NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, VIRGINIA

ELECTRONICS DIVISION TECHNICAL NOTE NO. 181

Title: On the Compensation of E-Plane Bifrucations in Rectangular Waveguide

Authors: E. Wollack

Date: October 20, 1997

DISTRIBUTION:

GB
GB Library
G. Anderson
G. Behrens
E. Childers
R. Fisher
J. Ford
W. Grammar
R. Lacasse
R. Norrod
D. Parker
D. Pedtke
D. Schiebel
M.Stennes
T. Weadon
S. White

CV
ER Library
IR Library
M. Balister
N. Bailey
R. Bradley
C. Burgess
L. D'Addario
R. Escoffier
N. Horner
A. R. Kerr
S.- K. Pan
M. Pospieszalski
S. Srikanth
D. Thacker
A. R. Thompson
J. Webber
E. Wollack

TU
Library-Downtown
Library-Mountain
R. Freund
J. Payne
A. Perfetto
W. Shillue

VLA
AOC Library
L. Beno
W.Brundage
J. Campbell
C. Janes
R. Latasa
P. Lilie
P. Napier
P. Rhodes
R. Sramek
R. Weimer

On the Compensation of E-Plane Bifrucations in Rectangular Waveguide

E. Wollack
NRAO, Charlottesville, VA
October 20, 1997

In applications where power division into approximately equal magnitudes is desired, E-plane waveguide dividers are commonly employed. Examples include series Y-junctions, T-junctions, and septum power dividers. The principal advantages of the E-plane junction include: 1) With modern computer-aided design tools broad bandwidths are achievable without tuning. 2) High accuracy is realizable without multiple machine setups during fabrication. 3) Resultant structures are relatively low loss compared to counterparts realized as TEM structures.

The approach's principal weakness can be seen from the form of its scattering matrix. A lossless reciprocal three-port cannot present three matched ports simultaneously (see, *e.g.*, Montgomery *et al.*, 1948). If one desires to match port one, $S_{11} \cong 0$, ports two and three should be terminated into well-matched loads to avoid complications. The coupling between port one and port two or three in this limit is 3 dB, and the resultant isolation from ports two to three is 6 dB. [1] However, in practical diplexer, power splitter, and orthomode junction designs, this is typically not the limiting concern.

Consider the three-port in Figure 1 in the limit $\alpha_1 = \alpha_2 = 0$. An infinitely thin metallic sheet perpendicularly divides the input guide to achieve the desired power ratio, and the resulting guides can be transformed back to standard height waveguide adiabatically or in discrete steps. If the septum thickness is small compared to the guide height, insertion (or removal) of the septum does not adversely affect the field distribution of the dominant mode; it merely defines a junction symmetry plane.

In an attempt to generalize the physical insight gained from the septum power divider, we revisit early attempts to predict junction performance in the electrostatic approximation (*e.g.,* Marcuvitz, 1951; also see discussion of series T-junction symmetry in Montgomery,

---

[1] More generally, if the signal path is divided N times:

$$\text{Coupling}(\mathrm{m} \neq 1) = 10\log({S_{m1}}^2) \simeq 10\log N$$

$$\text{Isolation}(\mathrm{m}, \mathrm{n} \neq 1; \mathrm{m} \neq \mathrm{n}) = 10\log({S_{mn}}^2) \simeq 20\log N$$

et al. 1948, sections 12.14–12.16). We recall that the frequency sensitivity is minimized to the extent that the total stored energy is the same for all junction eigen-solutions. This would suggest the following design rules are desirable to achieve broad band response: 1) The dominant mode symmetry should be preserved by junction geometry. 2) The guide heights of the three ports are linked by the power division ratio ($R = b_1/b_2 \sim O(1)$) and the desire to minimize the frequency dependence of the junction discontinuities ($b_o \cong b_1 + b_2$). 3) The shaded region in Figure 1 is a perfect E-wall. Thus, any element which compensates a compact bend in the spirit of De Ronde (1966) can achieve the desired match by consideration of the junction symmetry under reflection and rotation.

A selection of examples is indicated in Figure 2 and Table 1. Mitre geometries for examples "A" through "F" were derived from the data presented in Reisdorf (1976) and analyzed. See Figure 3. The step compensation used in examples "G" and "H" may be useful to consider if the block must be split in the H-plane or electroforming is employed to realize the power divider (*e.g.*, see design notes, Wollack, 'Simple Split-Block 90° E-Plane Bends for Low Power Applications,' 1995). Measured data for examples "A" and "C" are presented in Figures 4 and 5, respectively. Note the measured return loss is essentially identical for the two data sets due to the calibration noise floor (8510C thru-reflect-line calibration, $\sim -35\,\text{dB}$). The low frequency upturn ($f/f_c < 1.2$) is due to the transition from the reduced height waveguide (4:1) to the standard guide (2:1) used in the fixtures. The data are uncorrected. In practice, designs "A," "B," and "C" have been found to have indistinguishable electrical response; however, design "B" is preferred from a fabrication standpoint.

