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Title: Notes on Right-Angle-Mitre Bends for Standard Rectangular Waveguide

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Notes on Right-Angle-Mitre Bends for Standard Rectangular Waveguide

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The return loss of a mitre bend is optimized by canceling the junction's higher order mode reactance over the desired frequency band. See Figure 1 for a sketch of a mitre comprised of two abrupt bends with a common inner corner discontinuity. Attempts to improve the match by varying the distance between two abrupt bends will have a greater frequency sensitivity than the simple mitered corner depicted. This is a result of the finite waveguide dispersion and the increase in discontinuity separation. In principle, the match can be improved by increasing the number of discontinuities in the mitre junction (see for example, Reisdorf (1976)). Due to the sensitivity of the junction's response to relatively small dimensional errors, this increase in manufacturing complexity is unlikely to be commensurate with the performance improvement for compact high frequency bends.

We examine the return loss for several E and H-plane right-angle-single-mitered bends [1]. For an E-plane bend, the normalized mirror position is

$$b_n \equiv \frac{b'}{b} = \frac{1}{\sqrt{2}}\left(1 + \frac{d_o}{b}\right). \tag{1}$$

where b is the guide height, b' is the mitre-wall-to-right-corner displacement, and d_o is the mitre offset. The normalized mirror position for a H-plane bend, $a_n \equiv a'/a$, is similarly defined in terms of the guide broad-wall width a. The results of the calculations are given in Figures 2 and 3. For convenience, the data is presented for the commonly used $a : b = 2.0 : 1$ and $2.5 : 1$ rectangular waveguide as a function of f/f_c, where f is the signal frequency, and $f_c = c/2a$ is the cutoff frequency. The E-plane bend data can be scaled to other guide aspect ratios by noting that in the single mode limit, the response can be expressed as function of

$$x_E \equiv \frac{2b}{\lambda_g} = \frac{b}{a}\sqrt{\left(\frac{f}{f_c}\right)^2 - 1}. \tag{2}$$

where λ_g is the TE_{10} guide wavelength. The H-plane bend response can be expressed as a function of $x_H \equiv 2a/\lambda_g$, thus, its single mode performance is essentially independent of the guide aspect ratio. See Table 1 for a summary of the computed bend performance. The E-plane bend geometries studied have good return loss down to the guide cutoff frequency. Viewing the E-plane bend data in light of Equation 2 indicates that the match and bandwidth can be improved by using reduced

[1]The Hewlett Packard High Frequency Structure Simulator (HFSS) was used to model the test bends. This finite element analysis algorithm typically requires eight adaptive passes at $1.6 f_c$ for a ~ 0.005 uncertainty in the calculated scattering matric elements. A lossless junction is assumed in the simulations. The 90° mitre bends, $b_n \approx 0.86$ and $a_n \approx 0.93$, described in Harvey (1963) were used in specifying the initial E and H-plane bend geometries.

height guide; however, this tightens the required fabrication tolerance. The single mitre H-plane bend has a narrow band match. Note the strong TE_{20} mode conversion near $f/f_c \approx 2$ displayed in Figure 3.

Mitre bends were manufactured in WR42 ($a : b = 2.471 : 1$) by electroforming for test. As indicated in Figure 1, a stainless steel dowel with outer diameter D was used to specify the distance between the dowel and the bend mirror position.

$$\Delta = b' + \frac{1}{2}\left(1 - \sqrt{2}\right) D. \tag{3}$$

A typical sample of the data measured on a HP8510C is given in Figure 4. The noise floor of the TRL (Thru-Reflect-Line) waveguide calibration test set employed is less than −45 dB across the measurement band.

TABLE 1
RIGHT MITRE BEND PERFORMANCE

Bend	Guide Aspect $[a : b]$	Normalized Mirror Position	Fullband VSWR
E-Plane	$2.000 : 1$	$b_n = 0.869 \pm 0.010$	$< 1.12 : 1$
	$2.471 : 1$	$b_n = 0.848 \pm 0.005$	$< 1.05 : 1$
H-Plane	$2.000 : 1$	$a_n = 0.960 \pm 0.016$	$< 1.3 : 1$
	$2.471 : 1$	$a_n = 0.960 \pm 0.016$	$< 1.3 : 1$

A fractional bandwidth of $\Delta\nu/\nu \approx 0.375$ ($1.2f_c$ to $1.9f_c$) is used in estimating the VSWR. The dimensional sensitivity observed in the simulations indicates that component yield will drop for WR10 waveguide and smaller if one assumes a $\pm 5\,\mu$m (± 0.0002 inches) mirror position tolerance is held during fabrication. Deviations in the mitre discontinuity symmetry $< 1°$ are desired for near optimal cancelation of the evanescent mode reactance. An adiabatic H-plane bend is preferred for broadband applications over the compact mitre designs investigated here.

