A TRANSITION TO NON-RADIATING DIELECTRIC WAVEGUIDE.

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Abstract

A transition between standard X-band waveguide and Non-radiating Dielectric (NRD) waveguide is descri= bed. It features an impedance taper from air-to-dielectric-filled waveguide cascaded with an impe= dance taper and mode converter to NRD. In both cases the taper shape and length are obtained through a theoretical calculation. The main proper= ty of the transition is a low reflection coefficient so that conventional waveguide equipment can be used for measurements in NRD waveguide.

INTRODUCTION

The Non-Radiating Dielectric Waveguide (NRD) has be= come increasingly more popular as more applications are being developed [1]-[4]. In order to enable the use of conventional waveguide equipment for measurements in NRD waveguide, high-quality transi= tions between NRD and standard waveguide are essen= tial. This paper describes the development of such a transition, to match standard X-band wave= guide (22.86x10.16mm) to NRD with a plate separa= tion of 15.00 mm and dielectric with $\varepsilon_r = 2.55$ (Polypenco Q200.5 cross-linked polystyrene) of di= mensions 15.00x10.16 mm. The design is based on an analytical procedure rather than an empirical method as described in [5].

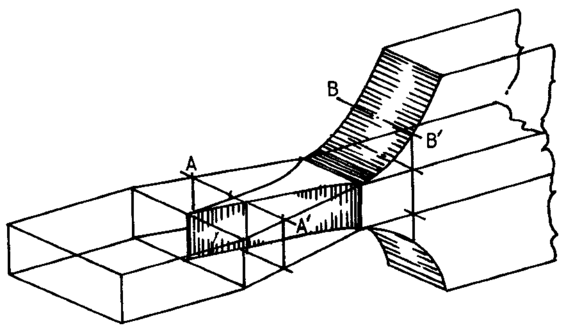

Fig 1. Composite Transition

The transition comprises two sections as shown in Fig 1; one is an impedance taper from air-to di= electric-filled metal-walled waveguide. At all cross sections along the taper, this guide is as shown in Fig 2(a). The second section transforms from the reduced-width waveguide of 15.00x10.16 mm to NRD with 15.00 mm plate separation. Its cross section is shown in Fig 2(b) where the height, c, is a va= riable, and width, a, is constant.

In the section that follows, the properties of both types of non-homogeneous guide will be briefly des= cribed. For each, it will be indicated that a taper can be designed that matches the guide properties at the extremities of each section, while performing the necessary mode conversion. Measured results will be described in conclusion.

TRANSITION FROM AIR-TO DIELECTRIC-FILLED WAVEGUIDE

A typical cross section of this transition is shown in Fig 2(a). It consists of a linearly tapered metal waveguide of width c, partially filled with a dielectric of varying width a. It can be shown [6]

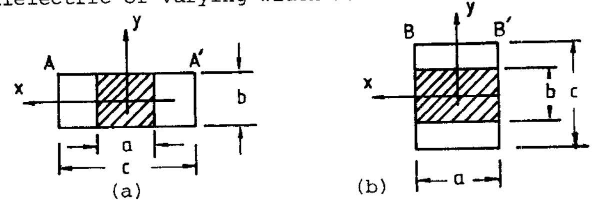

Fig 2. Non-homogeneous Cross Section

that the fields in the dielectric-filled region are given by (with $exp\ (-j\beta_g z)$ suppressed in all cases),

$$E_{x_1} \equiv 0 \tag{1}$$

$$E_{y_1} = -j\omega \cos(\beta_{x_1} x) \tag{2}$$

$$E_{z_1} \equiv 0 \tag{3}$$

$$H_{x_1} = -\frac{j\beta_y}{\mu}\cos(\beta_{x_1} x) \tag{4}$$

$$H_{y_1} \equiv 0 \tag{5}$$

$$H_{z_1} = -\frac{\beta_{x_1}}{\mu}\sin(\beta_{x_1} x) \tag{6}$$

For the air-filled region,

$$E_{x_2} \equiv 0 \tag{7}$$

$$E_{y_2} = -j\omega K_1 \sin(\beta_{x_2}[a/2-x]) \tag{8}$$

$$E_{z_2} \equiv 0 \tag{9}$$

$$H_{x_2} = -j\omega K_1 \frac{\beta_g}{\mu}\sin(\beta_{x_2}[a/2-x]) \tag{10}$$

$$H_{y_2} \equiv 0 \tag{11}$$

$$H_{z_2} = -K_1\frac{\beta_{x_2}}{\mu}\cos(\beta_{x_2}[a/2-x]) \tag{12}$$

where

$$K_1 = \cos(\beta_{x_1} c/2)\csc(\beta_{x_2}[a/2-c/2]) \tag{13}$$

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and

$$\beta_{x_1} \tan(\beta_{x_1} c/2) = \beta_{x_2} \cot(\beta_{x_2} [a/2-c/2]) \qquad (14)$$

