A MATCHED TURNSTILE TYPE 4-WAY DIVIDER/COMBINER

Dr. R. L. Eisenhart
N. W. Nevils
J. J. Gulick
R. C. Monzello

Hughes Aircraft Company
Canoga Park, California 91304

Abstract

Two-port Z-parameter characterization techniques have been applied in a novel way to a 6-port turnstile[1] type waveguide junction, resulting in a matched 4-way power divider/combiner. The circuit is new with many interesting characteristics and has application in high power or millimeter wave power combining where waveguide is best used.

Introduction

It was desired to construct a 4-way power divider/combiner in waveguide in which all of the five (5) ports (one common port and four N-ports) were matched. In order to do this the junction would have to include a loss element, or expand to a 6-port junction. We chose to develop a matched 6-port, keeping the junction lossless, and terminating the 6th port. The configuration chosen, shown in Figure 1, resembles an earlier turnstile junction design in the literature which utilized circular waveguide[2] on the upper common port and had no lower port. In this new

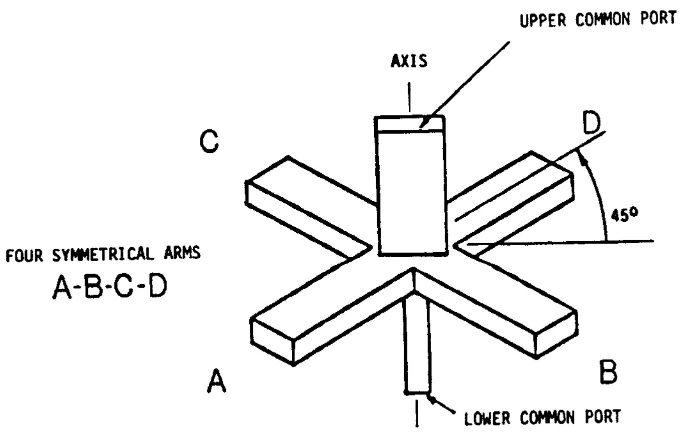


Figure 1. 6-port waveguide junction configured as a 4-way power divider/combiner. The lower common port is matched to act as a ballast.

design the rotation of the common ports (upper and lower) by 45° with respect to the side ports (and 90° to each other) establishes the 4-way symmetry desired as well as mutual isolation between the common ports.

This paper discusses the matching technique utilized and presents measured results of the design.

Discussion

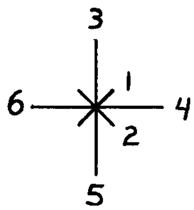
An S-parameter analysis was completed to establish 1) the theoretical possibility of the design and 2) the values of the scattering matrix elements. Figure 2a defines the port designations and shows the generalized S-matrix accounting for the symmetry of this junction. Application of lossless and unitary property conditions results in the values given in Figure 2b. It is interesting that while three dimensional symmetry does not exist in the jucntion mechanically, it does electrically. As a divider, power incident at any of the six ports is split equally to the four spatially orthogonal ports and the opposite port is isolated. As a four-way combiner, power can be summed at either of the remaining two ports depending on the established phases.

The next step was to match the junction. Waveguide short circuits were simultaneously used as variable known loads on the four turnstile arms to provide measurement data for interpretation as Z-parameter element values. As indicated in Figure 3, proper use of the symmetry conditions allows the 6 x 6 Z-matrix to be consolidated into a 2 x 2, dramatically simplifying the junction characterization. (Note: this is not the same as sequentially reducing the matrix to two particular ports for any one set of measurements.) These measurements were made from

PORTS #

1, 2 COMMON PORTS

3 - 6 SIDE PORTS

a) 

$$\begin{bmatrix} \alpha & \delta & \gamma & -\gamma & -\gamma & \gamma \\ \delta & \alpha & \gamma & \gamma & -\gamma & -\gamma \\ \gamma & \gamma & \beta & -\kappa & \theta & -\kappa \\ -\gamma & \gamma & -\kappa & \beta & -\kappa & \theta \\ -\gamma & -\gamma & \theta & -\kappa & \beta & -\kappa \\ \gamma & -\gamma & -\kappa & \theta & -\kappa & \beta \end{bmatrix}$$

