown in Fig. 6. Frames defining hyperbolic secant and triangular (linearly tapered) curvature variations for these arc lengths were actually constructed; the measured mode conversion losses of about 0.8 dB and 0.28 dB, respectively, are consistent with an effective corrugation depth of 0.28 $\lambda/4$ (Fig. 6).

The actual corrugation depth in the waveguide used for TE01 bends at PDX was 0.5 $\lambda/4$, the period was 1.2 $\lambda/4$, and the corrugation width was slightly less than half the period. The space between corrugations reduces the surface reactance and hence the effective corrugation depth; a decrease from 0.5 $\lambda/4$ to effectively 0.28 $\lambda/4$ appears reasonable for this waveguide.

When TE01 was propagated in a test corrugated bend with a corrugation depth of 0.6 $\lambda/4$, the measured insertion loss was higher than for 0.5 $\lambda/4$ [9], in agreement with the trend for all curvature variations in Figs. 5 and 6. As expected, the loss was extremely large in bends with a corrugation depth of $\lambda/4$ [9].

The actual bends used at PPPL are enclosed in frames both to prevent damage and also to ensure that the desired curvature variation was not disturbed. The curvature is defined by inner and outer sets of standoff against which brass strips have been placed to ensure a smooth surface for the waveguide exterior. Cosine curvature over 72-inch arc lengths was used for both 90-degree and 45-degree TE01 bends, yielding measured mode conversion between 59 and 60 GHz of less than 0.1 dB and 0.05 dB, respectively. Numerical integrations also indicated the superiority of the cosine curvature variation for TE02 bends, but even a 60-inch arc length 90-degree bend with a triangular curvature variation produced only 0.1 dB of mode conversion when propagating TE02 in this same waveguide.

V. PARABOLIC HE11 TAPERS

The TE01-HE11 mode converters and the waveguide bends must be made in relatively small diameter waveguide in order to keep their length (roughly proportional to diameter squared) reasonably short. As we have seen, the HE11 mode is also desirable for negotiating the last bends near the plasma device when space is cramped. After the last bend, however, an increase in the waveguide diameter is desirable in order to reduce the beamwidth of the radiation from open-ended waveguide.

For PDX we used 2.5-inch windows obtained from Varian Associates, and thus we needed a taper to that diameter from the 1.094-inch diameter of the mode converter and bends. To preserve the HE11 mode, the walls of the taper must be corrugated. To minimize the mode conversion, the taper profile must be nonlinear.

A nonlinear taper can be designed easily if the profile is "parabolic." For such a taper of total length L, the axial distance z is related to the local radius a(z) by

$$z = \frac{[a^2(z) - a_1^2]L}{a_2^2 - a_1^2}, \qquad (4)$$

where $a_1 = a(0)$ and $a_2 = a(L)$. The mode conversion vanishes for taper lengths L_n, where [10]

$$L_n = \frac{K_o\left(a_2^{\,2} - a_1^{\,2}\right)}{P_o\,\lambda_o}\left[\left(\frac{n\pi}{K_o\,\ell n\left(a_2/a_1\right)}\right)^2 - 1\right]^{1/2}, n \text{ integer,} \tag{5}$$

subject to the approximation that the mode coupling is $K_o\ d(\ell na)/dz$, K_o constant, and the difference in propagation constants $\Delta\beta$ between the desired and undesired modes is

$$\Delta\beta = P_o\ \lambda/a^2, \tag{6}$$

where λ is the free space wavelength. The former approximation is usually extremely good even close to cutoff, and the latter (for $\Delta\beta$) is quite good when both modes are reasonably far from cutoff.

The taper length for the first null, L_1 in the above formula, is shorter than that for other nonlinear tapers [10]. The coupling in a parabolic taper is actually the analog of constant coupling in constant diameter waveguide. The length required in either case for the first zero in the mode conversion is quite small, but the bandwidth for low mode conversion (about 10%) is also less than that for other coupling variations, primarily due to the coupling discontinuities at the ends. Nevertheless, in electron cyclotron heating applications, a very wide bandwidth is ordinarily not required.

The theoretical situation for our HE11 taper is shown in Fig. 7. The theoretical mode conversion to HE12 with K_o = 1.076 and P_o = 1.965 exhibits nulls at L_1 = 12 inches and L_2 = 24.5 inches. The curve calculated from numerical integration of the coupled mode equations shows a shift to shorter lengths due to a small deviation of $\Delta\beta$ from the approximation (6) at smaller diameters and also the fact that the corrugations are not quite as deep as $\lambda_o/4$. This last fact also causes the coupling to EH12 to be nonzero, which results in nonzero total mode conversion near L_1 = 12 inches.

A corrugated taper fabricated by electroforming with a parabolic profile and L = 24 inches is shown in Fig. 8. The mode conversion measured with back to back tapers of the same kind between 59 and 60 GHz was less than the experimental uncertainty, about 0.5%.

VI. HIGH VOLTAGE DC BREAK

A DC break was required in the waveguide near PDX to prevent transient or accidental potentials on PDX from reaching equipment located on the machine floor. Fortunately, at a diameter D = 2.5 inches, the diameter to wavelength ratio D/λ_o is sufficiently large at 60 GHz to allow low-loss propagation of the HE11 mode in a short piece of dielectric waveguide. If the dielectric is effectively infinite in extent in the transverse plane, then the fields of the HE11 mode in the dielectric waveguide are virtually the same as those in corrugated waveguide, and the transmission loss depends mainly on the real part of the dielectric constant and λ_o^2/D^3 [11].

The transverse extent of the dielectric can be made effectively very large if a material with a large imaginary part of the dielectric constant (large loss tangent) is used. Phenolic is very good for this application at millimeter wavelengths; the measured loss in a sample of linen - based phenolic was about 20 dB per inch near 60 GHz.

