# Waveguide-to-Microstrip Power Splitter

by

Y.-S. Wu, M. V. Schneider and R. Trambarulo
AT&T Bell Laboratories
Holmdel, New Jersey 07733

ABSTRACT

We describe a novel coupling structure which permits both power combining and division. The structure divides power equally from a rectangular waveguide to two microstrip lines. The microstrips are T-shaped conductor patterns placed symmetrically in the waveguide. The splitter has a return loss of better than 20 dB from 3.3-4.6 GHz measured at the waveguide port.' The power difference between the two microstrip output ports is less than 0.1 dB. The coupler is useful for power combining at microwave and millimeter-wavelengths with minimal power loss.

## I. INTRODUCTION

For certain applications such as amplifier arrays, a change from waveguide to microstrip circuits is required [1]. In the present paper a waveguide-to-microstrip power divider will be described. This divider splits the microwave signal entering the waveguide port equally into two microstrip output ports. Two T-shaped probes couple the microwave signal from the waveguide to each of the two microstrip ports. This structure is more compact than conventional couplers.

Figure 1 shows the structure of the waveguide to microstrip power divider. The drawing on the left is a side view which illustrates that the microwave signal arriving from the left is coupled to two T antennas on a dielectric substrate. Behind the alumina substrate is a sliding short that is adjusted to tune out the probe reactances. The drawing on the right shows the front view of the power divider which consists of two T-shaped coupling antenna patterns on an alumina substrate. The two output ports, marked port 2 and port 3, are standard coaxial connectors.

The design of the power divider relies on symmetry of the divider. The divider has a plane of symmetry along the dotted line shown in Fig. 1. Since the E field is normal to the symmetry plane, which is an electric wall, a metal plate can be inserted without changing the field distribution. Furthermore, the incoming microwave energy is split evenly above and below the symmetry plane. Because of this property, the design of the double T can be simplified to that of a single T shown in Fig. 2. Notice that the waveguide height in Fig. 2 is only half that of Fig. 1. Thus each T has to match to half the impedance of the original full-height waveguide.

The scattering matrix for the double T is derived in Figure 3 and is described by:

$$S = \begin{bmatrix} 0 & 1/\sqrt{2} & -1/\sqrt{2} \\ 1/\sqrt{2} & 1/2 & 1/2 \\ -1/\sqrt{2} & 1/2 & 1/2 \end{bmatrix} \qquad (1)$$

## II. THEORY OF T-BAR WAVEGUIDE TO MICROSTRIP TRANSITION

Referring to Figure 2, the T-bar antenna has a total width $2w$ and a height $h$, and its current distribution can be described by

$$\vec{J}_y = \vec{a}_y\, J_0 \sin k_0(h+w-y') \qquad y' < h \text{ and} \qquad (2a)$$

$$\vec{J}_x = \vec{a}_x \frac{J_0}{2} \sin k_0 \left[ w - \left( \frac{a}{2} - x' \right) \right] \qquad y' = h \text{ and } x' < \frac{a}{2} \qquad (2b)$$

$$\vec{J}_x = \vec{a}_x \frac{J_0}{2} \sin k_0 \left[ w - \left( x' - \frac{a}{2} \right) \right] \qquad y' = h \text{ and } x' > \frac{a}{2} \qquad (2c)$$

It is important to point out that the $\vec{J}_y$ component excites the $TE_{nm}$ modes inside the waveguide while the $\vec{J}_x$ component excites the $TM_{nm}$ mode.