FOR MATCHED CONDITIONS $\alpha, \beta = 0$.
ALSO $\delta = 0$ FROM CROSS COUPLING.
LOSSLESS AND UNITARY
RESULTS IN:

b)

$$\frac{1}{2}\begin{bmatrix} 0 & 0 & 1 & -1 & -1 & 1 \\ 0 & 0 & 1 & 1 & -1 & -1 \\ 1 & 1 & 0 & -1 & 0 & -1 \\ -1 & 1 & -1 & 0 & -1 & 0 \\ -1 & -1 & 0 & -1 & 0 & -1 \\ 1 & -1 & -1 & 0 & -1 & 0 \end{bmatrix}$$

WHERE

$4\gamma\gamma^* = 1$

$\gamma, \kappa = 1/2$

AND

$\theta = 0$

Figure 2. Scattering Matrix for the 6-port.
a) Port designations and generalized matrix.
b) Results of S-parameter analysis.

9 to 11 GHz for a variety of internal junction heights. The established mathematical models for the various junction configurations were then reversed so that the necessary matching conditions on the four turnstile side ports could be calculated. Simple matching circuits, each consisting of a properly positioned obstacle, were determined for each configuration. Each matched design (at 10 GHz) was now considered at 9 and 11 GHz and the best selected for bandwidth.

$$[Z] = \begin{bmatrix} z_{11} & z_{12} & \cdot & \cdot & \cdot & z_{16} \\ z_{21} & z_{22} & & & & \cdot \\ \cdot & & \cdot & & & \cdot \\ \cdot & & & \cdot & & \cdot \\ \cdot & & & & \cdot & \cdot \\ z_{61} & \cdot & \cdot & \cdot & \cdot & z_{66} \end{bmatrix}$$

THIS REDUCES TO A 2 x 2 CONSIDERING CERTAIN SYMMETRY CONDITIONS DURING MEASUREMENT.

"CONSOLIDATED" $$[Z^c] = \begin{bmatrix} Z^c_{11} & Z^c_{12} \\ Z^c_{21} & Z^c_{22} \end{bmatrix}$$

Figure 3. Impedance Matrix with indicated simplification.

This initial match is shown as the solid line S_{11} on Figure 4a. The remaining step of matching the side port S_{33} was accomplished by placing a wire of suitable length on the axis of the turnstile. This matched the side ports with minimal effect on S_{11}. These results for the final S_{11} and S_{33} are also shown in 4a. Figure 4b shows the transmission coefficient S_{13}, representing the 4-way dividing effect. It is close to the ideal value of 0.5 over the whole band. A scale in decibels is shown on the right side of the S_{13} plot, indicating the variation from the ideal 6 dB.

Figure 5 shows the prototype circuit. The "half" turnstile shown in the inset gives a better picture of the internal region, showing the step to the reduced height junction. The capacitive obstacles used in the final design are not indicated here but are about half-way between the junction step and the flange face. The capacitive iris opening is about 0.160 inches.

