Analysis and Design of an Homogeneous and an Asymmetrical Rectangular Coaxial-to-Microstrip Directional Coupler by the Finite Element Method

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ABSTRACT

In this paper we present the analysis and the design of an homogeneous and an asymmetrical rectangular coaxial-to-microstrip directional coupler using the finite element method (FEM) [1], [2], [3]. This coupler is proposed for uses in high power applications in order to overcome the main drawbacks of coaxial, waveguide, and stripline couplers. The effect of a metallic diaphragm, partially separating the asymmetrical inner conductors, is easily taken into account. This metallic diaphragm allows us to control easily the coupling factor of the proposed coupler.

The fact that we do not possess any numerical or experimental results in the scientific literature for this type of homogeneous coupler, we use the moment method (MoM) [4] to validate the results obtained by the finite element method.

As an application, we present the design of a broad-band homogeneous coaxial-to-microstrip directional coupler operating in the frequency range [3-6] GHz with about 20 dB of coupling and with a high directivity (22 dB).

KEY WORDS

Homogeneous rectangular coaxial coupler, Coaxial-to-microstrip coupler, Metallic diaphragm, Analysis and design, Directional coupler, FEM method.

RESUME

Dans cet article, nous présentons l'analyse et la conception d'un coupleur homogène asymétrique et directif formé par un câble coaxial et une ligne micro-ruban blindée, en utilisant la méthode des éléments finis (MEF) [1], [2], [3]. Ce coupleur est proposé pour des applications hautes puissances pour surmonter les inconvénients principaux des coupleurs coaxiaux, stripline et en guide d'ondes. Nous tenons compte, dans l'analyse et la conception de l'effet du diaphragme métallique séparant partiellement les conducteurs internes asymétriques du coupleur. Ce diaphragme métallique nous permet facilement d'ajuster le coefficient de couplage du coupleur proposé.

Du fait que nous ne possédons d'aucun résultat numérique ou expérimental dans la littérature scientifique pour ce type de coupleur homogène, nous utilisons la méthode des moments (MoM) [4] pour valider les résultats obtenus par la méthode des éléments finis.

Comme application, nous présentons les résultats de conception d'un coupleur homogène directif large bande (coax-microruban) fonctionnant dans la gamme de fréquence [3-6] GHz et ayant un couplage de 20 dB et une grande directivité (22 dB).

MOTS CLES

Coupleur coaxial rectangulaire homogène, Coupleur coax-microruban, Diaphragme métallique, Analyse et conception, Coupleur directif, Méthode des éléments finis (MEF).

1. INTRODUCTION

Directional couplers are key components in many RF applications, in particular for the realization of test setups. Nowadays, off-the-shelf devices are stripline couplers, waveguide couplers and coaxial couplers. Stripline or microstrip couplers are well suited for broad-band applications [5]; unfortunately their significant losses can prevent their use when high power handling is required. Waveguide Bethe-hole couplers [6] are used in high power applications, but are not a practical solution for broad-band use, even though many techniques have been proposed for this purpose [7], [8], since the primary mode is limited at low frequencies by the cutoff frequency and the higher order modes limit the upper frequency. Eventually, coaxial directional couplers are the traditional high power solution when bandwidth specifications are not critical [9] and would be ideal for their low losses, their TEM field configurations ensuring zero cutoff frequency, and their high power handling capabilities.

Our contribution in this work is to analyze and to design an homogeneous and an asymmetrical rectangular coaxial-to-microstrip directional coupler, using the finite element method (FEM), for high power applications. For this coupler the rectangular asymmetrical coaxial main line is coupled to a microstrip through an aperture inside the dielectric substrate (Figure 1).

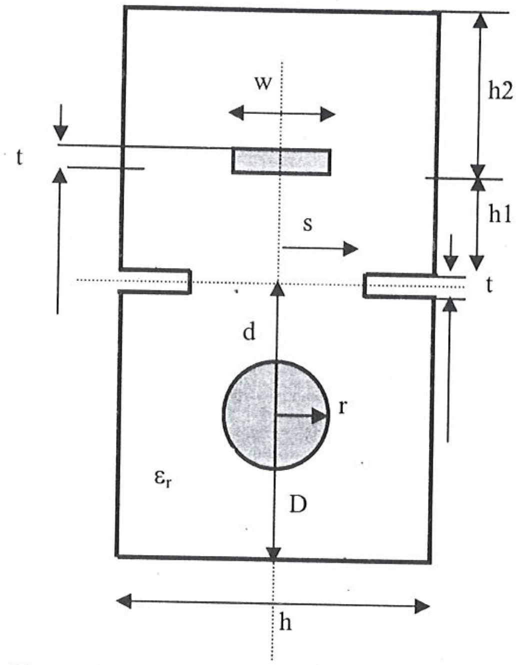

Figure 1: The cross section of an homogeneous rectangular coaxial-to-microstrip coupler.

2. NUMERICAL RESOLUTION

The electrical properties of the lossless and the homogeneous coupler presented in figure 1 can be described in terms of its primary parameters [L] and [C], [3].

