Wide-Band Waveguide-to-Microstrip Transition and Power Divider

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Abstract—**A waveguide-to-microstrip transition is proposed, modeled, and validated through a prototypical design. The transition is shown to possess characteristics required in many high-frequency systems, namely wide-band response, ease of construction and hermetic isolation of the two transmission media. Implementation in a waveguide-to-microstrip power divider (three-port) form is detailed here, but other feasible variants are mentioned. Favorable agreement between the proposed model and measured results is observed.**

I. Introduction

Transfer of microwave signals between different transmission media is required in many modern antenna systems. The microstrip-to-waveguide transition (MWT) is encountered in planar antenna feed systems as a connection between the radiating antenna surface and the signal-processing circuitry. Among the desirable characteristics of such transitions are large bandwidth, ease of construction, and hermetic isolation between layers. A number of designs for the MWT have been proposed in the past. Among the pertinent references are the ones by Das *et al.* [1], Grabherr *et al.* [2], and Stones [8]. In each case, the basic configuration features a microstrip line coupled to a waveguide through a slot aperture in its ground plate, the waveguide's axis being perpendicular to the plane of the substrate. Theory presented in [1] predicted a narrow, resonant frequency band for which complete power transfer should occur. No experimental validation was reported, and the results could not be confirmed theoretically by this author. In [2] a matching patch element is introduced into the guide at a pre-determined distance from the aperture. The design is shown to work well over a band width of $\approx$10%. Manufacturing and assembly of this transition appears to require a number of high-precision steps. A MWT/Combiner described in [8] was also limited to a bandwidth of $\approx$13%.

A modified, low-insertion-loss transition is proposed. A simple, "one-term" analysis is carried out to keep the model computationally tractable, yet accurate enough for design. The transition is shown to operate well over almost the entire waveguide band.

A brief description of the model is outlined in Section I. The assumptions are presented and discussed. In Section II an X-band MWT design is described and a set of comparison of measured data with the results calculated using the model is presented.

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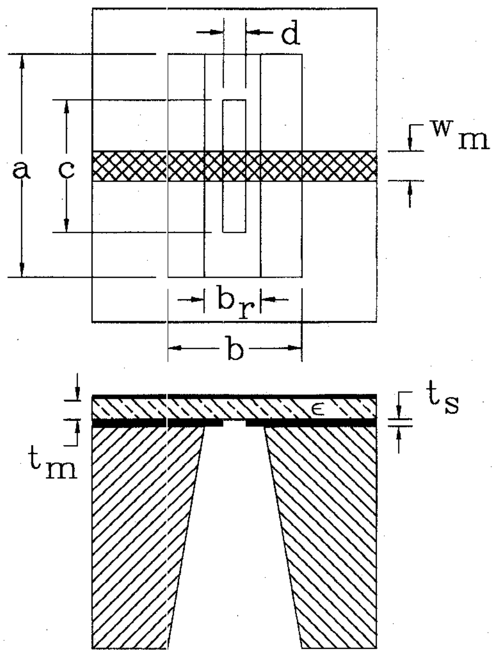

Fig. 1. Waveguide-to-microstrip power divider geometry.

II. Model Description

The proposed transition is depicted in Fig. 1. The key feature is the tapered section of waveguide, feeding the aperture in the microstrip ground. Such a taper provides the match between the high impedance of the standard guide and the relatively low impedance associated with the reduced-height waveguide (RHW). Decreased impedance at the slot leads to wide-banded performance. A relevant intuitive analysis was carried out for a waveguide T-junction by Montgomery and Dicke [3]. The model presented here takes into account the transition starting at the RHW feeding the slot. The effects of the taper on the design are excluded; investigations of such tapers can be found elsewhere [5]. Moreover, low-insertion-loss tapers are commercially available.