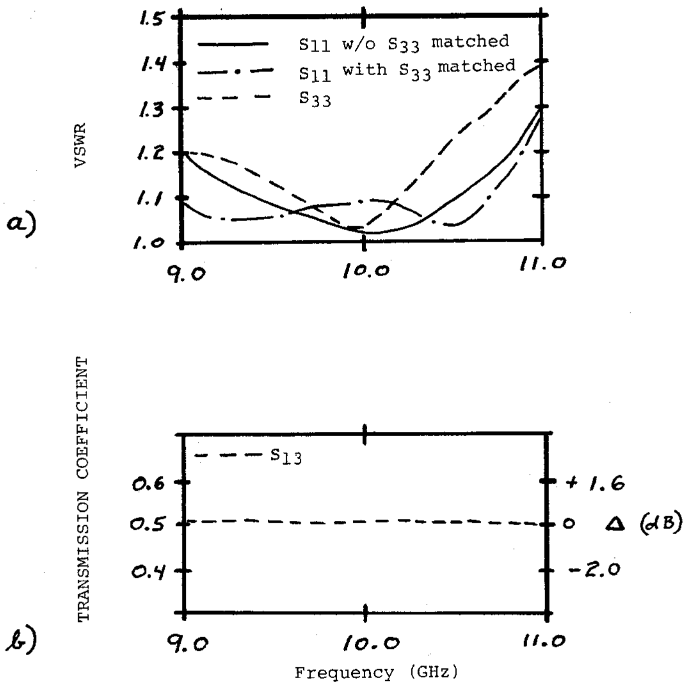


Figure 4. Measured Performance of the 6-port junction.
a) VSWR of common and side port
b) Transmission coefficient from common to the side port

The procedure used in developing this matched 6-port was very methodical, with no empirical "tweaking" prior to selecting of the wire length to match S_{33}. Excellent symmetry was measured throughout.

References

1. Patent Application filed Sept. 17, 1981.
2. Montgomery, Dicke and Purcell, Principles of Microwave Circuits, Radiation Lab Series Volume 8, 1948 pgs. 459 - 466.

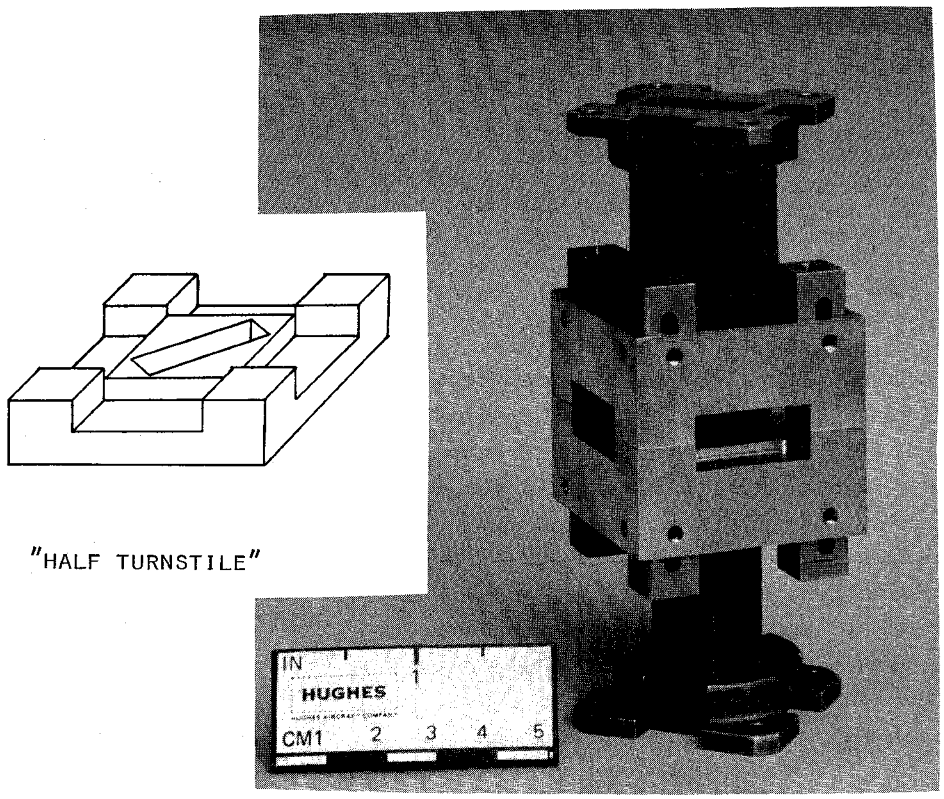


Figure 5. Prototype turnstile in X-band waveguide.