The radiation resistance $R_{10}$, of a T-bar antenna inside a waveguide is found by using the dyadic Green's Function techniques [2], where we use for convenience the abbreviation $\rho = \pi r/a$

$$R_{10} = \frac{2Z_0}{ab\beta_{10}k_0} \frac{\left\{ \cos(k_0 w) - \cos[k_0(h+w)] \right\}^2}{\sin^2 k_0(h+w)}$$

$$\times \sin^2(\beta_{10}\ell) \sin^2\rho/\rho^2 \qquad (3)$$

## III. DESIGN OF THE DOUBLE-T POWER DIVIDER

The design goal is to select a T-bar structure such that its radiation impedance is matched to the 50 ohm coaxial load. Based on Equation (3), Fig. 4 shows the calculated T radiation resistance for two reduced-height WR-229 waveguides. The dimensions for T are half-width $w_1 = 0.480$ inch, height and $h_1 = 0.165$ inch for $b_1 = 0.200$ inch; and $w_2 = 0.600$ inch, $h_2 = 0.190$ inch for $b_2 = 0.300$ inch. As shown in the figure, the output resistance is very close (within 2 ohm) to 50 ohm from 3.6 to 4.6 GHz for both waveguide heights.

It is important to point out that all the calculations so far assume that there is no dielectric substrate in the waveguide. If the T is patterned on a dielectric substrate such as alumina, its dimensions will be shrunk by a factor of $\sqrt{\epsilon_{eff}}$, where $\epsilon_{eff}$ is the effective dielectric constant [3]. The thickness of the alumina substrate is 0.050" which is a small fraction of a wavelength.

It is difficult to calculate the effective dielectric constants of the suspended stripline structure shown in Figure 1b, [4]-[7] since the alumina substrate (width $w_a$ = 1 inch) only occupies $1/2.29 = 43.7\%$ of the total waveguide width. Nevertheless, Smith [8] has studied the case of a fully filled (i.e. $w_a = a$) suspended stripline inside waveguide. Based on Smith's work, one can obtain some idea about the effective dielectric constants.

Figure 5 shows the T effective dielectric constants calculated using Smith's paper [8]. As shown in Figure 5A, the horizontal effective dielectric constant is calculated to be $\epsilon_{eff} = 4.524$ which will shrink the effective T width by more than 50 percent. Figure 5B demonstrates that the vertical effective dielectric constant is calculated to be $\epsilon_{eff} = 2.196$ which will shrink the T height by about 33 percent.

Table 1 is a comparison between calculated and actual T dimensions for two different heights of WR-229 waveguides. Notice that the T widths and heights after being modified by their respective effective dielectric constants are very close to their real final dimensions. The fact that the final dimensions are slightly larger than the modified dimensions is understandable. Since the alumina substrate does not occupy the entire waveguide width as shown in Fig. 5, the observed effective dielectric constants are slightly less than those given in Fig. 5.

A simple equivalent circuit of the T in the waveguide is a series resonant circuit driven from a microstrip line with the radiation resistance of the waveguide as the load. Inductance of the resonant circuit is provided by the leg of the T, and the cross bar is the resonating capacitor. The waveguide short is approximately a quarter guide wavelength from the T at the frequency band center which is an open circuit in the plane of the T. Its function is to assure radiation into only one branch of the waveguide.

## *IV. EXPERIMENTAL RESULTS OF THE DOUBLE-T POWER DIVIDER*

Figure 6 is a photograph of the C-band waveguide to microstrip double-T power divider whose optimized dimensions are shown in the drawing on the left. The waveguide used here is WR-229 with width $a = 2.29$ inch and height $b = 0.600$ inch. The microstrip is made of 0.062 inch wide copper on a 0.050 inch thick alumina substrate. As shown in the picture, the size of the alumina substrate is 1.000×2.000 inch, and two 50 ohm coaxial loads are connected to the top and bottom microstrip output ports for termination. The sliding short, which is barely visible, is 0.810 inch behind the alumina substrate.

Figure 7 are two photographs showing the measured (A) reflection and (B) transmission of the C-band double-T waveguide-to-microstrip power divider. As shown in picture (A), the input return loss is almost 20 dB from 3.3 to 4.6 GHz. This result indicates that the double-T power divider can be operated over a bandwidth of more than 30%. The lower picture (B) shows a 3-dB transmission loss from waveguide to microstrip port #3 with a similar loss to port #2.

## *V. CONCLUSION*

We describe a novel coupling structure which permits both power combining and division required for building amplifier arrays. The structure divides power equally from a rectangular waveguide to two microstrip lines. The microstrips are T-shaped conductor patterns placed symmetrically in the waveguide. The bandwidth of the splitter has a return loss better than 20 dB from 3.3-4.6 GHz measured at the waveguide port. The power difference between the two microstrip output ports is less than 0.1 dB with very low loss in the structure.

