A COMPACT Ku-BAND POWER COMBINING NETWORK USING RECTANGULAR COAXIAL LINE TECHNOLOGY

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ABSTRACT

A compact Ku-band power combining network with a combining loss less than 0.45dB has been developed using rectangular coaxial line technology. Novel hybrid couplers using impedance-transforming nonuniform coupled transmission-lines are employed as power combiners to reduce the degradation in the combining network performance due to manufacturing inaccuracy.

INTRODUCTION

In the C-band and below, rectangular coaxial line technology is useful to realize compact, lightweight and low-loss beam-forming networks (BFNs) and power combining networks [1][2]. But, in the X-band and above, degradation in rectangular coaxial line device performance due to manufacturing inaccuracy becomes a serious problem because the dimension of a rectangular coaxial line cross section should be designed very small to avoid excitation of higher order propagation modes. Consequently, most of low-loss BFNs and power combining networks in these frequency bands are designed using waveguide technology [2][3].

This paper proposes a Ku-band compact and low-loss 4-way power combining network using rectangular coaxial line technology. The network consists of three novel hybrid couplers using impedance-transforming nonuniform coupled transmission-lines. These transmission-lines can reduce the degradation in the hybrid coupler performance due to manufacturing inaccuracy by lowering the coupled-line impedance around the center of coupled lines and by optimizing coupling coefficient distribution. The design method of the hybrid coupler and experimental results of a Ku-band 4-way power combining network are presented.

CONFIGURATION

A block diagram of the 4-way power combining network is shown in Figure 1. Four input signals are combined with three 3dB hybrid couplers. The configuration of the 3dB hybrid coupler using impedance-transforming nonuniform coupled transmission-lines is shown in Figure 2. Nonuniform coupled transmission-lines are employed in order to avoid discontinuity effect which degrades the performance of hybrid coupler in high frequency bands. Nonuniform coupling is obtained by varying the width W and the offset value S of each inner conductor continuously along the longitudinal direction x.

The coupled-line impedance $Z_C(x)$ and the coupling coefficient K(x) at position x on the non-

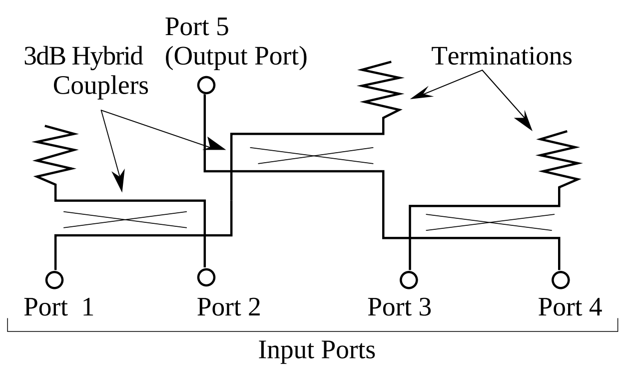

Figure 1. 4-Way Power Combining Network

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uniform coupled transmission-lines are defined by:

$$Zc(x) = \sqrt{Z_e(x) \cdot Z_o(x)} \quad (1)$$

$$K(x) = \frac{Z_e(x) - Z_o(x)}{Z_e(x) + Z_o(x)} \quad (2)$$

where $Z_e(x)$ and $Z_o(x)$ are even and odd mode characteristic impedances of the coupled lines, respectively. In the impedance-transforming nonuniform coupled transmission-lines, both Zc and K are varied continuously along the longitudinal direction x, and the performance degradation due to manufacturing inaccuracy can be reduced by lowering the impedance Zc around the center of coupled lines and by optimizing coupling coefficient distribution K(x).

Zc has the lowest value at the center of the coupled lines (x=0). The nonuniform coupled transmission-lines operate as impedance transformers which match the lowered impedance around the coupled line center with input/output impedance Z_L at the coupled line ends. By lowering the impedance Zc around the coupled line center, the conductor width W and conductor gap d can be enlarged all along the coupled lines and, therefore, the performance degradation due to manufacturing inaccuracy can be reduced.