If the power combiner is fabricated as an E-plane split-block by conventional milling techniques, we note the following: 1) The cutting depth is limited to ~ 3 times the tool outer diameter, OD. 2) The cutter diameter must clear the mitre region. In this case, the tool diameter is restricted to the range: $a_o/6 \leq OD < b_m$. If the structure is realized by electroforming, these constraints can be relaxed; however, the ease of fabrication is somewhat compromised.

1. Acknowledgments

The fabrication skills and experience of D. Barker and D. Dillon are appreciated. Discussions with A. Kerr, M. Pospieszalski, and S. Srikanth are also gratefully acknowledged.

Bibliography:

De Ronde, F.C., "Full-Band Matching of Waveguide Discontinuities," 1966, *G-MTT Digest*, p. 208.

Hewlett Packard EEsof Division, Hewlett Packard High Frequency Structure Simulator (HFSS, 1995, version A.04.01), Santa Rosa, CA 95403.

Marcuvitz, N., *Waveguide Handbook,* 1986, IEE Electromagnetic Wave Series, vol. 21, Peter Peregrinus, London, pp. 336–355, 380–383. (First published 1951, MIT Radiation Laboratory Series, vol. 10, McGraw-Hill, New York.)

Montgomery, C.G., Dicke, R.H., Purcell, E.M., *Principles of Microwave Circuits,* 1987, IEE Electromagnetic Waves Series, vol. 25, Peter Peregrinus, London, chapter 12. (First published 1948, MIT Radiation Laboratory Series, vol. 8, McGraw-Hill, New York.)

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

Other Selected References on Power Divider Junctions:

Arndt, F., *et al.*, "Optimized E-Plane T-Junctions Series Power Divider," 1987, *IEEE Trans. on Microwave Theory and Techniques,* vol. 35, no. 11, pp. 1052–1059.

Bialkowski, M.E., "Analysis of an N-Port Consisting of a Radial Cavity and E-Plane Coupled Rectangular Waveguide," 1992, *IEEE Trans. on Microwave Theory and Techniques,* vol. 40, no. 9, pp. 1840–1843.

Bialkowski, M.E., *et al.*, "Simplified Mode-Matching Techniques for the Analysis of Coaxial-Cavity-Coupled Radial E-Plane Power Dividers," 1995, *IEEE Trans. on Microwave Theory and Techniques*, vol. 43, no. 8, pp. 1875–1880.

Bornemann, J., "Design of Millimetre-Wave Diplexers with Optimized H-Plane Transformer Sections," 1990, *Can. J. Elect. & Comp. Eng.*, vol. 15, no. 1, pp. 5–8.

Dittloff, J., Bornemann, J., Arndt, F., "Computer Aided Design of Optimum E- or H-Plane N-Furcated Waveguide Power Dividers," 1987, *Conference Proceedings*, 17th *European Microwave Conference*, Rome, Italy, Sept., pp. 181–186.

Griemsmann, J.W.E. and Kasai, G.S., "Broad-Band Waveguide Series T for Switching," 1956, *IRE Trans. on Microwave Theory and Techniques,* vol. 4, no. 4, pp. 252–255. (T-junction matched with half-wave transformers).

Hirokawa, J. *et al.*, "An Analysis of a Waveguide T Junction with an Inductive Post," 1991, *IEEE Trans. on Microwave Theory and Techniques,* vol. 39, no. 3, pp. 563–566. (compensation of shunt T-junctions).

Liang, Xiao-Peng, *et al.*, "A Rigorous Three Plane Mode-Matching Technique for Characteriz-