## *VI. ACKNOWLEDGMENTS*

The authors are indebted to Robert Wilson for constructive comments. We also would like to thank Erwin Muller for his critical review of the manuscript We are also indebted to Harry Lenzing and William Ahlborn for their assistance in the experiments.

## REFERENCES

[1] B. Glance and R. Trambarulo, "A Waveguide to Suspended Stripline Transition," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-21, pp. 117-118, 1973.

[2] R. E. Collin, "Field Theory of Guided Waves", New York, McGraw Hill Book Company, 1960.

[3] T. Q. Ho and Y. C. Shih, "Analysis of Microstrip Lines to Waveguide End Launchers", IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-36, No. 3, pp. 561-567, March 1988.

[4] E. Yamashita and K. Atsuki, "Stripline with Rectangular Outer Conductor and Three Dielectric Layers", IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-18, No. 5, pp. 238-244, May 1970.

[5] S. B. Cohn and G. D. Osterhues, "A More Accurate Model of the $TE_{10}$ Type Waveguide Mode in Suspended Substrate," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-30, No. 3, pp. 293-296, March 1982.

[6] M. D. Deshpande, B. N. Das and G. S. Sanyal, "Analysis of an End Launcher for an X-Band Rectangular Waveguide", IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-27, pp. 731-735, August 1979.

[7] T. Itoh and R. Mittra, "A Technique for Computing Dispersion Characteristics of Shielded Microstrip Lines," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-22, pp. 896-898, Oct. 1974.

[8] J. I. Smith, "The Even- and Odd-Mode Capacitance Parameters for Coupled Lines in Suspended Substrate", IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-19, No. 5, pp. 424-431, May 1971.

TABLE 1. COMPARISON BETWEEN CALCULATED AND EXPERIMENTAL T DIMENSIONS

| WR-229 WAVEGUIDE HEIGHT (INCH) | CALCULATED T WIDTH (Free Space) | T WIDTH MODIFIED BY $\epsilon_H = 4.524$ | REAL T WIDTH (INCH) | CALCULATED T HEIGHT (Free Space) | T HEIGHT MODIFIED BY $\epsilon_v = 2.196$ | REAL T HEIGHT |
|---|---|---|---|---|---|---|
| 0.200 | 0.960 | 0.451 | 0.480 | 0.165 | 0.111 | 0.131 |
| 0.300 | 1.200 | 0.564 | 0.600 | 0.190 | 0.128 | 0.154 |

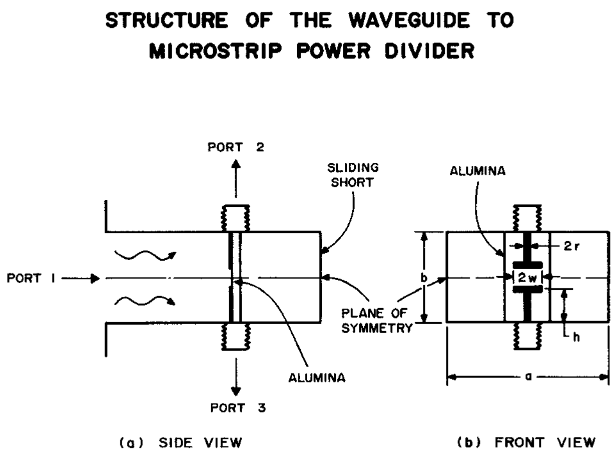


Fig. 1. Structure of the waveguide to microstrip power divider. The side view illustrates that the microwave signal is coupled to two T antennas on an alumina substrate. The front view of the power divider consists of two T-shaped coupling antennas.