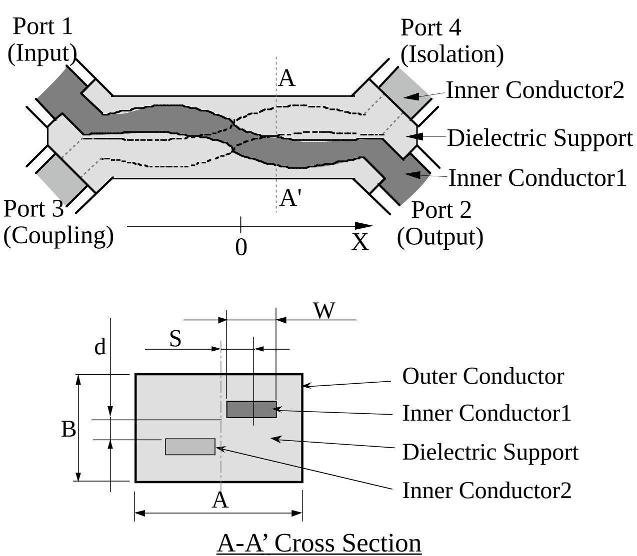

Figure 2. 3dB Hybrid Coupler

DESIGN

In order to simplify the design, multisection coupled transmission-lines with reduced sensitivity to manufacturing inaccuracy are designed by lowering impedance and optimizing coupling coefficient distribution first, and then the coupling distribution K(x) and impedance distributions Zc(x) of the nonuniform coupled transmission-lines are derived by tapering the multisection coupled transmission-lines. Figure 3 shows an equivalent circuit of multisection coupled transmission-lines. The center coupled section is designed to have lowest impedance Zc_N and the other sections are designed to operate as quarter wavelength impedance transformers which can match Zc_N with input/output impedance Z_L. The impedance of each section is determined by the impedance matching condition. In the case of N=3, the condition is given by :

$$Z_L \cdot Zc_2^{\,2} = Zc_1^{\,2} \cdot Zc_3 \quad (3)$$

The coupling characteristic of the multisection coupled transmission-lines can be analyzed by the even and odd mode model [4]. For N=3, a relation between the coupling of the entire coupler, K_0, and the coupling coefficient of each section, K_i, is give by:

$$\frac{(K_1 - K_2)(1 - K_1K_2)}{(K_1 - K_2)^2 + (1 - K_1K_2)^2} = \frac{K_3 - K_0}{2(K_3K_0 - 1)} \quad (4)$$

Equation (4) is transformed to

$$K_0 = \frac{2K_1 - 2K_2 + K_3 + \alpha_1}{1 + \alpha_2} \quad (5)$$

where α_1 and α_2 are higher order terms of K_1, K_2 and K_3. Equation (5) indicates that K_2 has nega-

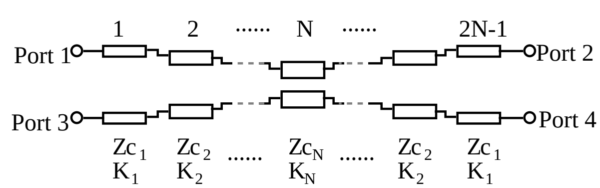

Figure 3. Equivalent Circuit of Multisection Coupled Lines

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tive contribution to the coupling K_0, and then the deviation of coupling K_0 caused by errors in K_1, K_2 and K_3 can be partially canceled if all errors have the same sign. Because an error in conductor gap d causes the same sign errors in K_1, K_2, K_3, a proper of choice of the coupling coefficients K_1, K_2 and K_3 will reduce the deviation of K_0 due to the manufacturing inaccuracy of d.

To avoid the performance degradation caused by step discontinuities between uniform coupled sections, the designed multisection coupled transmission-lines are transformed into nonuniform coupled transmission-lines[5]. Figure 4 shows a designed distribution of Zc(x) and K(x), and Figure 5 shows the designed performance of the hybrid. The physical dimensions W(x) and S(x) are determined by using rectangular boundary division method[6]. Coupling deviations caused by errors in d and S are estimated for the designed hybrid coupler and a conventional quarter wavelength uniform coupled line hybrid coupler. Table I shows the comparison of the coupling deviations. The coupling deviation is reduced to less than 30% of that in conventional one.

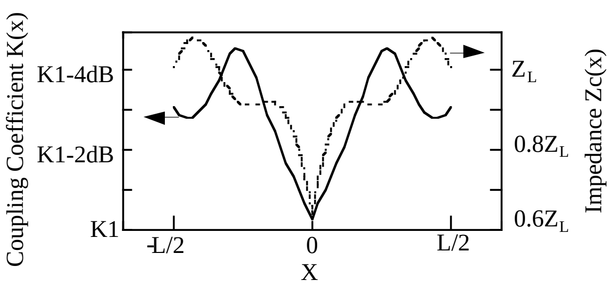

Figure 4. Designed Distribution of Zc(x) and K(x)

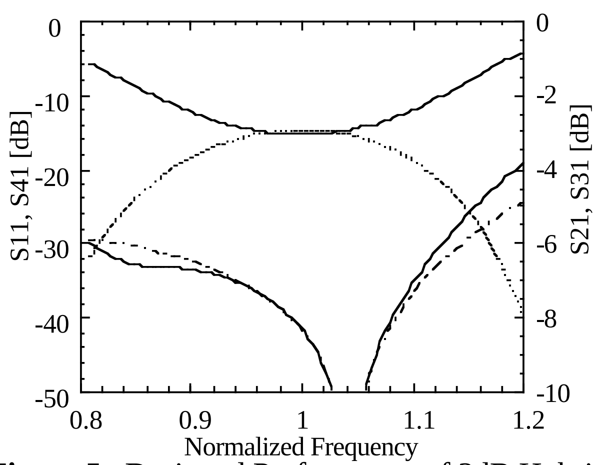

Figure 5. Designed Performance of 3dB Hybrid Coupler

Table I
Comparison of Coupling Deviation
(Designed Coupling Ko=-3dB, Z0=50ohm)