Consider the coupling region between the microstrip and the RHW. Recently a portion of this configuration was modeled in [4]. The presence of a cross-section discontinuity from the RHW to the slot requires modification of the previous analysis and introduction of additional impedances into the equivalent circuit model presented in [4]. An appropriate equivalent circuit model of the transition under consideration is shown in Fig. 2. The origin values of the various elements and impedances, as well as the assumptions made in the derivations of their values, are given in the sequel or in

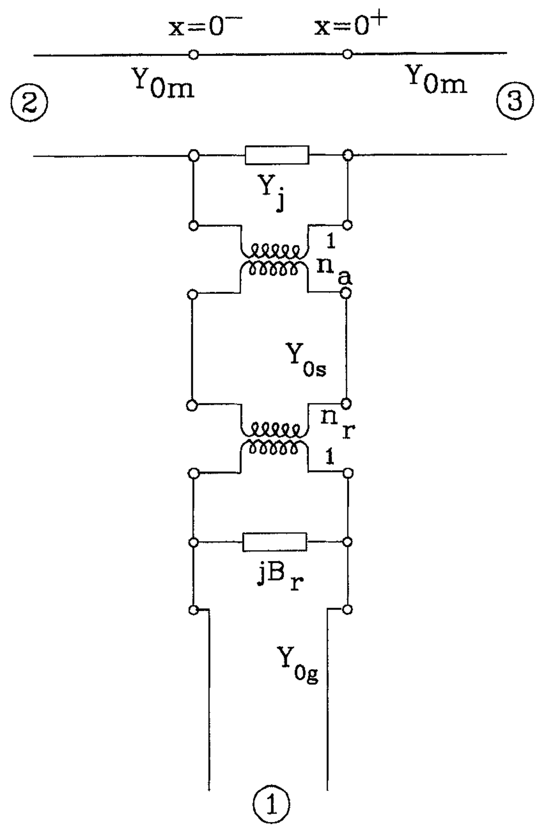

Fig. 2. Equivalent-circuit representation for the waveguide-to-microstrip power divider.

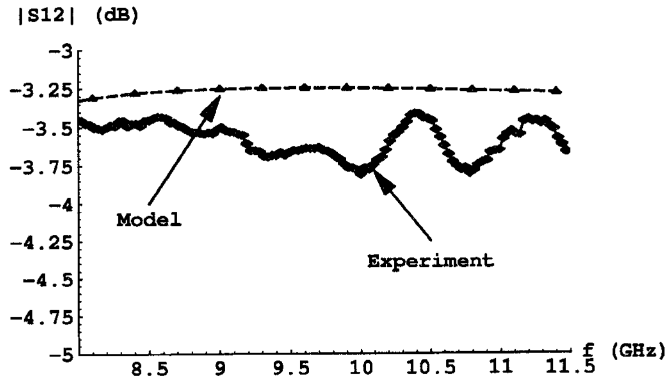

Fig. 3. Frequency dependence of the input-to-output power transfer. (Port 1 is the input waveguide; port 2 is one of the microstrip outputs.)

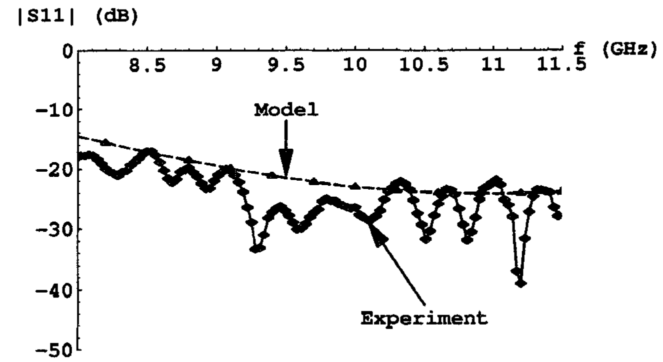

Fig. 4. Frequency dependence of the input return-loss power transfer. (Port 1 is the input waveguide.)

referenced publications:

- Y_{0m} is the characteristic admittance of the microstrip line.
- Y_{0s}, Y_{0g} are, respectively, the TE_{10} modal admittance of the rectangular waveguide associated with the slot in the thick (t_s) ground plate of the microstrip line, and the the RHW feed.
- Y_j, n_a are the equivalent circuit parameters for the slot-to-microstrip junction. These parameters were derived and discussed in [4].
- B_r, n_r are the equivalent circuit parameters for the step reduction in cross section from the RHW to the slot waveguide. The values of these quantities were derived using standard variational formulas with one-term aperture-field approximation [5].

An ABCD representation of the equivalent circuit and straightforward analysis yield the formulas for the scattering parameters of interest.