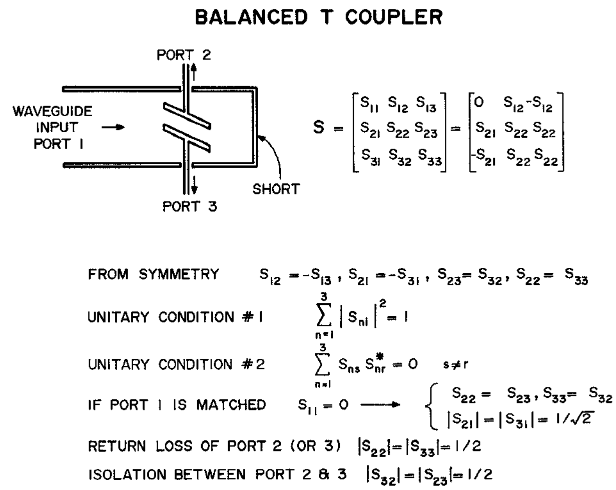


Fig. 3. Scattering parameters of lossless balanced T coupler are derived by using (A) symmetry property between port 2 and port 3 and (B) unitary conditions which come from the conservation of energy.

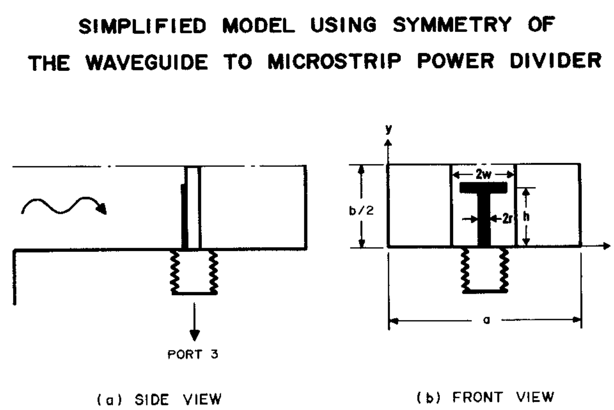


Fig. 2. Simplified model using symmetry of the waveguide to microstrip power divider. The plane of symmetry in Fig. 1 is an electric wall where a metal plate can be inserted without changing the field distribution. Thus the power divider problem is changed to the waveguide-to-microstrip transition design.

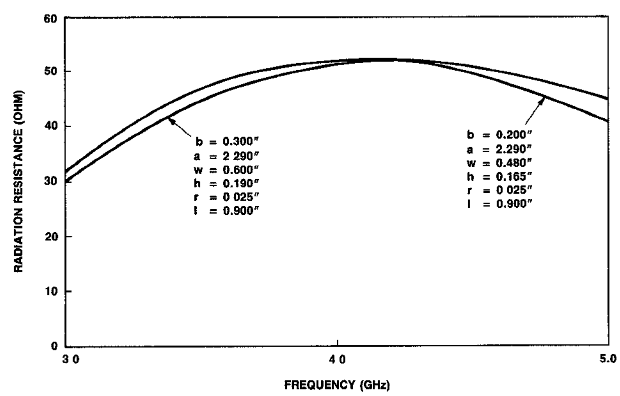


Fig. 4. Calculated radiation resistances for two T-bar transitions using WR-229 reduced-height waveguides. The first transition has a T-bar half-width $w_1 = 0.480$ inch, height $h_1 = 0.165$ inch, waveguide height $b_1 = 0.200$ inch. The second transition has a T-bar half-width $w_2 = 0.600$ inch, height $h_2 = 0.190$ inch, waveguide height $b_2 = 0.300$ inch.