A picture of a DC break using this principle is shown in Fig. 9. A phenolic annulus was sandwiched between two corrugated waveguide lengths. The outside diameter of the phenolic piece was 4.5 inches, ensuring a 20 dB loss between inside and outside and suppressing RF leakage as well as providing the proper boundary conditions as discussed above. In a 3/4-inch length, assuming a dielectric constant of 3.5, the loss theoretically should be less than 0.03 dB. The measured insertion loss for the HE11 mode was actually about 0.3 dB near 60 GHz. This break could stand off 20 kV. A gas inlet/output port was attached through a small hole in the phenolic. A similar break without the corrugated waveguide lengths but with a 1-1/2 inch length of phenolic was made by M. Goldman of PPPL for use on the PLT tokamak. The HE11 insertion loss of this piece was only 0.1 dB.

VII. SYSTEM CONSIDERATIONS

Assuming close to 100% of the output of the Varian 100 millisecond single cavity gyrotron is in the TE02 mode near 60 GHz (this was confirmed with the use of a TE02 directional coupler and a TE02-TE01 converter [12]), it is estimated from measurements on individual components that about 10% was lost in the walls due to ohmic loss on the way to the 2.5-inch DC break near PDX (primarily due to excitation of high loss modes), and about 10% appeared in other modes besides HE11. Unfortunately, approximately another 10% of mode conversion is caused by the window assembly, because it was mechanically impractical to corrugate the waveguide walls in that piece. The HE11 mode cannot propagate in smooth waveguide. At the junction between corrugated and smooth waveguide, the incident HE11 is decomposed into approximately 84% TE11 and 15% TM11 [13]. Since these latter modes have different propagation constants, they will in general not add in the proper phase to regenerate HE11 at the place where the waveguide again becomes corrugated. The power in spurious modes (HE12, EH12, etc.) in the output corrugated waveguide varies as the square of the length ℓ of smooth waveguide inserted between the corrugated pieces, when ℓ is small.

Nevertheless, the radiation pattern from open-ended corrugated waveguide after passing through the window is still quite good. Figure 10 shows the pattern in the E-plane (which is the toroidal plane for ordinary mode launching) measured after a HE11 mode launched by the TE01-HE11 converter had passed through the 1.094-2.5 inch taper, a 2.5-inch I.D. corrugated bellows, the DC break of Fig. 9, the window, and a length of corrugated waveguide attached to a tokamak vacuum flange similar to the one used on PDX for the outside ordinary mode launch.

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REFERENCES

[1] J.L. Doane, "Mode converters for generating the HE11 (gaussian-like) mode from TE01 in a circular waveguide," Int. J. Electronics, vol. 53, pp. 573-585, Dec. 1982.

[2] H.E. Rowe and W.D. Warters, "Transmission in multimode waveguide with random imperfections," Bell System Tech. J., vol. 41, pp. 1031-1170, May 1962.

[3] J.L. Doane, "Propagation and mode coupling in corrugated and smooth wall circular waveguides," in Infrared and Millimeter Waves, Vol. 13, K.J. Button, ed. , New York: Academic Press, to be published.

[4] C. Moeller, "Mode converters used in the Doublet III ECH microwave system," Int. J. Electronics, vol. 53, pp. 587-593, Dec. 1982.

[5] B. MacA. Thomas, "Mode conversion using circumferentially corrugated cylindrical waveguide," Electron Lett., vol. 8, pp. 394-396, July 1972.

[6] M. Thumm et al., "Conversion of gyrotron TE_{0n} mode mixtures into a linearly polarized HE_{11}-wave," presented at Eighth International Conference on Infrared and Millimeter Waves, Miami, Florida, Dec. 1983.

[7] J.L. Doane, "Hyperbolic secant mode coupling," Princeton Plasma Physics Lab. Rep. PPPL-1923, July 1982.

[8] J.W. Carlin and S.C. Moorthy, "TE_{01} transmission in waveguide with axial curvature," Bell System Tech. J., vol. 56, pp. 1849-1872, Dec. 1977.

[9] C. Moeller, private communication.

[10] J.L. Doane, "Parabolic tapers for overmoded waveguides," presented at the Eighth International Conference on Infrared and Millimeter Waves, Miami, Florida, Dec. 1983.

[11] E.A.J. Marcatili and R.A. Schmeltzer, "Hollow metallic and dielectric waveguides for long distance optical transmission and lasers," Bell System Tech. J., vol. 43, pp. 1783-1809, July 1964.

[12] C. Moeller, private communication.

[13] C. Dragone, "Reflection, transmission, and mode conversion in a corrugated feed," Bell System Tech. J., vol. 56, pp. 835-867, July-August 1977.

TABLE I

Sequence of Major Components in PDX ECH Transmission System

COMPONENT	DIAMETER	MODE
GYROTRON	2.5"	TE02
ARC DETECTOR, MODE FILTER	2.5"	TE02
TAPER	2.5 → 1.094"	TE02
90° BEND, BIDIRECTIONAL COUPLER	1.094"	TE02
MODE CONVERTER	1.094"	TE02 → TE01
90° AND 45° BENDS WC109 WAVEGUIDE BIDIRECTIONAL COUPLER	1.094"	TE01
MODE CONVERTERS	1.094"	TE01 → TM11 → HE11
90° BENDS	1.094"	HE11
CORRUGATED TAPER	1.094 → 2.5"	HE11
BELLOWS, DC BREAK, WINDOW	2.5"	HE11
OPEN-ENDED CORRUGATED WAVEGUIDE AT PDX	2.5"	HE11

FIGURE CAPTIONS

FIG. 1 Propagation constants relative to TE01 in 1.094-inch I.D. corrugated circular waveguide as a function of slot (corrugation) depth at 60 GHz.

FIG. 2 Generation of HE11 from TE01 via TM11. TM11 and HE11 are polarized perpendicular to the plane of the bend.