The following references are recommended for practical information regarding design and fabrication of waveguide bends:

[1] Harvey, A.F., 'Microwave Engineering,' 1963, Academic Press, New York, pp. 76–78.

[2] Lewin, L., 'Propagation in Curved and Twisted Waveguides of Rectangular Cross Section,' 1955, *Proc. IEE*, vol. 102, pp. 75–80 (constant curvature adiabatic bends).

[3] Marcuvitz, N., 'Waveguide Handbook,' 1986, Peregrinus, London, pp. 312–322, 333–335.

[4] Ragan, G.L., 'Microwave Transmission Circuits,' 1948, McGraw Hill, New York, p. 207.

[5] Reisdorf, F., 'Analysis and Design of Broadband-Matched Multi-Stage Angle Bends in Rectangular Waveguides,' 1976, *Frequenz*, vol. 30, no. 5, pp. 126–131.

[6] Wray, D. and Hastie, R.A., 'Waveguide Bend,' 1960, *Electronic Technol.*, vol. 37, pp. 76–83 (binomial weight stepped bends, Gaussian curvature adiabatic bends).

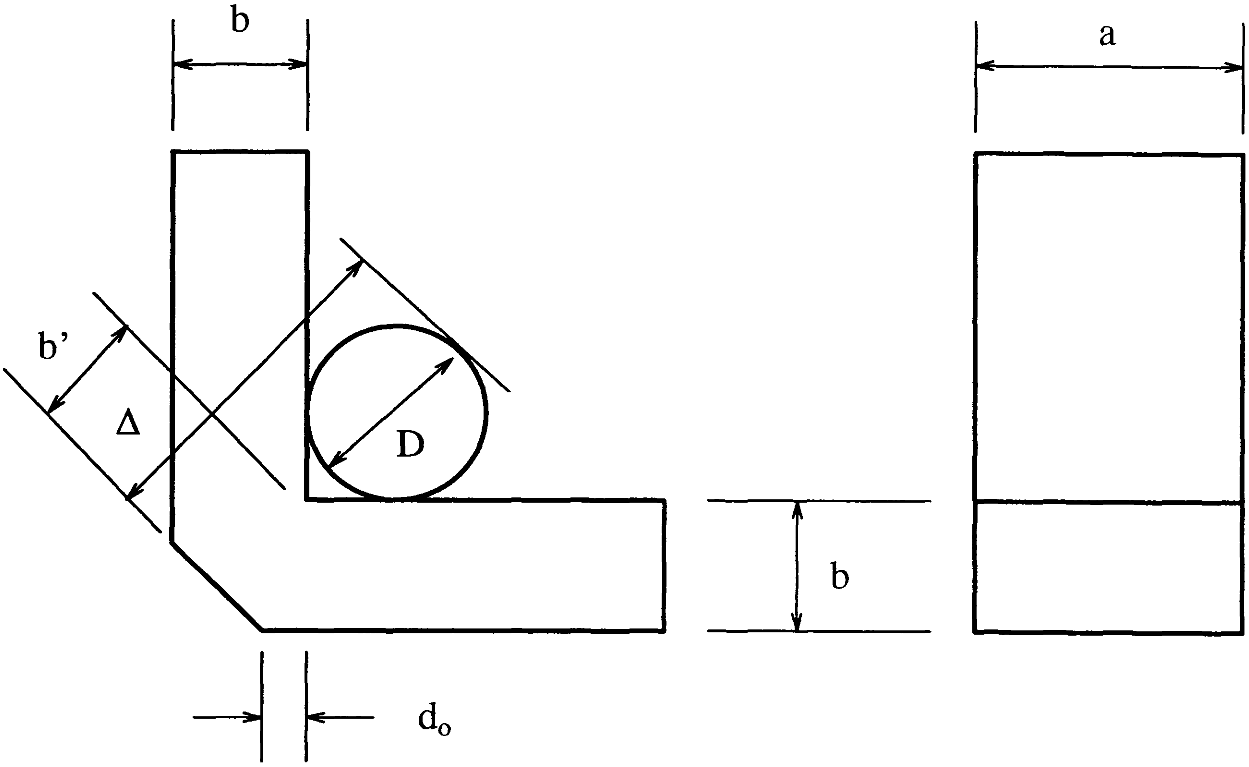

Figure 1. Right-Angle E-Plane Mitre Bend Geometry.

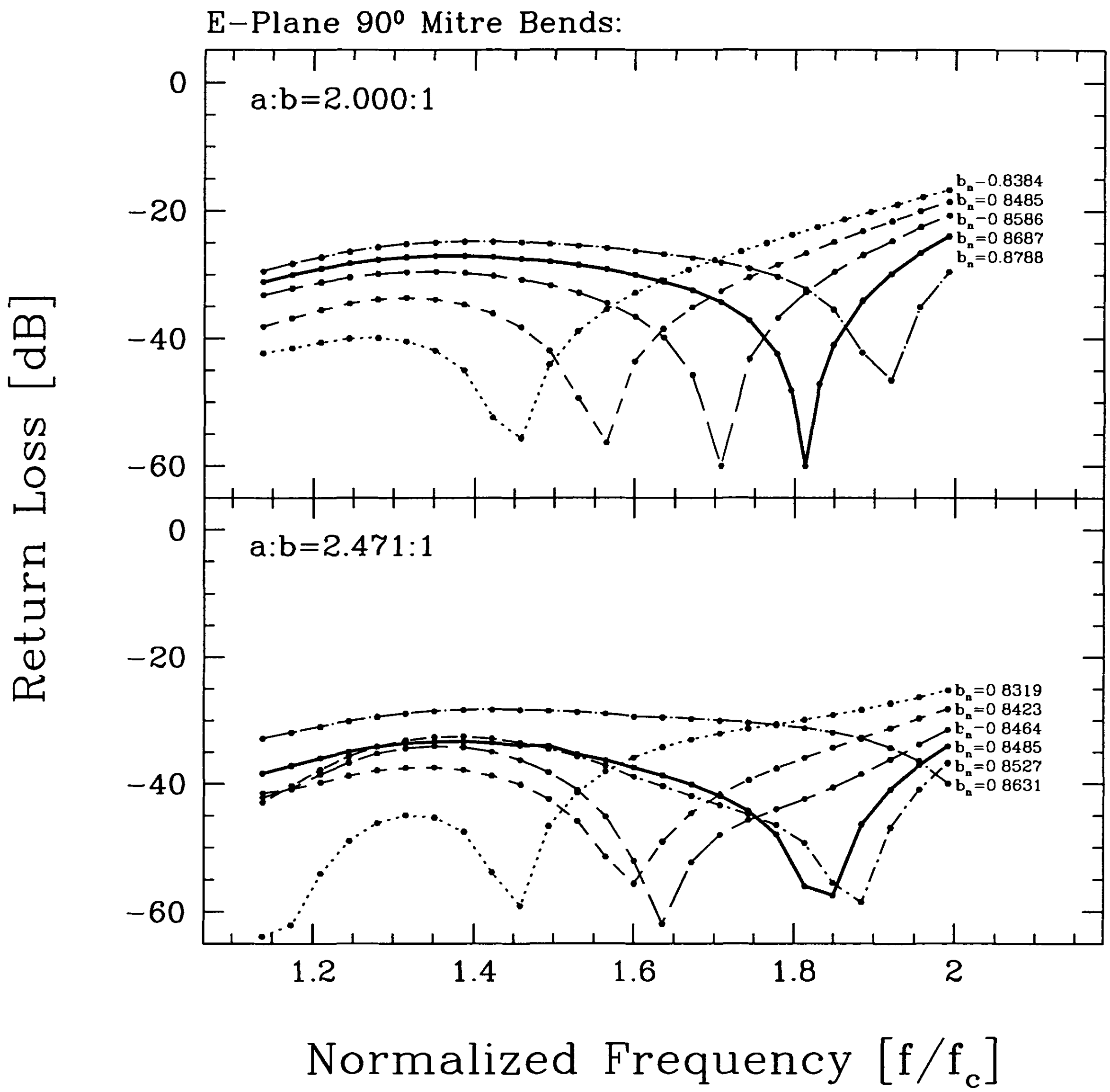

Figure 2. Calculated Right-Angle E-Plane Mitre Bend Return Loss.