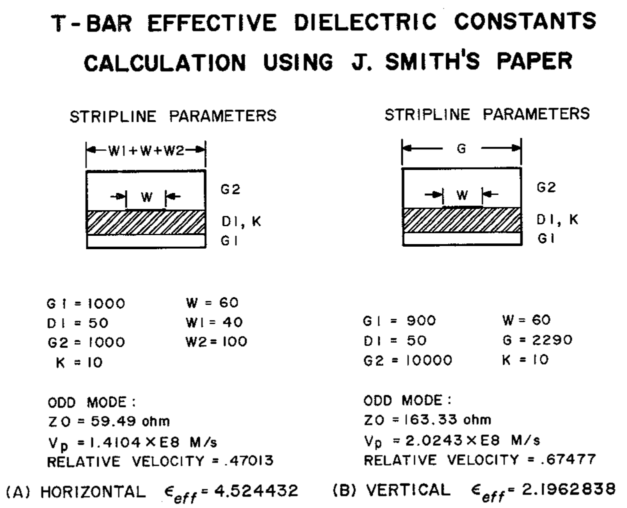


Fig. 5. T-bar effective dielectric constants calculation using Smith's paper. The T-bar can be considered as two suspended transmission lines: one horizontal cross bar and one vertical leg. Fig. 5A demonstrates that the horizontal cross bar has an impedance $Z_0 = 59.49$ ohm and effective dielectric constant $\epsilon_{eff} = 4.524$. Fig. 5B demonstrates that the vertical T-bar leg has an impedance $Z_0 = 163.33$ ohm and effective dielectric constant $\epsilon_{eff} = 2.196$.

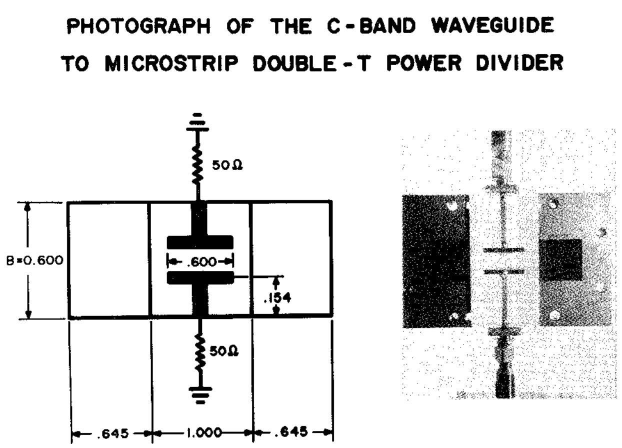


Fig. 6. Photograph of the c-band waveguide to microstrip double-T power divider whose optimized dimensions are shown in the left drawing. The size of the alumina substrate is 1.000×2.000×0.050 inch and two 50 ohm coaxial loads are connected to the top and bottom microstrip output ports for termination.

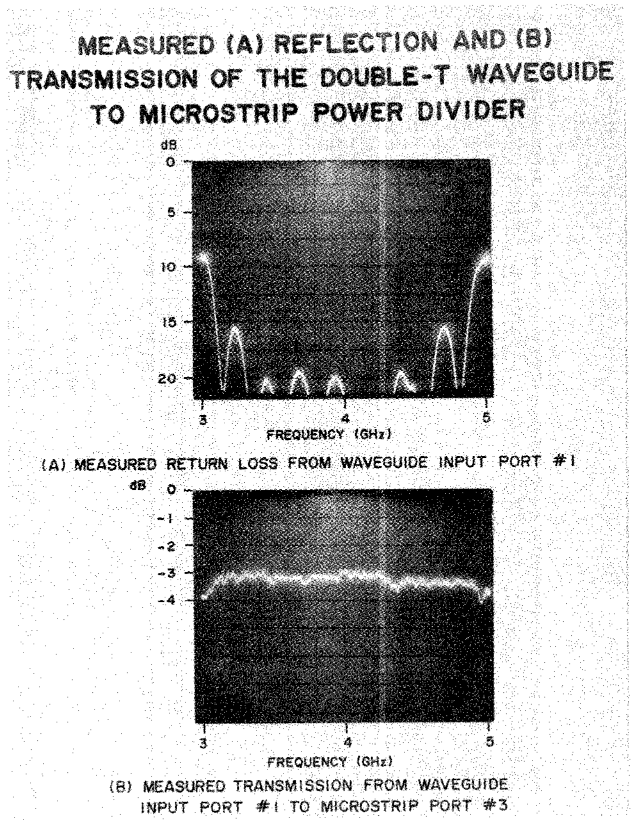


Fig. 7. Photographs showing the measured (A) reflection and (B) transmission of the c-band double-T waveguide-to-microstrip power divider. The input return loss is 20 dB from 3.3 to 4.6 GHz and 50/50 even power split is achieved over this band.