FIG. 3 Mode conversion as a function of arc length L for HE11 propagation in a 90-degree H-plane bend with various curvature variations; calculated numerically from the coupled mode equations including simultaneous coupling to TE01, HE21, and HE31; waveguide I.D. = 1.094 inches, effective (electrical) corrugation depth = $\lambda/8$, frequency = 60 GHz. Minimum radius R_o for hyperbolic secant curvature is L/4.

FIG. 4 A 90-degree HE11 bend in 1.094-inch I.D. corrugated waveguide with R_o = 8 inches, arc length L = 32 inches, and overall waveguide length (before bending) 40 inches. Hyperbolic secant curvature variation.

FIG. 5 Mode conversion as a function of effective (electrical) corrugation depth for TE01 propagation in a 90-degree bend with a cosine curvature variation and 72-inch arc length; calculated numerically from the coupled mode equations assuming simultaneous coupling to HE11, EH12, and HE21; waveguide I.D. = 1.094 inches, frequency = 60 GHz.

FIG. 6 The same as Fig. 5, except that the arc length is 60 inches and other curvature variations are compared. The asterisks denote measured losses for triangular and hyperbolic secant ($L/R_o = 4$) curvature variations, showing consistency with an effective corrugation depth of 0.28 ($\lambda/4$).

FIG. 7 Total mode conversion as a function of taper length for HE11 propagation at 60 GHz with initial and final diameters of 1.094 and 2.5 inches, respectively: (a) Ideal curve calculated from analytical solution for a parabolic taper assuming validity of Eq. (6), coupling only to HE12, and an effective corrugation depth of $\lambda/4$; (b) curve calculated numerically from the coupled mode equations assuming simultaneous coupling to HE12, EH12, and EH13, an effective corrugation depth of 0.7 ($\lambda/4$), and a parabolic taper; (c) same as (b), but for linear taper.

FIG. 8 Parabolic taper in corrugated circular waveguide. Total length = 24 inches; initial and final diameters are 1.094 and 2.5 inches, respectively.

FIG. 9 High voltage DC break in 2-5 inch I.D. waveguide.

FIG. 10 E-plane radiation patterns at 59.68 GHz 40 inches away from open-ended 2.5-inch I.D. corrugated waveguide excited by TE01-HE11 converter, parabolic taper, corrugated bellows, DC break, and vacuum window.

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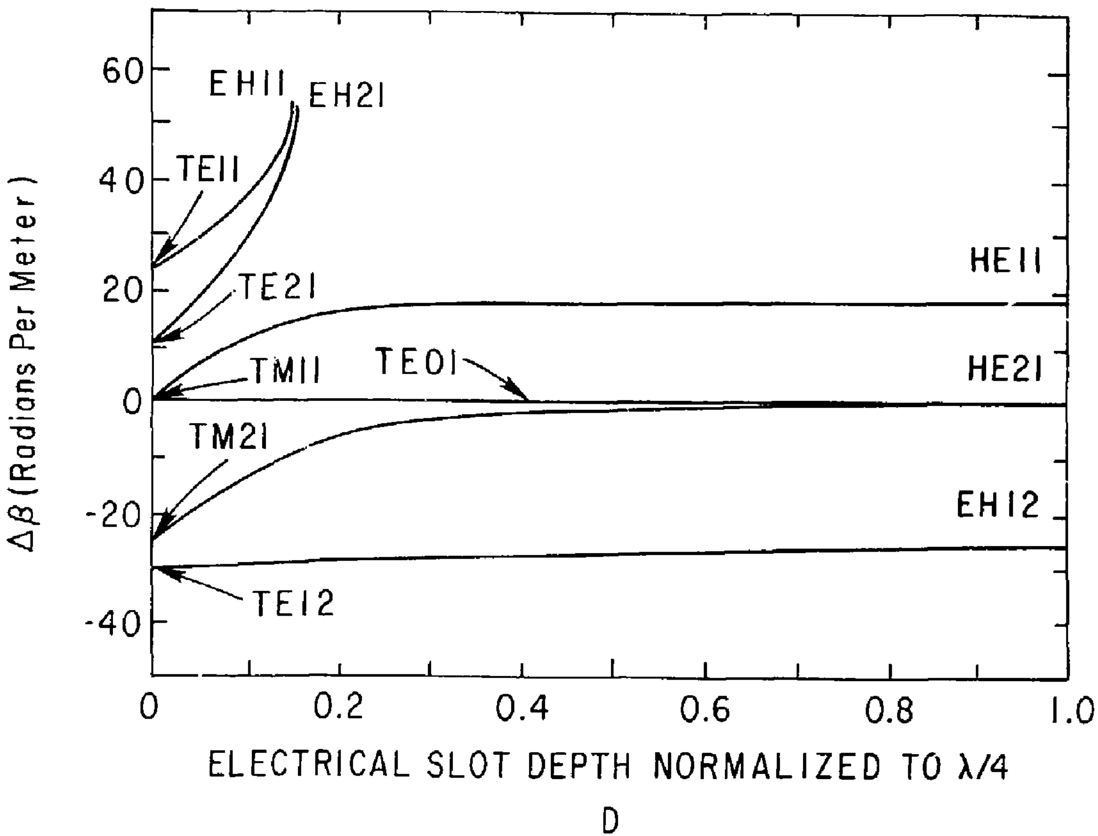

