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QUARTER WAVE TRANSFORMERS FOR MATCHING TRANSITIONS BETWEEN WAVEGUIDES AND FIN LINES

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ABSTRACT

This paper presents closed-form expressions for the design of a quarter-wave transition-matching transformer. This structure takes the form of a notch or protrusion cut in the finline substrate at the waveguide-to-finline interface. Measurements show a 5 db improvement in return loss over a full waveguide band due to such a transformer.

INTRODUCTION

Broadband transitions between fin lines and commensurate waveguides are usually realized in the form of a tapered fin line section in which the gap between the fins is gradually widened to the full waveguide height. Even if reflections due to the taper are minimized, there will be residual reflection losses at the front of the substrate. This discontinuity can be considered as a step transition between an empty and a partially dielectric-loaded waveguide. Its effect can be considerably reduced by providing a quarter-wave transformer between the two transmission media in the form of either a rectangular notch or a protrusion as shown in Fig. 1.

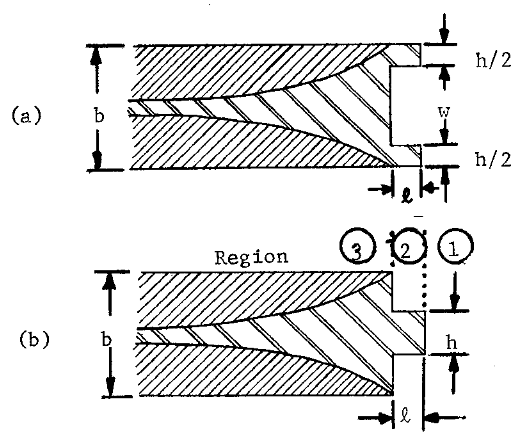

Fig. 1. Quarter-wave matching sections in the form of a notch (a) or a protrusion (b) cut in the substrate of a fin line taper.

In this paper closed-form expressions for the design of such transformers are derived, and measurements which demonstrate the validity of these formulae as well as the improvement in reflection loss are presented.

ANALYSIS

For analysis, the three regions identified in Fig. 1 are modelled by equivalent homogeneously filled waveguide sections having the same propagation characteristics as the real structures (Fig. 2). For this purpose, the following assumptions are made:

a) The taper is ideal, i.e. its input impedance is that of a matched slab-loaded waveguide.

b) The dielectrical loading is light, i.e. it does not significantly alter the field configuration in the guide. Thus, its effect can be evaluated using the theory of small perturbations.

c) The parasitic reactances due to fringing at the step discontinuities can be neglected. Higher order mode effects are insignificant.

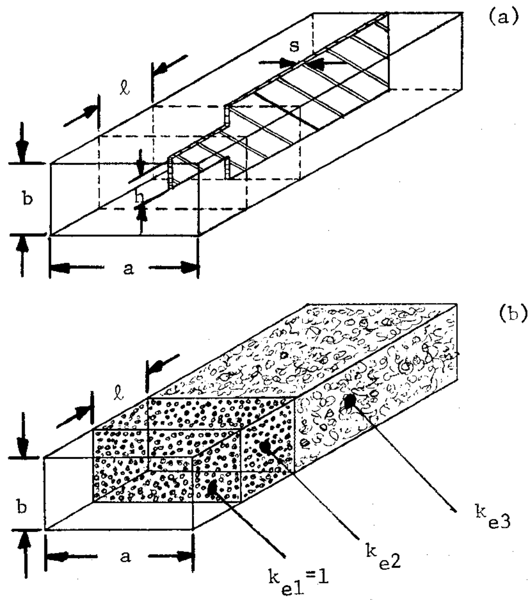

Fig. 2 Modeling of transformer section (a) Real structure, (b) Equivalent homogeneous waveguide model.

As a consequence, the dispersion in the loaded waveguide sections can be modelled by commensurate waveguides uniformly filled with fictitious dielectrics of equivalent permittivity, k_{e_i}. The theory of perturbations

yields the equivalent permittivities of sections 2 and 3, and their effective dielectric constant is obtained using the relation

$$\varepsilon_{eff_i} = k_{e_i} - (\lambda/2a))^2 \qquad (1)$$

where ε_{eff_i} is the effective dielectric constant of the i-th section ($\varepsilon_{eff}=[\lambda/\lambda_g]^2$), k_{e_i} is the equivalent permittivity of that section, and a is the broad side of the waveguide.

