NEW SLOT-COUPLED DIRECTIONAL COUPLERS BETWEEN DOUBLE-SIDED SUBSTRATE MICROSTRIP LINES, AND THEIR APPLICATIONS

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ABSTRACT

This paper describes a newly developed slot-coupled directional coupler between two microstrip lines coupling through a rectangular slot in the common ground plane, and its application to a planar multiport directional coupler (MDC). An effective slot-coupled MDC is easily fabricated, and has many useful applications such as beam-forming networks and multiport amplifiers.

1. Introduction

This paper describes a newly developed slot-coupled directional coupler between two microstrip lines coupling through a rectangular slot in the common ground plane, and its applications to a planar multiport directional coupler. A multiport directional coupler (MDC) is a very useful and interesting circuit. Many practical circuits, such as beam-forming networks(1) and multiport amplifiers(2), etc., can be constructed by mounting active circuits such as phase shifters and power amplifiers between two MDCs. The proposed slot-coupled directional coupler can be applied both to loose couplings, such as 10dB couplings, and tight couplings, such as 3dB couplings. The design method is very simple and easy.

2. Construction

A cutaway view of the slot-coupled directional coupler between double-sided substrate microstrip lines is illustrated in Fig.1. Two microstrip lines with a common ground plane are coupled through a slot in the common ground plane. The coupling slot length and the coupling strip length are the same, and equal to a quarter of the midband wavelength.

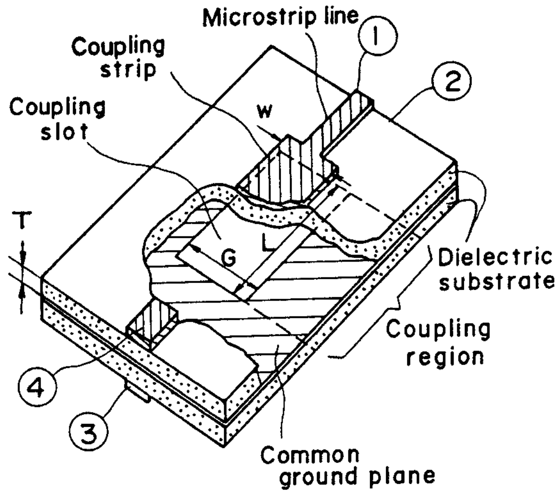


FIG. 1 A cutaway view of the slot-coupled directional coupler

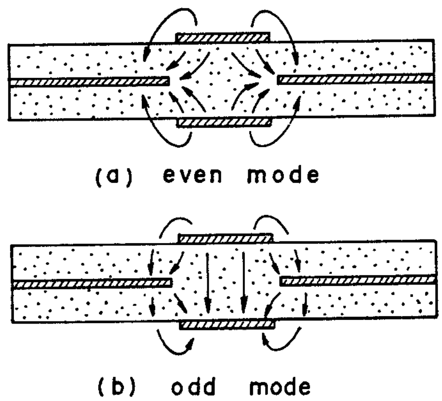
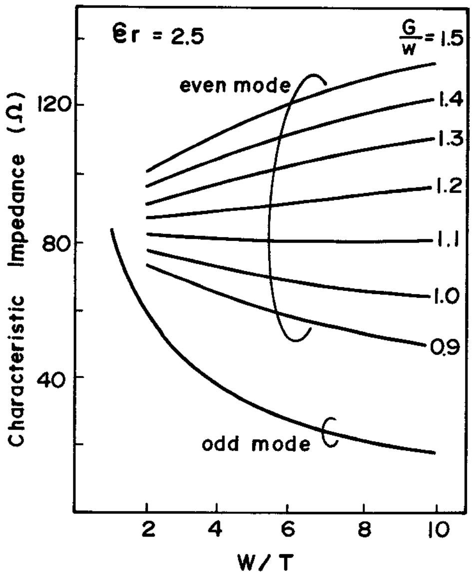