Fig. 1

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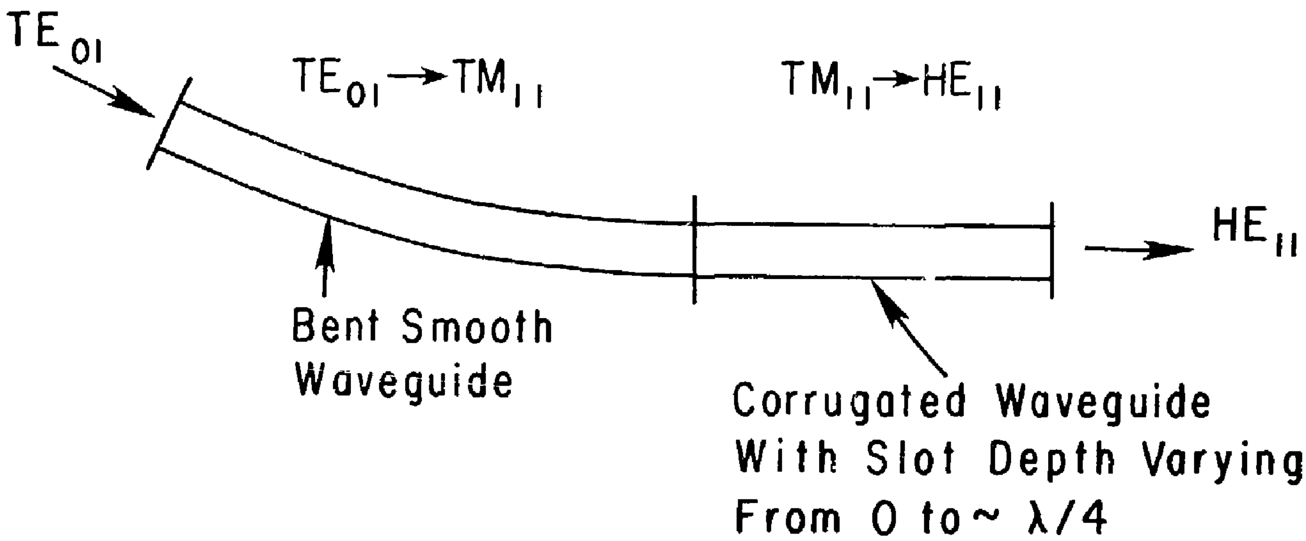
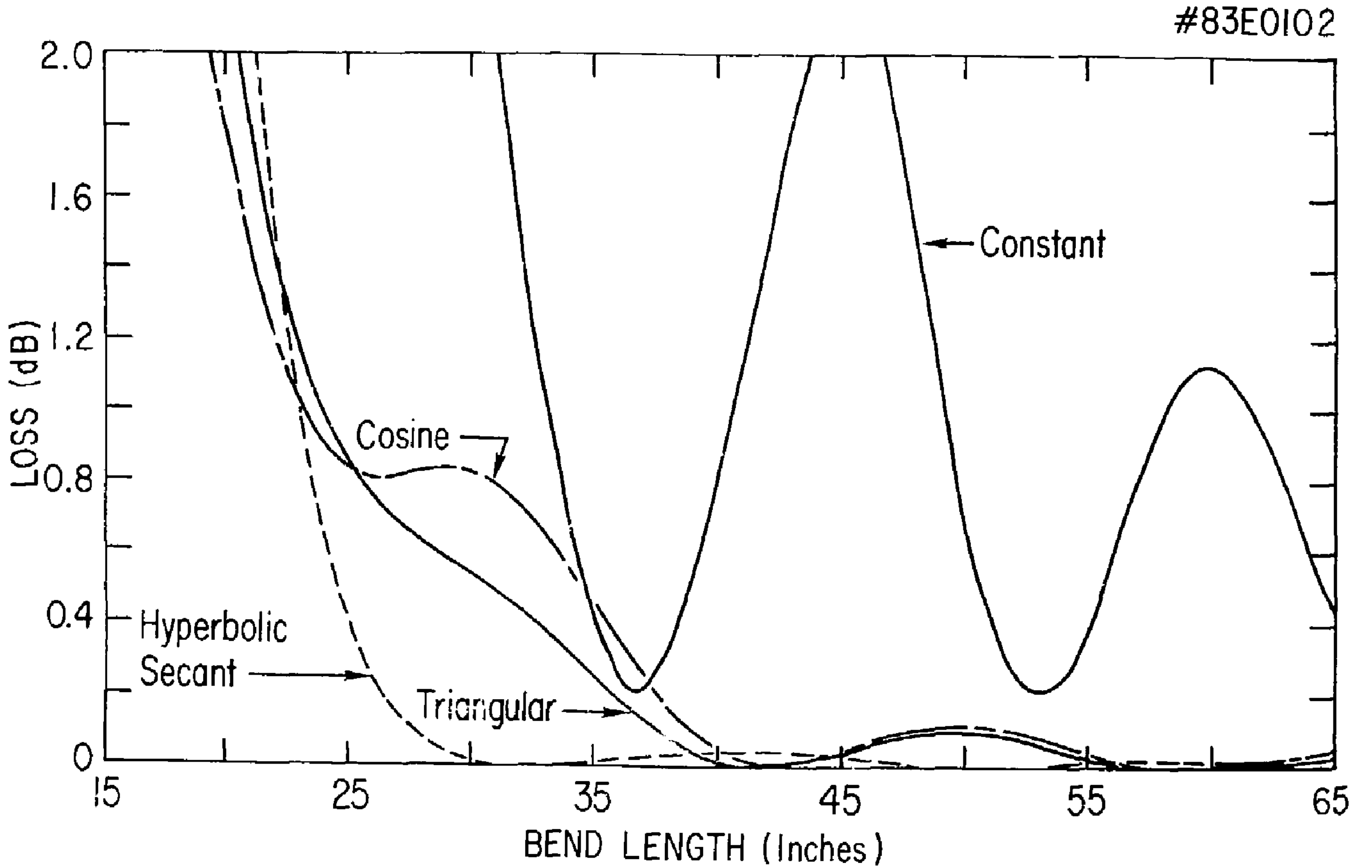