	Error in S $\Delta S/A=0.03$	Error in d $\Delta d/B=0.005$
Conventional Type	0.42dB	0.33dB
Impedance-transforming type	0.01dB	0.10dB

EXPERIMENTAL RESULTS

Figure 6 shows a photograph of the fabricated Ku-band 4-way power combining network. Figure 7 shows the measured performance including input and output connectors. The combining amplitude and phase errors are less than 0.3dB and 5 degrees, respectively, in the 7% frequency band. Figure 8 shows the estimated combining loss using the measured performance of the combining network. A combining loss less than 0.45dB (a combining efficiency greater than 90%) is obtained in the 7% frequency band.

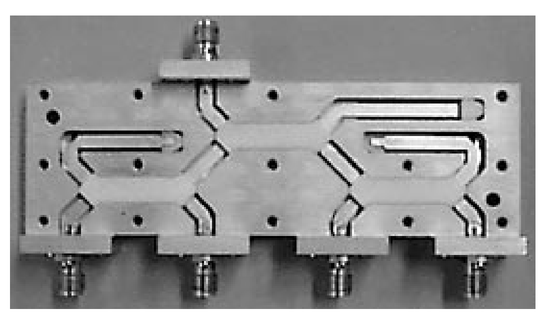

Figure6. Ku-band 4-Way Power Combining Network

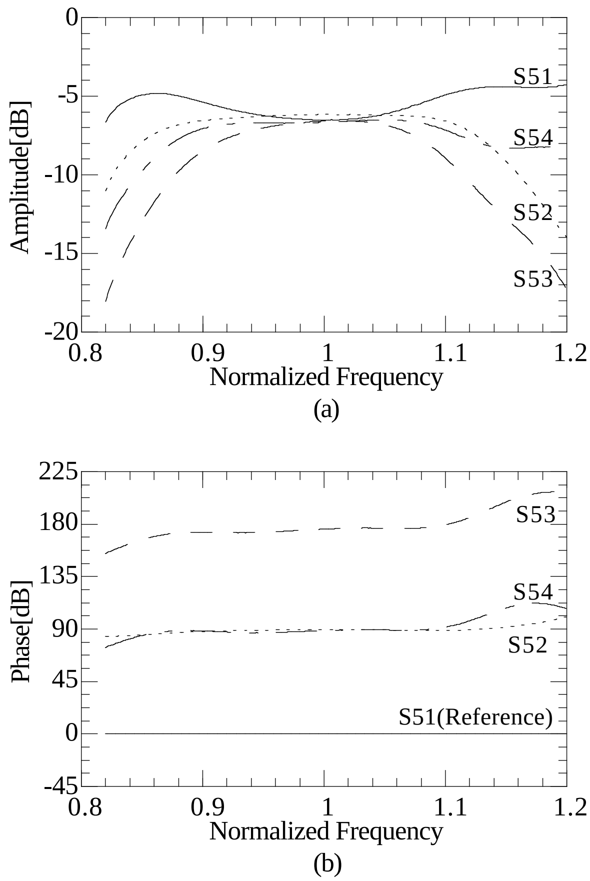

Figure 7. Measured Performance: (a) Amplitude Characteristic. (b) Phase Characteristic.

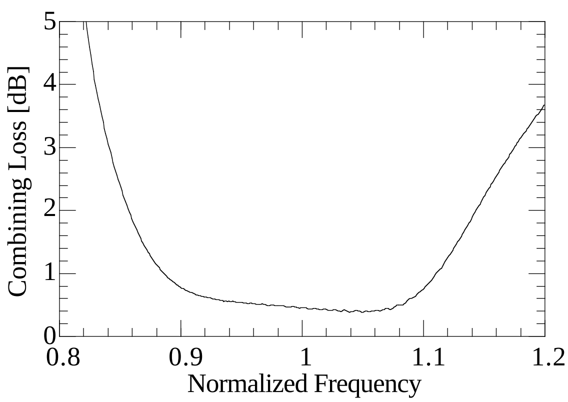

Figure 8. Estimated Combining Loss

CONCLUSION

A compact and low-loss Ku-band power combining network using rectangular coaxial line technology was presented. Novel hybrid couplers using impedance-transforming nonuniform coupled transmission-lines are employed as power combiners to reduce the degradation in combining network performance due to manufacturing inaccuracy. A compact size power combining network with a combining loss less than 0.45dB has been realized.

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