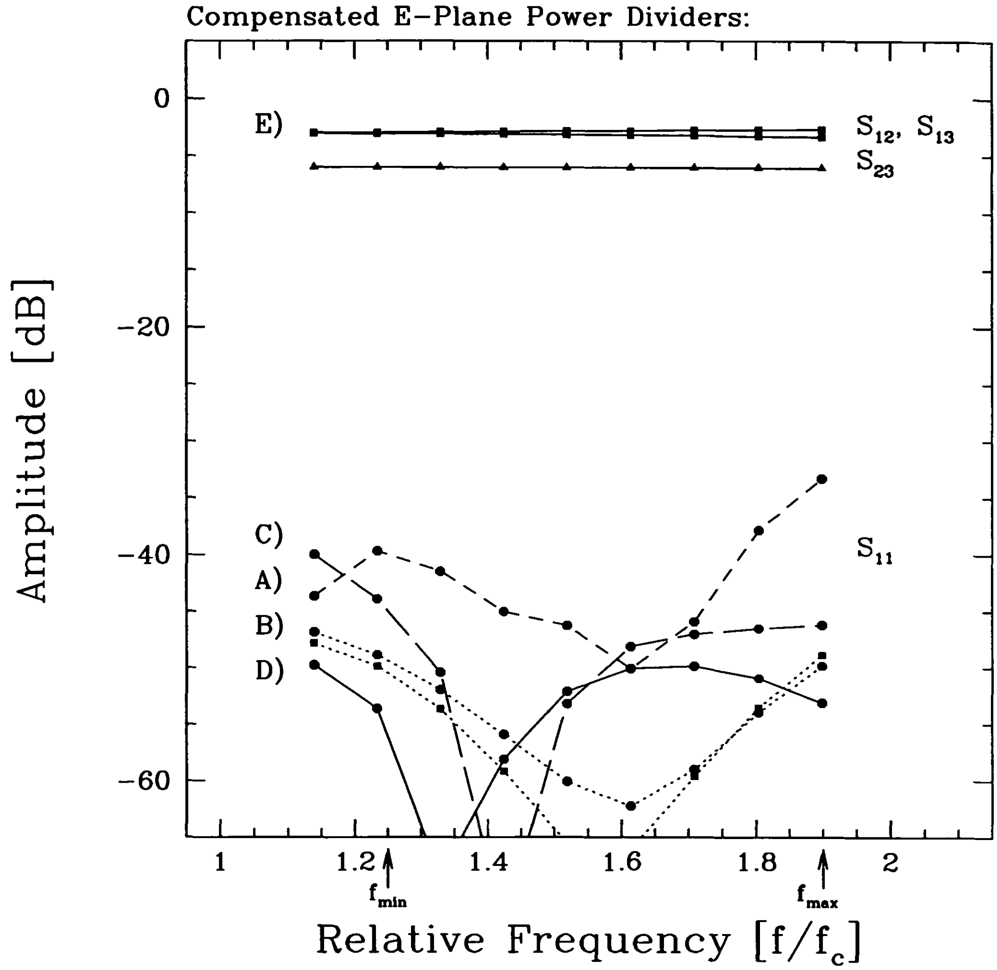

Figure 3. Selected Modeled Responses of Compensated E-Plane Power Divider Junctions: The asymmetry between S_{12} and S_{13} indicated in the figure is the worst case encountered (test case "E"; $\alpha_1 \neq \alpha_2$). Achievable designs with unequal power division, $b_1 \neq b_2$, result in discrepancies of similar magnitude from the design goal.