Fig. 2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1.6
1.2
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0.4
0
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25
35
45
55
65
BEND LENGTH (Inches)
Constant
Cosine
Hyperbolic
Secant
Triangular

Fig. 3

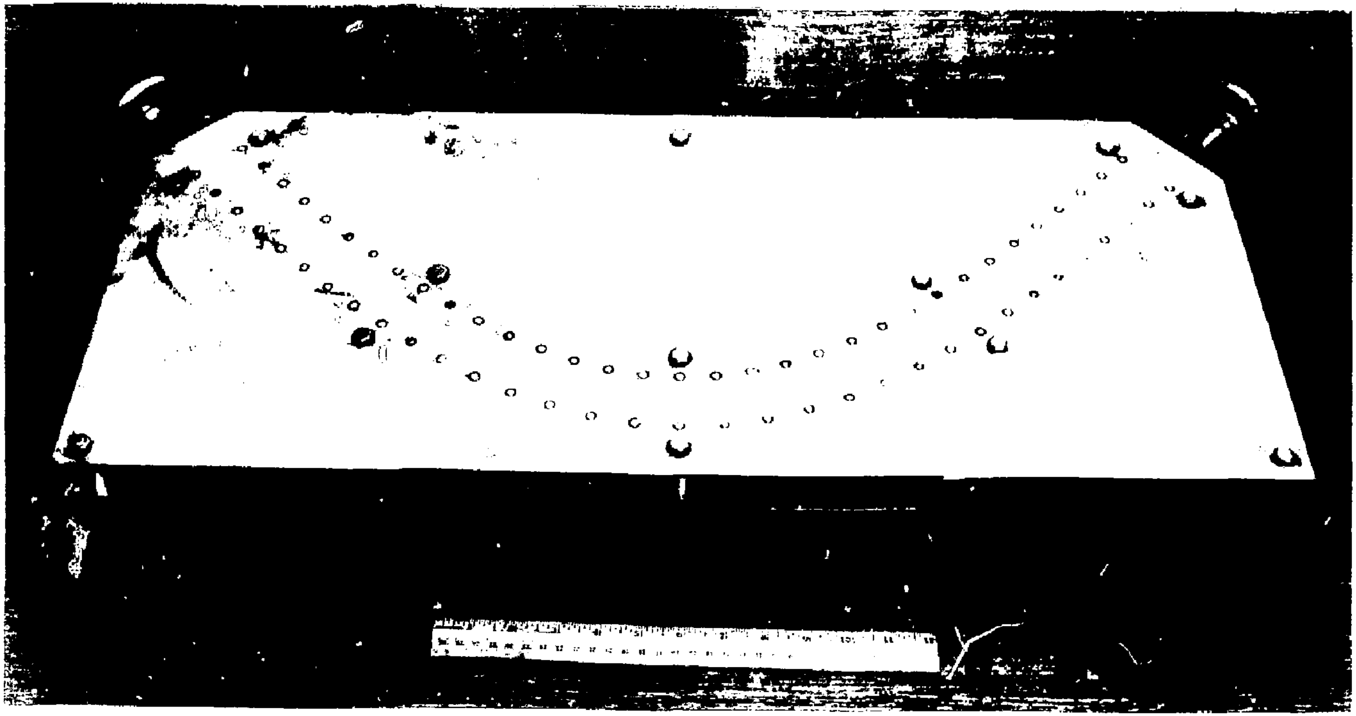

Fig. 4

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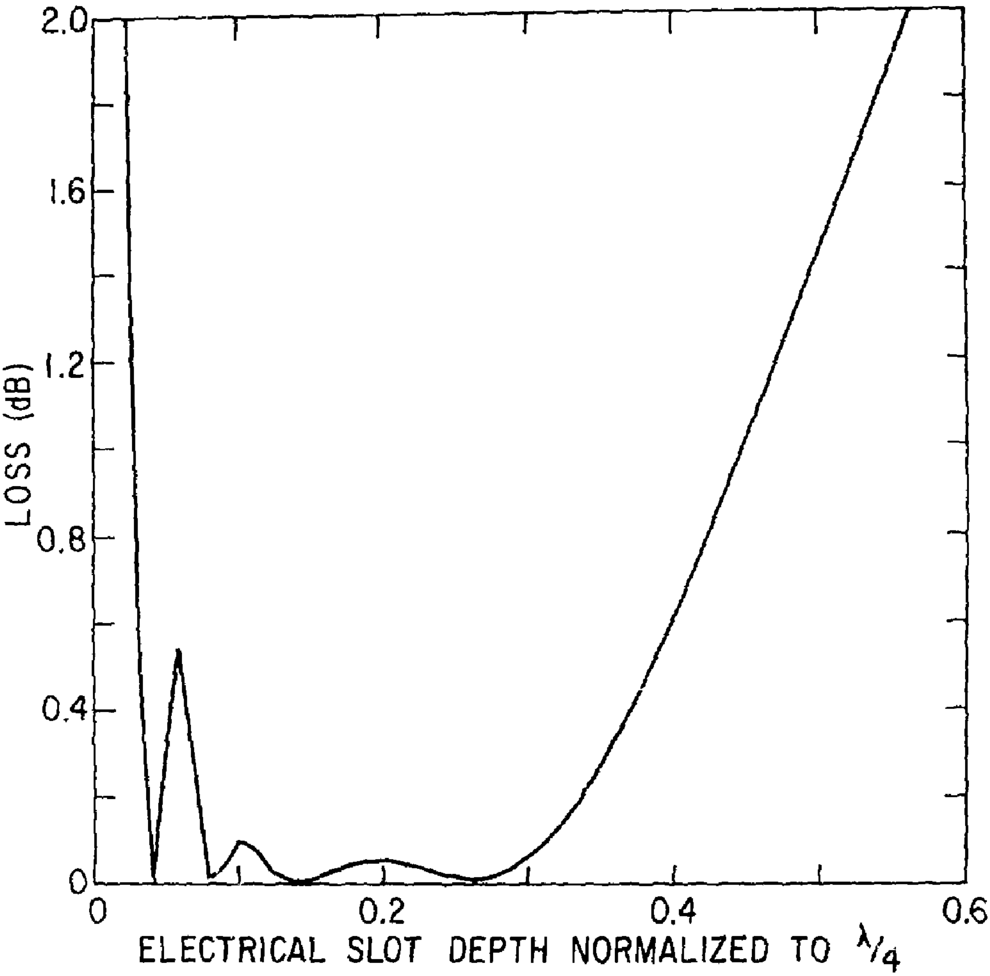
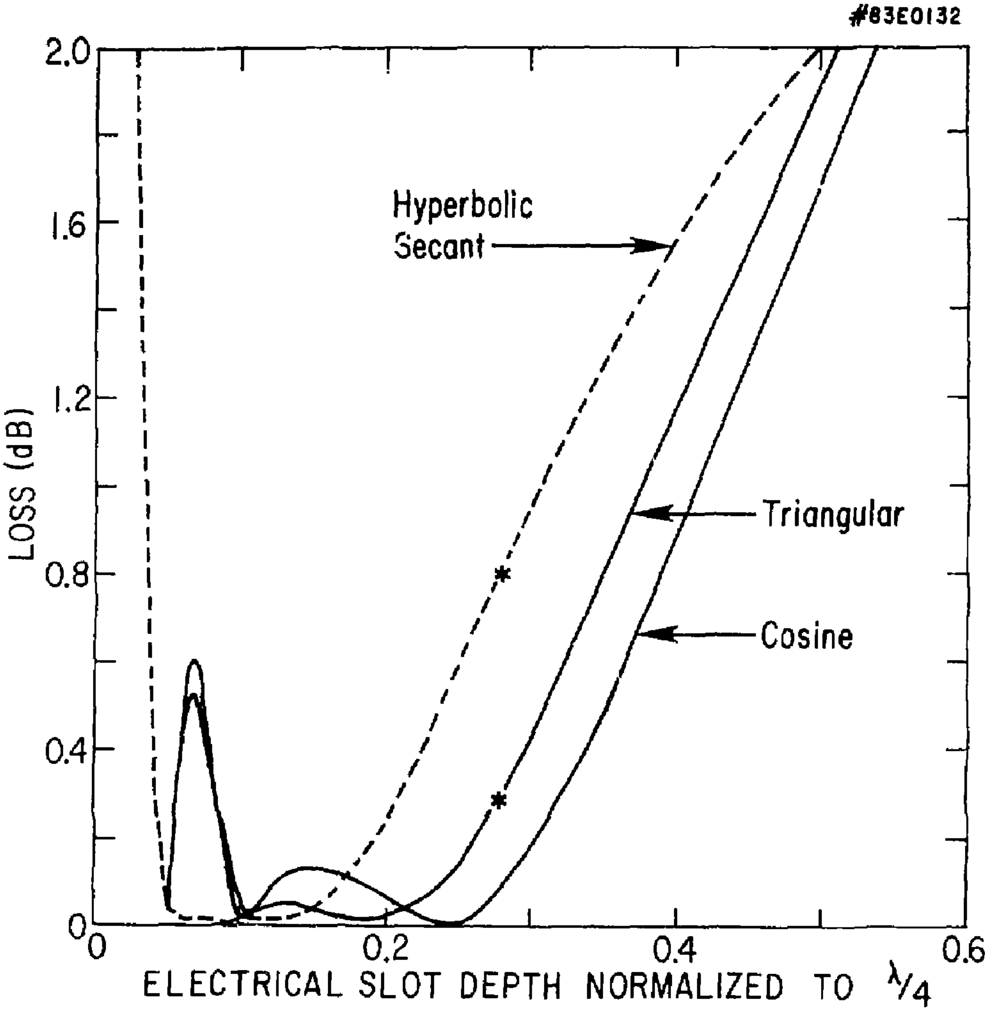