The transition tapers between values c_1 = 22.86mm, b = 10.16 mm and a_1 = 0, and c_2 = 15.0mm,, b = 10.16 mm, a_2 = 15.0 mm. For ease of manufacturing,

$$c(z) = c_1+(c_2-c_1)z/\ell \qquad (15)$$

The equations (1) to (12) above indicate that a TE_{10} mode exists in the entire region. The dielectric must therefore have sides parallel to the metal walls. Hecken's impedance function [7] was selec= ted for the calculation of the varying dielectric width, while the wave impedance was chosen as the appropriate impedance for calculations [8]. The material used as dielectric was Polypenco Q200.5 cross-linked polystyrene with ε_r = 2.55 and the start ($z = 0$) and end ($z = \ell$) parameters of the transition are shown in Table I.

TABLE I. WAVEGUIDE PARAMETERS AT EXTREMITIES OF TAPER

Position	$z = 0$	$z = \ell$
Wave Impedance Z	550.4Ω	372.0Ω
Guide wavelength λ_g	48.70 mm	32.92 mm
Cutoff frequency f_c	6.56 GHz	6.65 GHz

The wave impedance and guide wavelength is computed from

$$Z = 376.7 \ \lambda_g/\lambda \qquad (16)$$

$$\lambda_g = \lambda \ [1 - (\beta_{x_1}/k_0)^2]^{-\frac{1}{2}} \qquad (17)$$

where k_0 is the free space wave number, and β_{x_1} is found by numerically solving simultaneously equation (14) and

$$\beta_{x_2}^2 = \beta_{x_1}^2 - (\varepsilon_r-1)k_0^2 \qquad (18)$$

The impedance function described by Hecken is for a TEM structure, where the variation of impedance, $Z(\zeta)$ is calculated for *equispaced* points ζ; in this instance, because the guide wavelength varies as $Z(z)$ varies, the function $Z(\zeta)$ for equispaced points ζ is converted to points equispaced *electrically*. The total taper length was chosen as ℓ = 40mm; the impedance values calculated are shown in Table II.

TABLE II IMPEDANCES FOR -25dB HECKEN TAPER
B = 3.2136 ($\beta\ell_{min}$) = 4.1046

ζ	-1.0	-0.8	-0.6	-0.4	-0.2	0.0
$Z(\zeta)$	550.4	541.5	526.3	504.9	497.3	452.3
ζ	0.2	0.4	0.6	0.8	1.0	
$Z(\zeta)$	426.9	405.2	388.8	377.8	372.0	

An iterative procedure was used with the impedance points equispaced as a starting value, and the guide wavelengths calculated. The spacing was ad= justed and the process repeated until the points were electrically equisdistant. Fig 3(a) shows the resulting taper to scale.

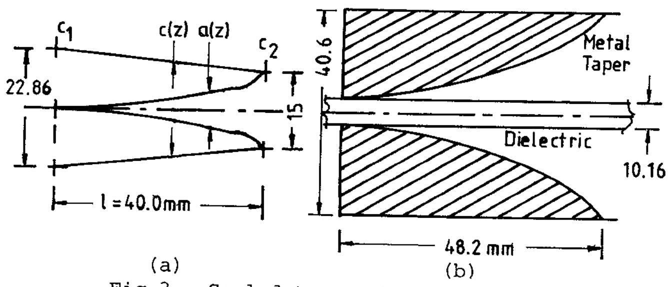

Fig 3. Scaled taper shapes

TRANSITION FROM DIELECTRIC-FILLED WAVEGUIDE TO NRD

The cross section of this part of the transition is shown in Fig 2(b). The dielectric dimensions are kept constant at a = 15.0 mm and b = 10.15mm, while the height is varied from c_1 = 15.0 mm at z = 0, to infinity. In practice the NRD waveguide was made 40 mm high. The fields in this transitional region are given by [6], inside the dielectric,

$$E_{x_1} = \frac{(\pi/a)\beta_y}{j\omega\mu_0\varepsilon_0\varepsilon_r} \sin\left(\frac{\pi x}{a}\right) \sin(\beta_y y) \qquad (19)$$

$$E_{y_1} = \frac{(k^2-\beta_y^2)}{j\ \omega\mu_0\varepsilon_0} \cos\left(\frac{\pi x}{a}\right) \cos(\beta_y y) \qquad (20)$$

$$E_{z_1} = \frac{\beta_g\beta_y}{\omega\mu_0\varepsilon_0\varepsilon_r} \cos\left(\frac{\pi x}{a}\right) \sin(\beta_y y) \qquad (21)$$

$$H_{x_1} = \frac{j\beta_g}{\mu_0} \cos\left(\frac{\pi x}{a}\right) \cos(\beta_y y) \qquad (22)$$

$$H_{y_1} \equiv 0 \qquad (23)$$

$$H_{z_1} = -\frac{(\pi/a)}{\mu_0} \sin\left(\frac{\pi x}{a}\right) \cos(\beta_y y) \qquad (24)$$