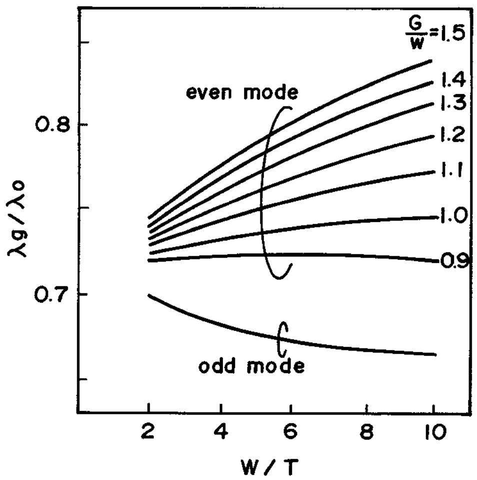
FIG. 2 The schematic expression of the even- and odd-mode electric fields

*ATR : Advanced Telecommunications Research Institute International

1988 IEEE MTT-S Digest



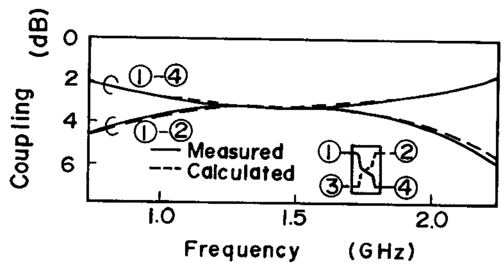
(a) Characteristic impedance



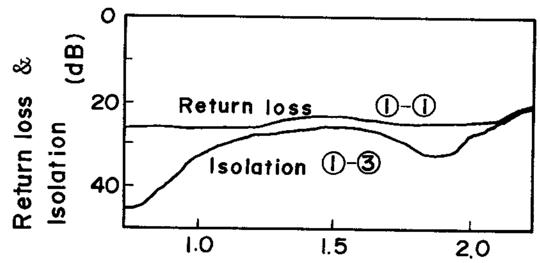
(b) Normalized wavelength

(T : Substrate thickness)

FIG. 3 Characteristic impedances and normalized wavelengths of the even- and odd-modes



(a) Coupling



(b) Return loss and Isolation

FIG. 4 The 3dB coupling slot-coupled directional coupler frequency performance

3. Design

In designing the slot-coupled directional coupler, the even- and odd-mode characteristics in the coupling region must be evaluated. Figure 2 shows the schematic expression of the even- and odd-mode electric fields. The finite element method (FEM) is adopted to calculate the propagation constant and the characteristic impedance of each mode. Figure 3 shows calculated characteristic impedances and normalized wavelengths of the even- and odd-modes. The coupling slot plane is an electric wall in the odd-mode and a magnetic wall in the even-mode. Since the odd-mode electromagnetic field is the same as that of the microstrip line, the odd-mode characteristic impedance is determined by the coupling strip width W only and is independent of the coupling slot width G.

The design procedure is as follows:

(1) Calculate the even-mode characteristic impedance $Ze(\Omega)$ and odd-mode characteristic impedance $Zo(\Omega)$ for the desired coupling C(dB) according to the following equations, where Z_0 is transmission line characteristic impedance[3];

$$C(dB) = -20\log_{10}\left(\frac{Ze-Zo}{Ze+Zo}\right), \qquad Z_0(\Omega) = \sqrt{ZeZo} .$$

(2) Determine the coupling strip width W corresponding to the Zo.

(3) Determine the coupling slot width G corresponding to the Ze.

(4) Determine the coupling length L equal to the arithmetic mean of the even- and odd-mode quarter wavelengths.