Fig. 5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1.2
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0.4
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Secant
Triangular
Cosine
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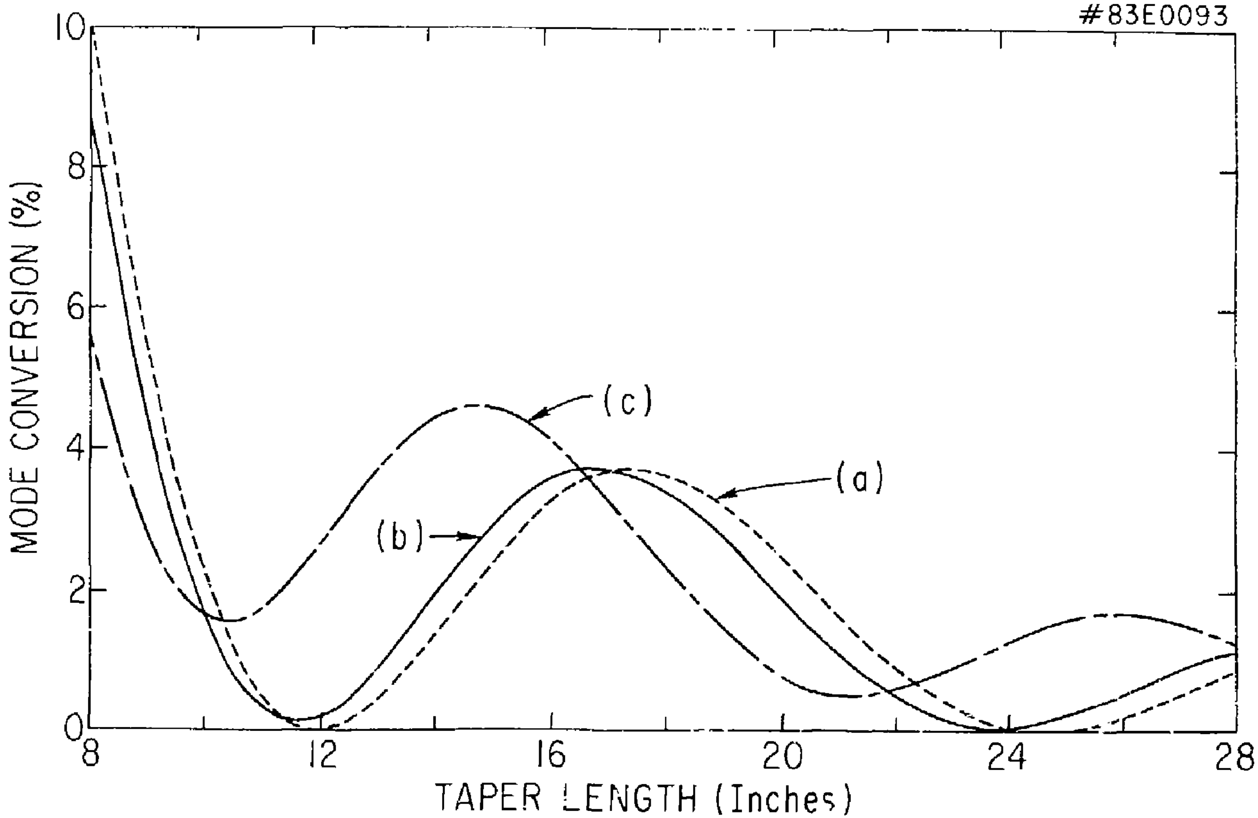
0.4
0.6
ELECTRICAL SLOT DEPTH NORMALIZED TO λ/4

Fig. 6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MODE CONVERSION (%)
10
8
6
4
2
0
8
12
16
20
24
28
TAPER LENGTH (Inches)
(a)
(b)
(c)