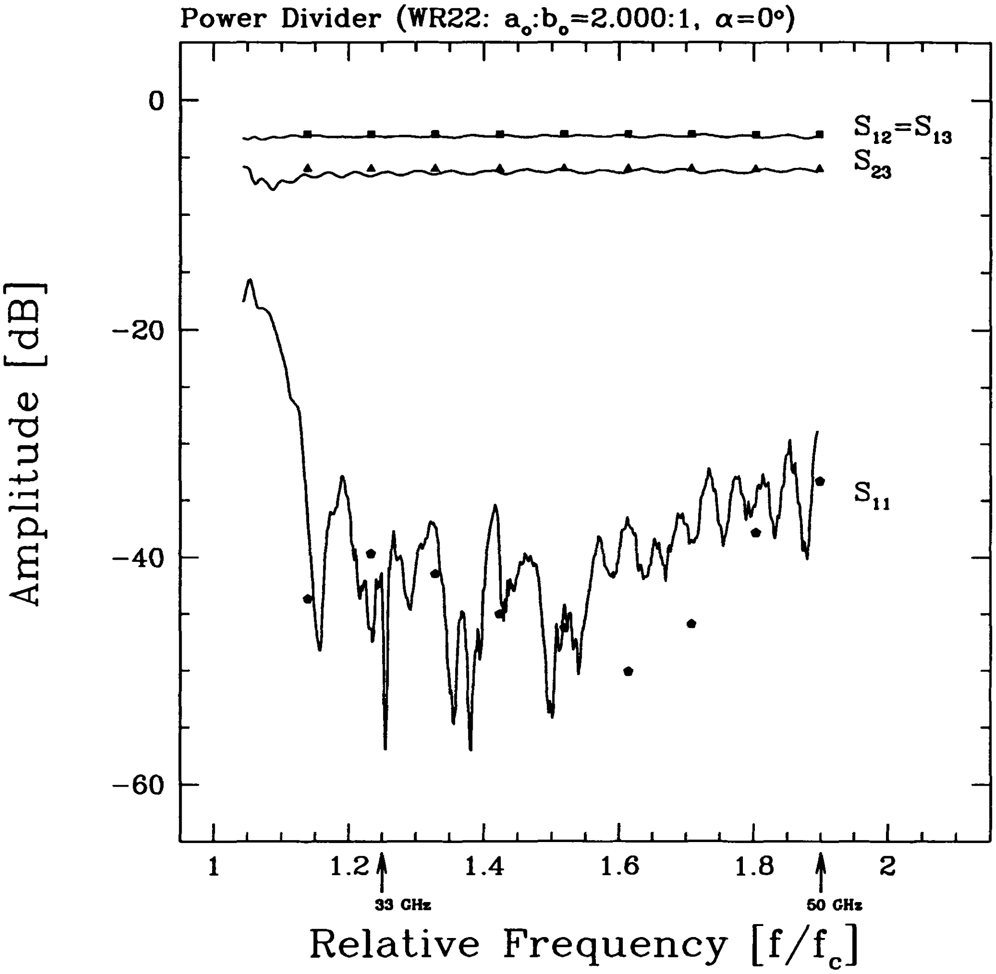

Figure 4. Measured Response: Bifurcated Waveguide "A" Power Divider (Septum; $t/a_o = 0.05$, $\alpha = 0°$). The computed finite element response is indicated by solid points in the figure.

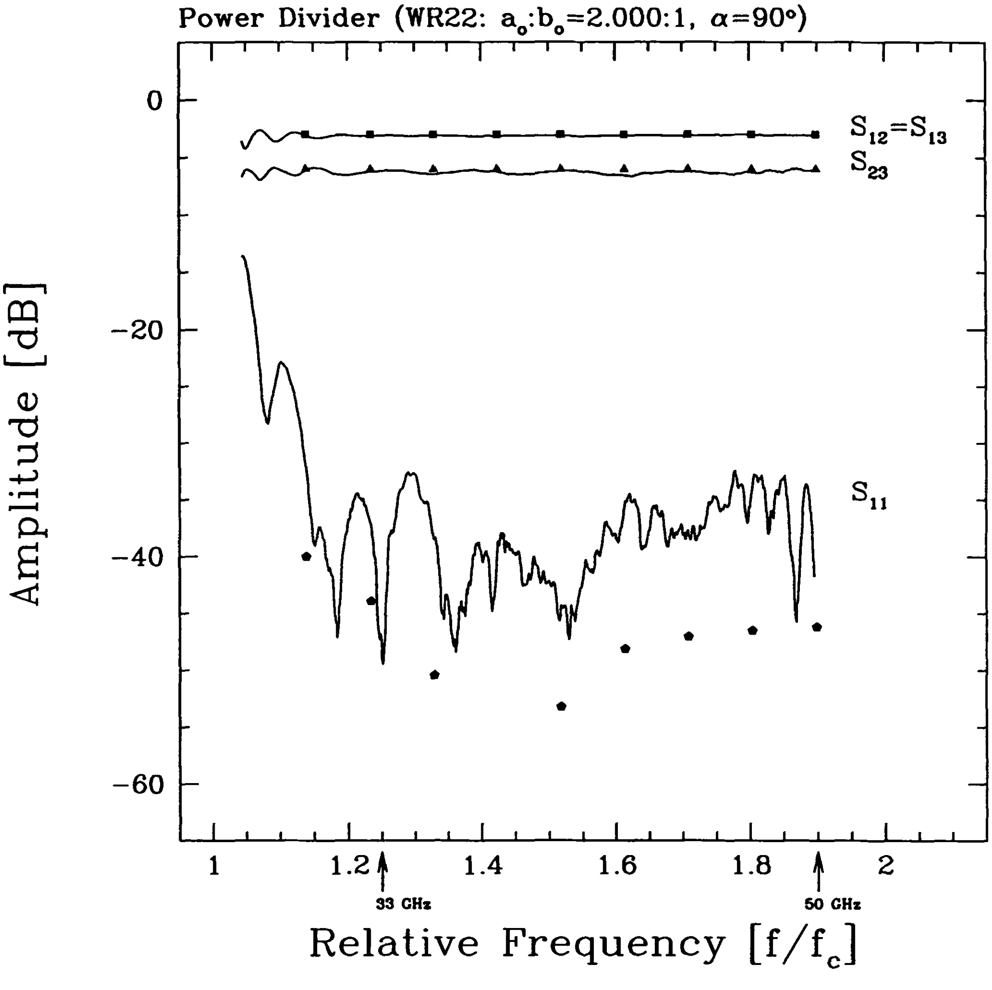

Figure 5. Measured Response: Bifrucated Waveguide "C" Power Divider (Mitre; $\alpha = 90^o$).The computed finite element response is indicated by solid points in the figure.