III. X-Band Prototype

The model descriptively outlined in the preceding section was used to design a prototypical waveguide-to-microstrip 3-dB power divider (WMPD), such as would be used to excite a corporate microstrip array feed-network. The microstrip line was etched on a 1oz copper-clad Rogers Duroid 5880 substrate, with $\epsilon_r = 2.2 \pm 0.015$, $t_m = 31\,\text{mils} \pm 1$, and $t_s = 1.34\,\text{mils}$. The line width w_m was set at 97 mils, corresponding to a 50 Ω characteristic impedance. The ground-plane aperture dimensions were $c = 750\,\text{mils}$ and $d = 60\,\text{mils}$. The X-band waveguide was tapered from the standard $a = 900\,\text{mils}$, $b = 400\,\text{mils}$ cross section, to one with $a = 900\,\text{mils}$, $b_r = 100\,\text{mils}$, over a length of 6 in.

A separate estimate of power dissipation in the waveguide taper structure was obtained by connecting two identical (within manufacturing tolerances) tapered sections at the reduced-height ends and measuring (after a TRL calibration) the insertion and return losses. Based on this measurement, the insertion loss for a single tapered section was determined to be between 0.1 and 0.15 dB in the 7.5–12.5 GHz range.

The WMPD was characterized as a three-port device, using a method requiring calibration and measurements at the two microstrip ports only [8]. The complete three-port scattering matrix is extracted from three sets of measurements made at the two microstrip ports with the waveguide port terminated in three well-characterized standards. In this particular case a short, an offset short, and a waveguide load were used. To remove the effects of SMA-to-microstrip connectors, a TRL calibration procedure was carried out. Due to experimental constraints, a PC board with lines of appropriate lengths was used in lieu of in-fixture calibration standards. It should be noted that such a procedure requires different SMA connectors for each calibration standard, and hence it is not expected to be as accurate as its in-fixture counterpart. A fuller discussion of the distinctions of the various calibration approaches can be found in [6].

The most important performance characteristics of the WMPD are presented in Figs. 3 and 4. The frequency response of the power transfer between ports 1 (input) and 2 (output) presented in Fig. 3 indicates that on the average it is around 0.5 dB over a very wide frequency range. To provide for a more direct comparison, 0.1 dB has been subtracted from the theoretical (model) trace to account for the taper losses. Power transfer between ports 1 and 3 exhibits similar characteristics, and the corresponding plot is not included. The return loss (Fig. 4) at the waveguide port is greater than 15 dB. The comparison between the theoretical model, and the measured data is favorable. The observed discrepancies can be attributed to two major sources. One is the low-order (one-mode) approximation of aperture fields, and neglect of higher-order (nonTEM) fields on the microstrip line; the other is the result of choosing a nonrigorous calibration procedure. The effects of the latter manifest themselves as oscillations in the measured traces.

Finally, it should be noted that power transfer from waveguide to a single microstrip port can be accomplished using the same principle. In that case, one of the power divider's microstrip ports would be terminated in a reflective (open- or short-circuit) stub of appropriate length. Moreover, the ground-plane aperture size, and thereby the associated radiative loss, can be reduced by using a dielectric-loaded feed waveguide and a pyramid-shaped dielectric compensator in the waveguide taper.

REFERENCES

[1] B. N. Das, K. V. S. V. R. Prasad, and K. V. S. Rao, "Excitation of waveguide by stripline- and microstrip-line-fed slots," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-34, no. 3, Mar. 1986.

[2] W. Grabherr, B. Hudder, and W. Menzel, "Microstrip-to-waveguide transition compatible with mm-wave circuits," *IEEE Trans. Microwave Theory Tech.*, vol. 42, no. 9, Sept. 1994.

[3] C. G. Montgomery *et al.*, Eds., *Principles of Microwave Circuits.* New York: McGraw-Hill, 1948, vol. 8, Radiation Lab. Series.

[4] M. Davidovitz, R. A. Sainati, and S. J. Fraasch, "A non-contact interconnection through an electrically thick ground plate common to two microstrip lines," *IEEE Trans. Microwave Theory Tech.*, vol. 43, no. 4, Apr. 1995.

[5] L. Lewin, *Advanced Theory of Waveguides.* London: Iliffe and Sons, 1951.

[6] *Network Analysis*, Hewlett-Packard Product Note 8510-8A.

[7] M. Davidovitz, "Reconstruction of the S-matrix for a 3-port using measurements at two ports only," *IEEE Microwave and Guided Wave Lett.*, vol. 5, no. 10, pp. 349–350, Oct. 1995.

[8] D. I. Stones, "Analysis and design of a novel microstrip-to-waveguide transition/combiner," in *1994 IEEE MTT-Symp. Dig.*, 1994, pp. 217–220.