Fig. 7

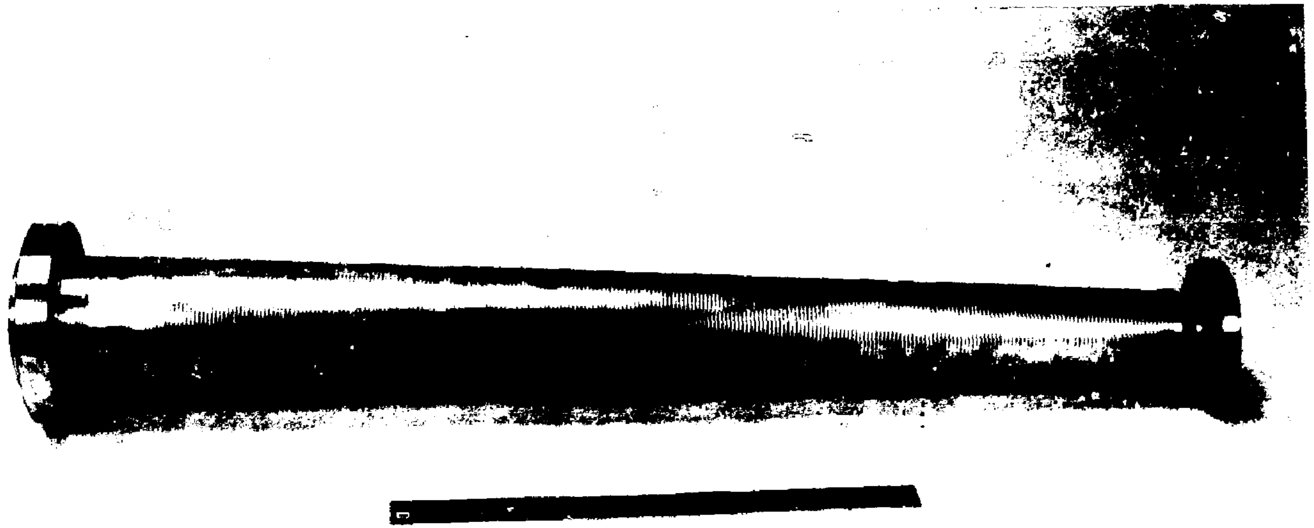

Fig. 8

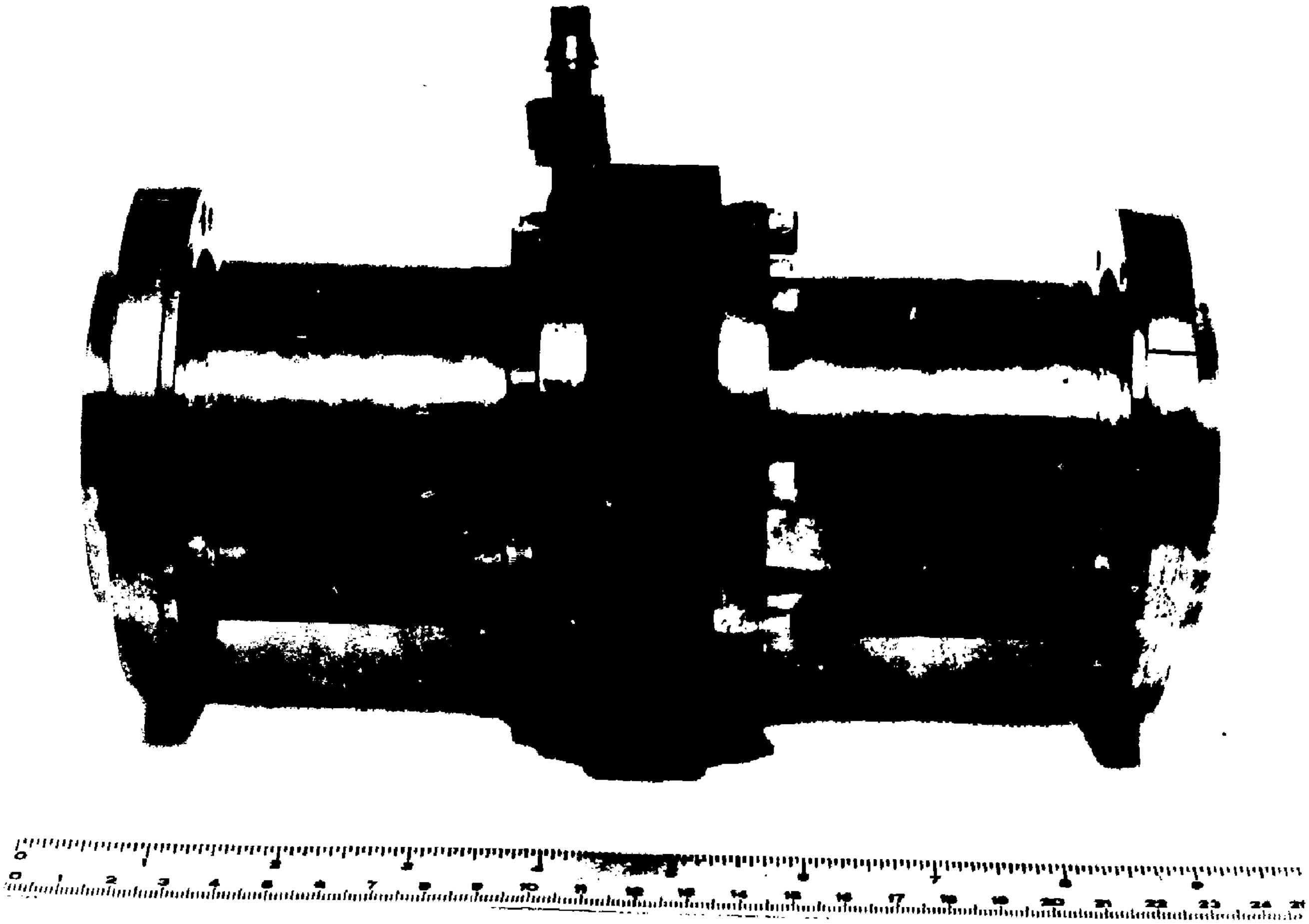

Fig. 9

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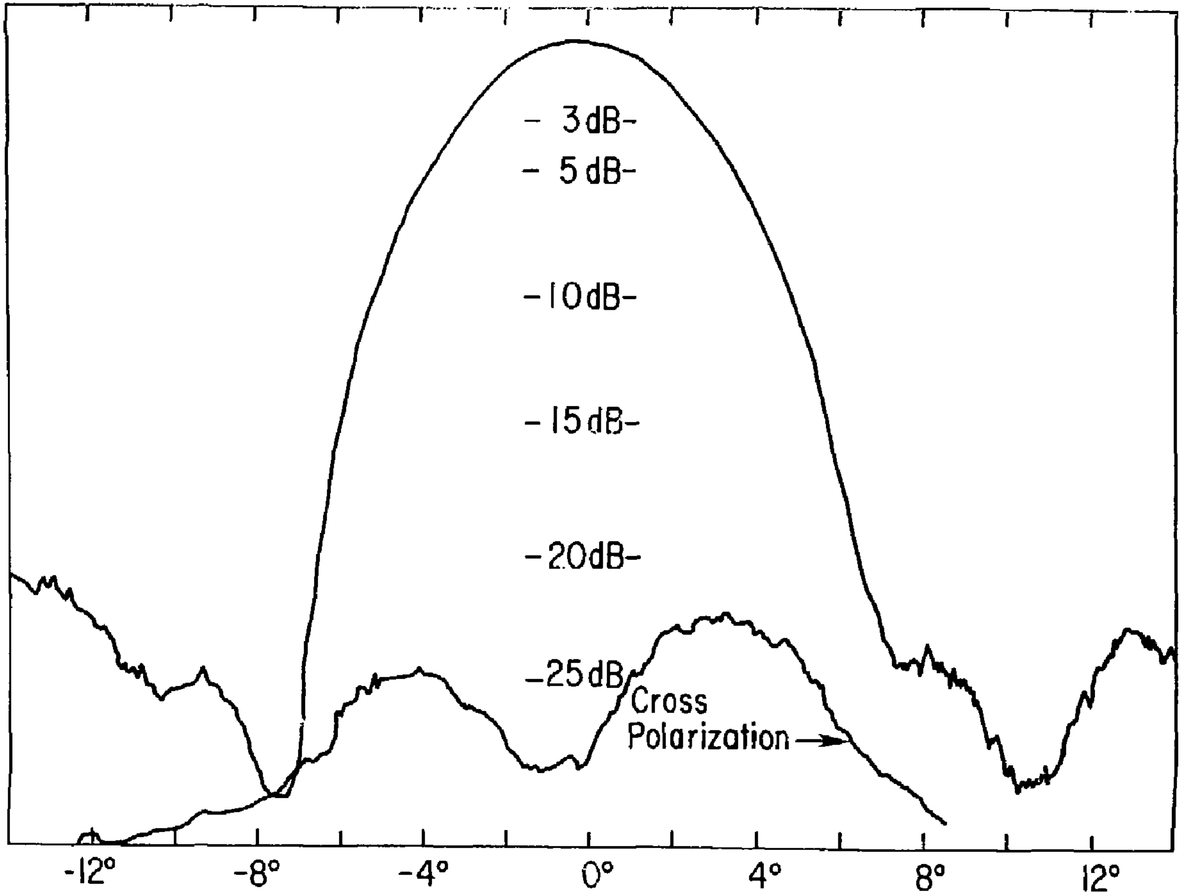

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