Assuming that the characteristic impedances of the three sections are inversely proportional to the square root of their respective effective dielectric constants, the condition for quarter-wave matching yields an expression for the height h of the protrusion (or the width w = b-h of the notch):

$$h = b-w = \frac{(\sqrt{k_{e2}} - 1)\ a \cdot b}{\sqrt{k_{e2}}\ (\varepsilon_r - 1) \cdot s} \qquad (2)$$

with

$$k_{e2} = p^2 + [(1 - p^2)(k_{e3} - p^2)]^{1/2} \qquad (3)$$

where $$k_{e3} = [1 - (\varepsilon_r - 1)\ s/a]^{-2} \qquad (4)$$

and $$p = \lambda/(2a) \qquad (5)$$

The length ℓ of the protrusion (or the depth of the notch) is

$$\ell = \frac{\lambda}{4}\ [k_{e2} - p^2]^{-1/2} \qquad (6)$$

where k_{e2} and p are also given by (3) through (5).

In these expressions, a and b are the inner waveguide dimensions, s and ε_r are the thickness and the relative dielectric constant of the substrate respectively, and λ is the free space wavelength.

EXPERIMENTAL VERIFICATION

In order to verify the developed design theory, return loss measurements were made on several back-to-back transitions between waveguide and slab-loaded waveguide, as well as fin line tapers. A computer-controlled automatic network analysis was used to obtain the results presented in this paper.

Measurements on Slab-Loaded Waveguides

Quarter-wave transformers between empty waveguide and full height dielectric slab-loaded waveguide were cut in the form of both a notch and a protrusion.

Fig. 3 shows the magnitude of the S_{11}-parameter of a back-to-back transition in WR-90 waveguide. The design frequency was 10 GHz, and the substrate was 0.03 in. thick RT/duroid 5880 (ε_r=2.22). These curves are shown against the S_{11}-curve of an unmatched section of slab-loaded waveguide. The improvement due to the transformers is significant over the whole X-band even though the design is strictly accurate at one frequency only.

Fig. 4 shows the return loss of a similar structure in WR-42 waveguide. The design frequency was 20.5 GHz, and the substrate was 0.01 in. thick RT/duroid 5880 (ε_r = 2.22). The transformers yield an improvement of at least 5 dB over the whole K-band.

Measurements on Finline Back-to-Back Tapers

Back-to-back parabolic tapers in a unilateral finline configuration were measured for return loss over the 15 to 26.5 GHz range. Protrusions were provided symmetrically, as well as asymmetrically, at both ends of a 5 in. long, 0.010 in. thick RT/duroid substrate, mounted in a WR-42 split block housing. The fin spacing was 0.085 in. As Fig. 5 shows, a typical return loss of -38 dB has been achieved near the 20.5 GHz design frequency for a symmetrical notch. The improvement in return loss is at least 6 dB over the unmatched transition, in the entire K-band. The asymmetric protrusion yields a similar improvement in return loss indicating the possibility of using a matching transformer for a single fin configuration. The reference curve is the return loss, of an unmatched symmetrical fin line taper.

CONCLUSION

Quarter-wave transformers in the form of notches or protrusions in the substrate of fin line tapers have been designed using perturbation theory. Measurements indicate that such transformers improve the return loss of back-to-back tapered sections by at least 5 dB over a full waveguide band. The closed-form expressions for the transformer dimensions are well suited for computer-aided design.