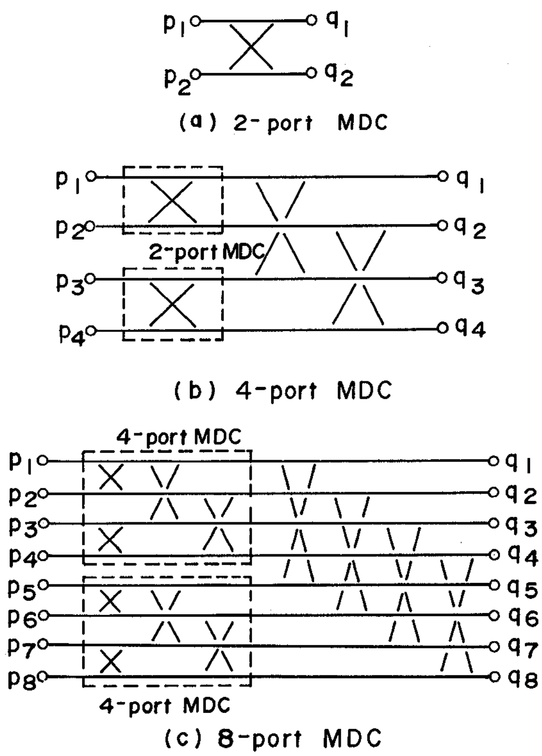


FIG. 5 Typical configuration of MDCs

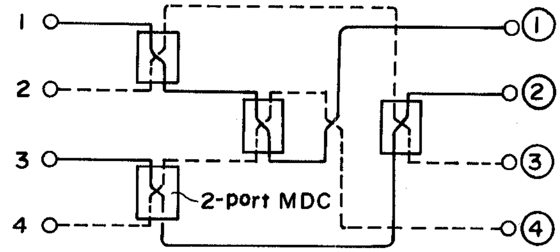
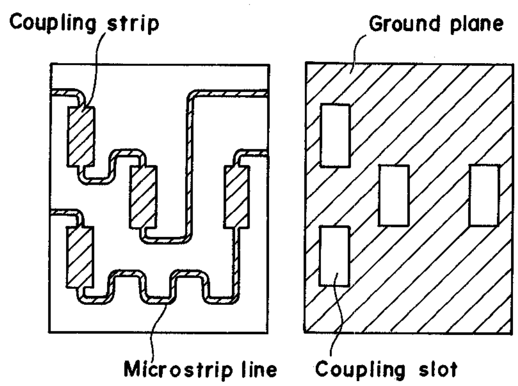
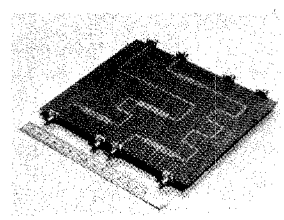


FIG. 6 4-port MDC configuration using slot-coupled directional couplers



(a) Pattern of the substrate surface (b) Pattern of the ground plane



(C) A photograph of a 4-port MDC

FIG. 7 4-port MDC circuit patterns and the photograph of a 4-port MDC

4. Performance

Figure 4 shows the frequency performance of a 3dB directional coupler. Substrate thickness is 0.8mm, and the relative permittivity ε_r is 2.5. For a 3dB coupler with microstrip line characteristic impedance $Z_0=50\Omega$, $Ze=120.5\Omega$ and $Zo=20.7\Omega$ are required. At a center frequency of 1.5 GHz, the values of W,G and L corresponding to the above characteristic impedances are 7.3mm, 10.2mm and 36.4mm, respectively. Couplings of 3.2±0.2dB with more than 25dB return loss and more than 28dB isolation have been obtained over the 1.2 to 1.8GHz frequency band as shown in Fig.4. The measured coupling results have agreed well with the calculated results. For the 6dB and 10dB couplings, good performance has also been obtained.

5. Application

An MDC is a very useful and interesting circuit. However it is difficult to get an effective planar configuration MDC with conventional directional couplers because of microstrip line cross-overs. A combination of the slot-coupled directional couplers, however, makes it possible to construct a planar 2^n-port MDC without microstrip line cross-overs.