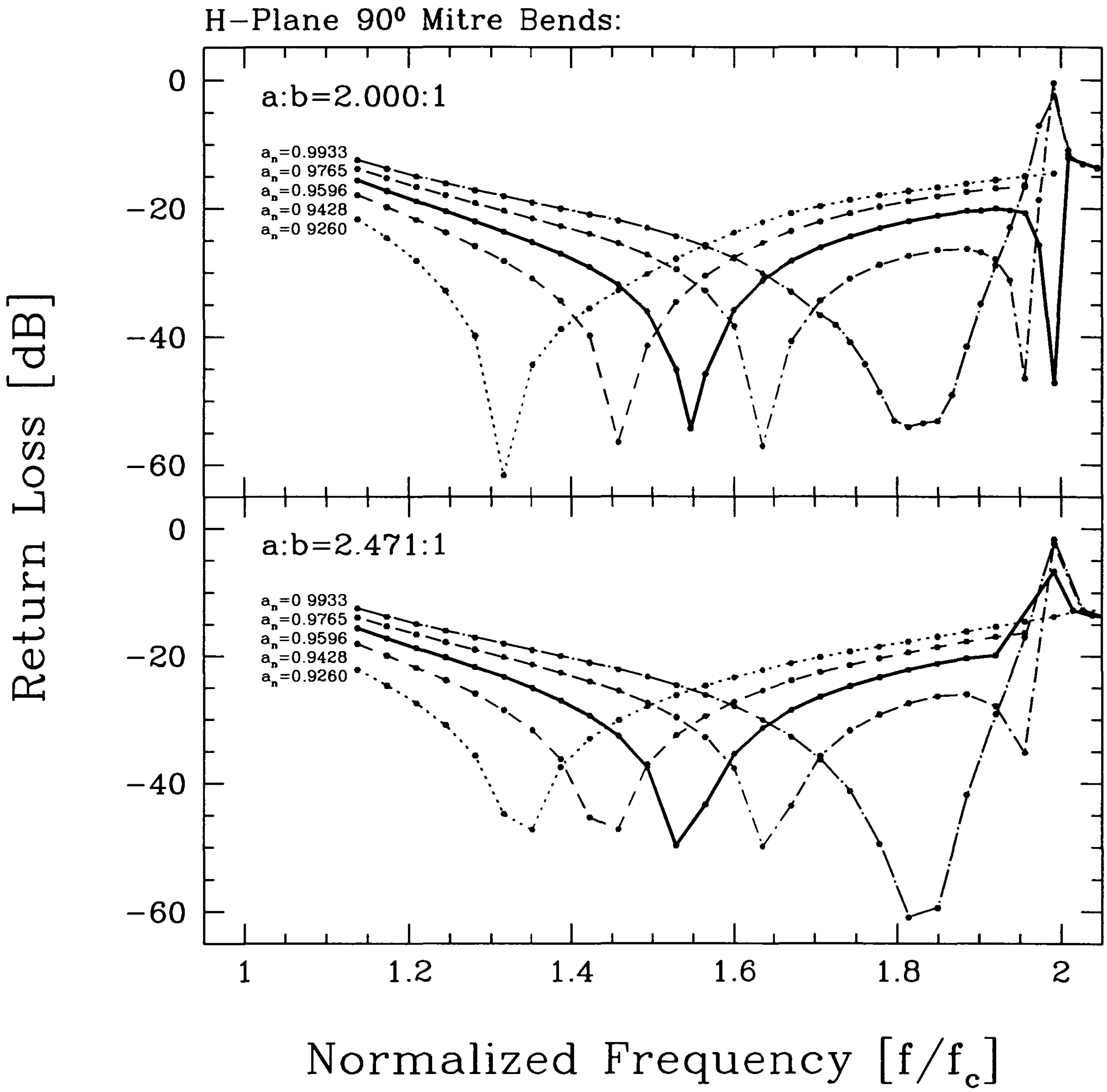

Figure 3. Calculated Right-Angle H-Plane Mitre Bend Return Loss.