ACKNOWLEDGEMENT

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REFERENCES

1. R.F. Harrington, "Time-Harmonic Electromagnetic Fields", McGraw-Hill Book Company, 1961.

2. R.E. Collin, J. Brown, "The Design of Quarter-wave Matching Layers for Dielectric Surfaces", IEE, 1955.

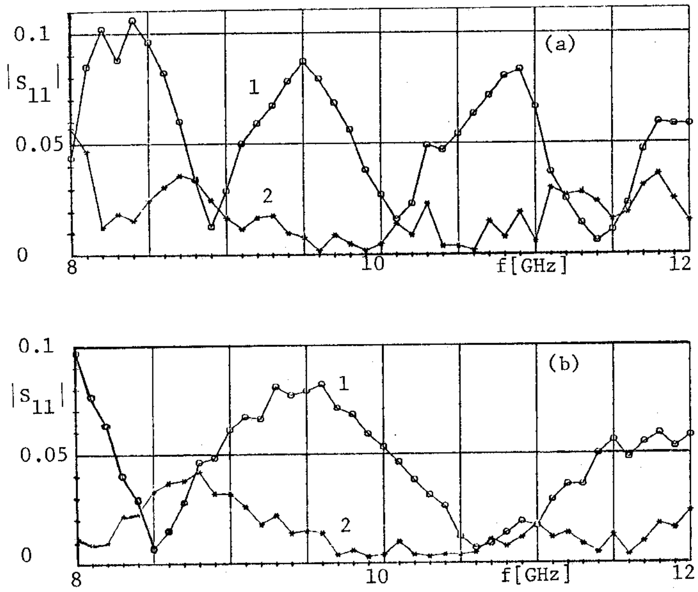

Fig.3-Magnitude of the S_{11}-parameters of unmatched (1) and matched (2) sections of slab-loaded waveguide. (a) Protrusion (b) Notch

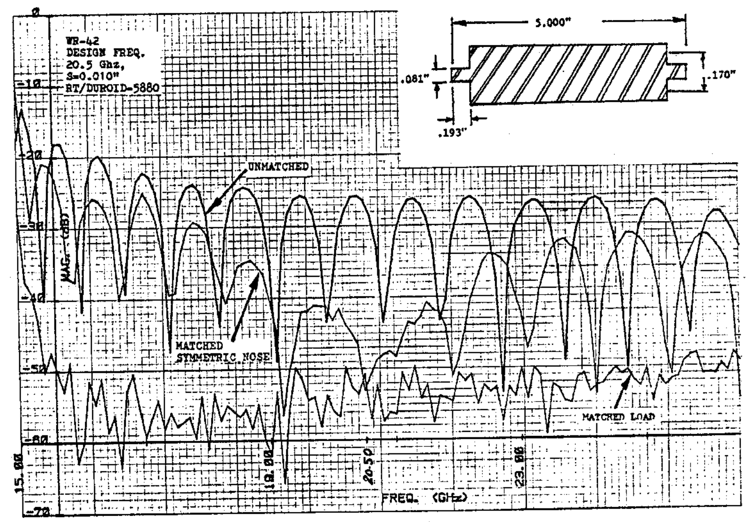

Fig.4-Return loss of unmatched and matched sections of slab-loaded waveguide in K-band.

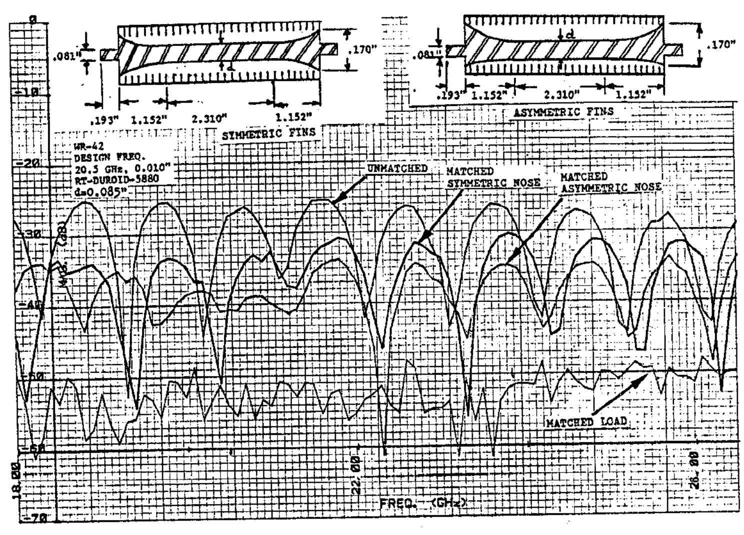

Fig.5-Return loss of unmatched and matched back-to-back fin line tapers.