Note that $exp(-j\beta_g z)$ has again been suppressed. In the air-filled region,

$$E_{x_2} = K_2 \frac{(\pi/a)\nu_y}{j\omega\mu_0\varepsilon_0} \sin(\pi x/a)\sinh[(c/2-y)\nu_y] \qquad (25)$$

$$E_{y_2} = K_2 \frac{(k^2+\nu_y^2)}{j\omega\mu_0\varepsilon_0} \cos(\pi x/a)\cosh[(c/2-y)\nu_y] \qquad (26)$$

$$E_{z_2} = K_2 \frac{\beta_g\nu_y}{\omega\mu_0\varepsilon_0} \cos(\pi x/a)\sinh[(c/2-y)\nu_y] \qquad (27)$$

$$H_{x_2} = jK_2 \frac{\beta_g}{\mu_0} \cos(\pi x/a)\cosh[(c/2-y)\nu_y] \qquad (28)$$

$$H_{y_2} \equiv 0 \qquad (29)$$

$$H_{z_2} = -K_2 \frac{(\pi/a)}{\mu_0} \sin(\pi x/a)\cosh[(c/2-y)\nu_y] \qquad (30)$$

where

$$K_2 = \cos(\beta_y \tfrac{b}{2})\mathrm{sech}[(c/2-b/2)\nu_y] \qquad (31)$$

and

$$\tan(\beta_y \frac{b}{2})\coth[c/2-b/2)\nu_y] = \frac{\varepsilon_r \nu_y}{y} \qquad (32)$$

The inherent mismatch of this section is 11.3dB, so that a Hecken impedance taper was designed to give an improvement of 30 dB. A similar procedure to that described in the previous paragraph was followed, useing $(\beta\ell_{min}) = 4.7533$; 20 equal parts of electrical length were used and the scaled taper is shown in Fig 3(b).

Note that the limiting form of equations (19)-(32) above is, for $c = b$, a TE_{10}-mode in a dielectrically loaded waveguide. For $c \to \infty$, the equations describe the TM_y-mode of the NRD. Thus mode matching is simul= naneously achieved.

MEASUREMENTS

A back-to-back set of the first type of taper was manufactured, with 250 mm of reduced width guide separating the two transitions. Fig 4 shows the measured reflection coefficient with the output

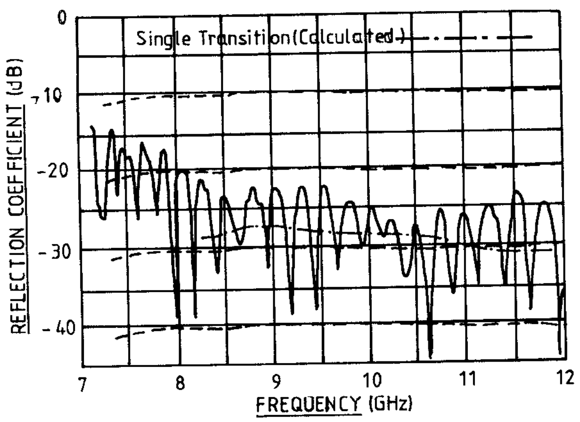

Fig 4. Measured performance of two back to back transisions between air- and dielectric-filled waveguide, separated by 250mm of di= electric filled guide.

transition terminated in a matched load. The oscillatory nature of the reflection coefficient is caused by the electrically varying length of line between the two transitions. The dotted line shows the calculated return loss of one transition; it is seen to be more than 27 dB over the useful fre= quency band of 8.5 to 10.5 GHz.

A complete transition was also manufactured. The NRD guide was terminated by laying two strips of Eccoshield FGM 40, each approximately 20 cm long and 15 mm wide on either side of the dielectric, with the leading edges of the absorber pulled away in the same shape as the launching taper. The mea= sured reflection coefficient is never worse than -19 dB above 9.5 GHz, and is shown in Fig 5.

CONCLUSION

The design of a transition between standard wave= guide and NRD has been described. The method is based on an analytical approach and the constructed model has shown excellent performance.

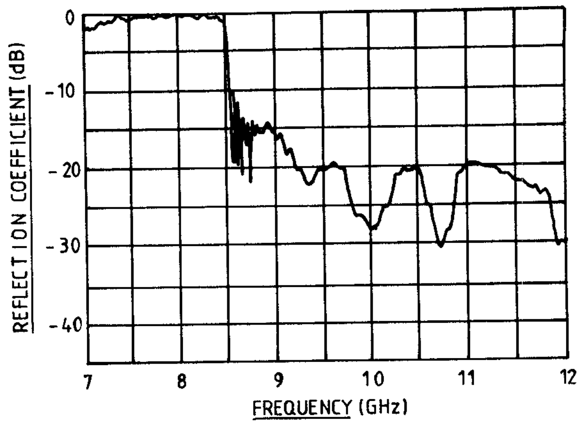

Fig 5. Measured performance of the composite tran= sition between standard waveguide and ter= minated NRD.

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