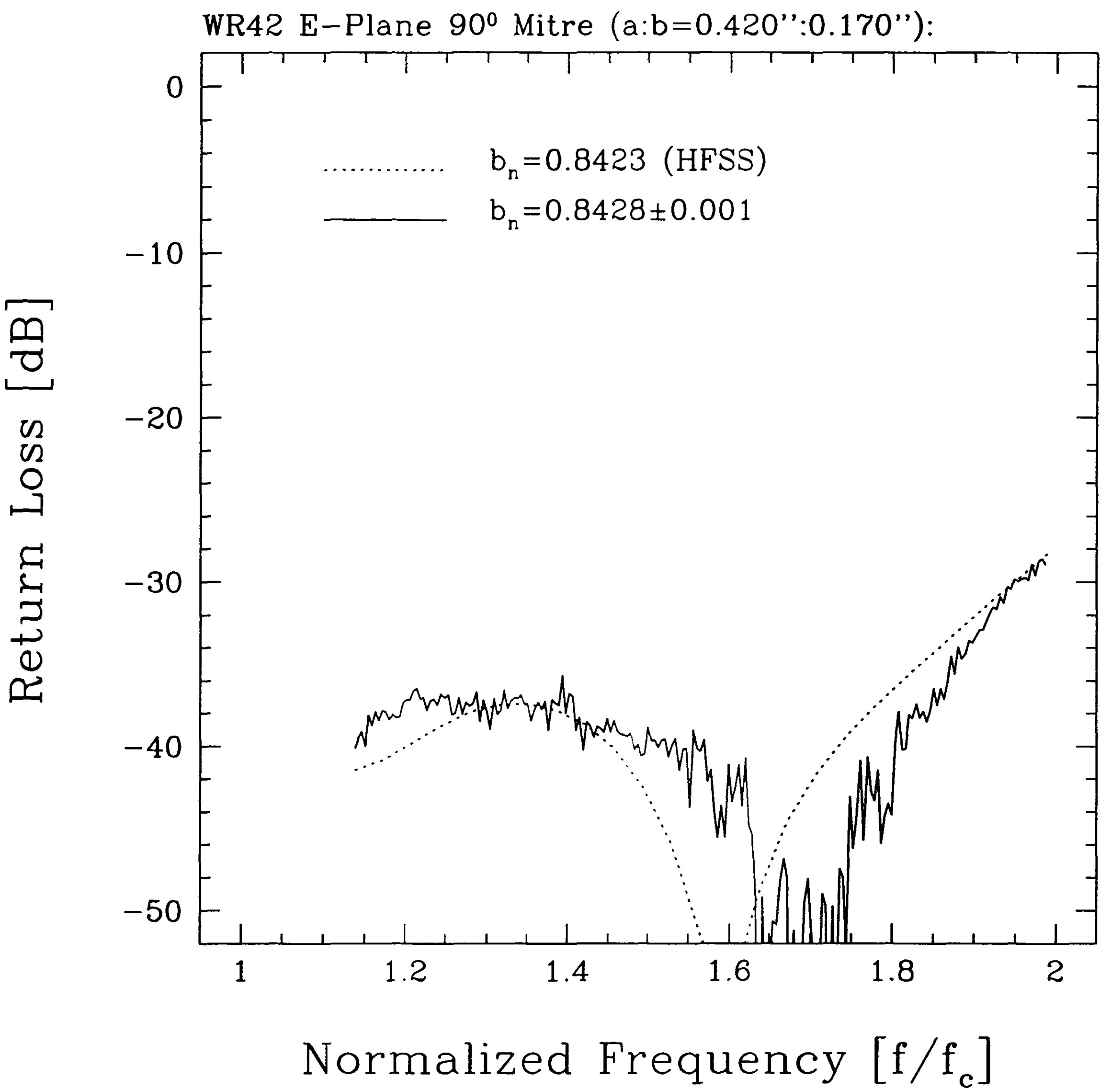

Figure 4. Measured Return Loss for a K-Band E-Plane Mitre Bend.