The MDC is a passive circuit with an even number of input and output ports. Power to any input port is equally divided among the output ports. Figure 5 shows a typical MDC configuration. In general, 2^n-port MDC (n = 1,2,...) can be constructed by using $n2^{n-1}$ directional couplers, where 2^n is the number of input ports and output ports. Figure 6 shows an example of a 4-port MDC configuration using the slot-coupled directional couplers. Solid lines show the microstrip lines on one side and broken lines show microstrip lines on the other side. Figure 7 shows 4-port MDC circuit patterns and the photograph of a fabricated MDC. The coupling region dimensions of this 4-port MDC, are the same as those of the 3dB coupler.The dimensions of the 4-port MDC are 150×180mm². The substrate surface pattern of the two sides is the same. Figure 8 shows the frequency performance of the 4-port MDC. Couplings of 6.4±0.4dB with more than 25dB return loss and more than 30dB isolation have been obtained over the 1.2 to 1.8GHz frequency band. An 8-port MDC can be constructed by connecting two 4-port MDCs and 4 slot-coupled directional couplers as shown in Fig.9. In the same way, a planar 2^n-port MDC can be constructed by using two 2^{n-1}-port MDCs and 2^{n-1} slot-coupled directional couplers.

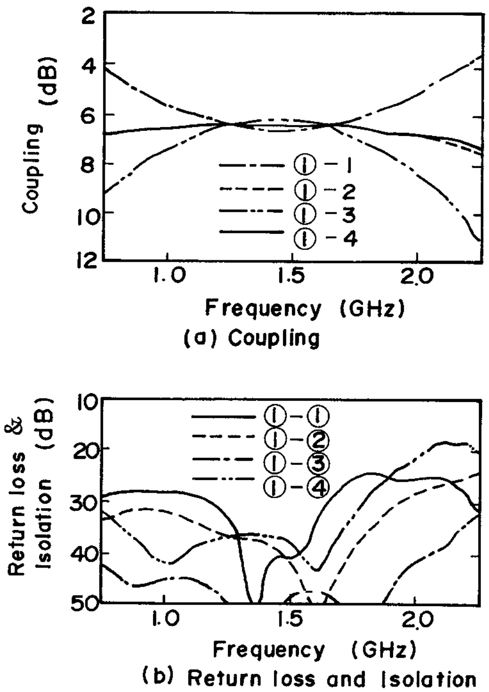


FIG. 8 4-port MDC frequency performance

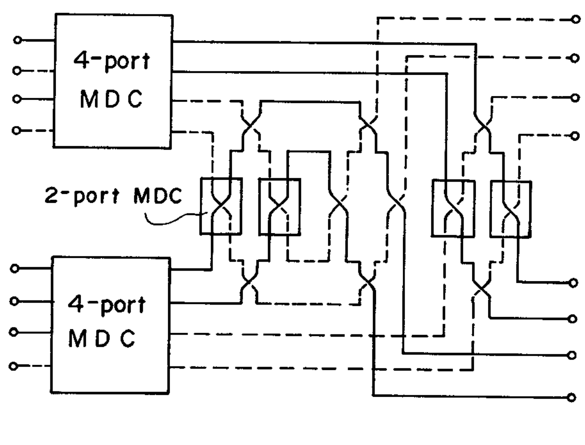


FIG. 9 8-port MDC configuration

6. Conclusion

A new slot-coupled directional coupler between two microstrip lines coupling through a rectangular slot in the common ground plane has been proposed and fabricated for the 1.5GHz band. The design method and the experimental results of the slot-coupled directional coupler have been described. The measured 3dB-coupling results have agreed well with the calculated results. Additionally the experimental results of 4-port MDC agreed well with the calculated results. A planar multiport directional coupler configuration determined by the combination of the slot-coupled directional couplers has also been proposed. An effective slot coupled multiport directional coupler is easily fabricated, and has many useful applications such as beam forming networks and multiport amplifiers.

7. Acknowledgements

The authors wish to thank Dr. Furuhama for his continuous encouragement.

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