Where:

$$[L]=\begin{bmatrix} L_1 & L_m \\ L_m & L_2 \end{bmatrix}, \quad [C]=\begin{bmatrix} C_1 & C_m \\ C_m & C_2 \end{bmatrix}$$

Various numerical techniques can be used to determine the accurate primary parameters of the coupler. This paper presents the analysis and the design of the coupler shown in figure 1 using the finite element method (FEM) [1], [2], [3].

The study of the coupler, in the electrostatic domain, is based on the resolution of the Laplace's equation in two dimensions.

$$div\,[\nabla_t V(x,y)]=0 \qquad (1)$$

For the asymmetrical inner conductors of the coupler [3], capacitances $C_i(\varepsilon_r)$ are computed for:

$$V_i = 1 \text{ volt} \qquad (2)$$

(all other conductors are grounded).

Setting $V_1=V_2=1$ volt yields a capacitance C_3, so that the coupling capacitance C_m is calculated by the following relation [3]:

$$C_m = \frac{1}{2}\left(C_1(\varepsilon_r)+C_2(\varepsilon_r)-C_3\right) \qquad (3)$$

Inductances L_i are given in terms of capacitances, as in the case of a single quasi-static line [3], and the mutual inductance L_m is calculated from the following relation:

$$L_m = L_1\frac{C_m(\varepsilon_r)}{C_2(\varepsilon_r)} = L_2\frac{C_m(\varepsilon_r)}{C_1(\varepsilon_r)} \qquad (4)$$

Using the presented theory, we established a CAD program to calculate the matrices [L] and [C] of the homogeneous coaxial-to-microstrip coupler. When these matrices are determined, we first evaluate the coupling coefficient using the relation (5), then we analyse the coupler response using an adapted numerical model [10].

$$k = \frac{L_m}{\sqrt{L_1\ L_2}} = \frac{C_m}{\sqrt{C_1\ C_2}} \qquad (5)$$

3. RESULTS

In order to design a broad band homogeneous rectangular coaxial-to-microstrip directional coupler we have analysed the structure shown in figure 1 with the following features:

r = 0,65 mm; D/r=3,03; h=2D; d/r =2; t=0.1 mm, w=2r; h1=d-r; h2=D, ε_r=2,03.

Figures 2 and 3 provide plots of the elements respectively of the inductance matrix [L] and the capacitance matrix [C], as functions of the s/h ratio of the asymmetrical rectangular coaxial-to-microstrip coupler.

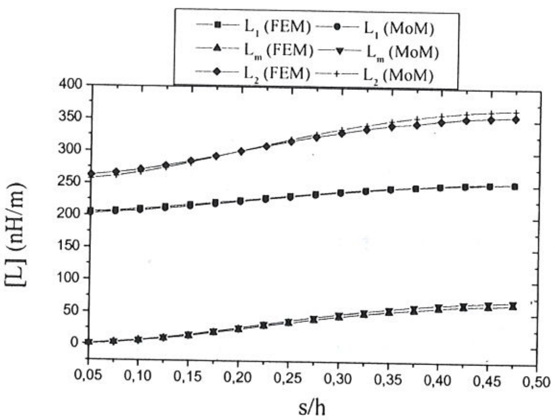

Figure 2: Influence of the s/h ratio on the elements of the inductance matrix [L] of the rectangular coaxial-to-microstrip coupler.

Through the comparison done between the results obtained by FEM and those obtained by MoM [4], it appears a good correlation between the two numerical models.

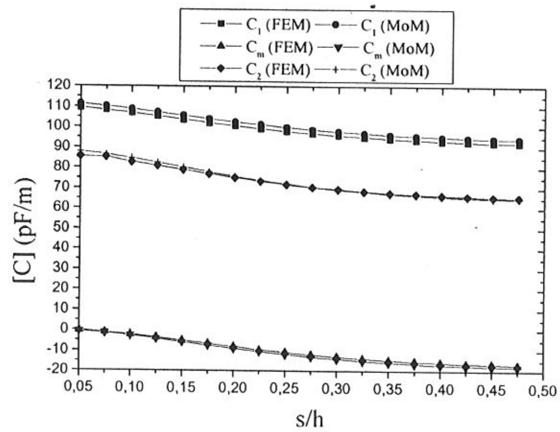

Figure 3: Influence of the s/h ratio on the elements of the capacitance matrix [C] of the rectangular coaxial-to-microstrip coupler.

The influence of the s/h ratio of the coupler on the coupling coefficient k is presented in figure 4.

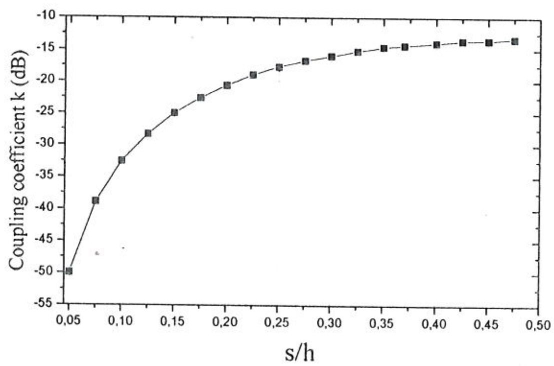

Figure 4: Influence of the s/h ratio on the coupling coefficient of the rectangular coaxial-to-microstrip coupler.

4. DIRECTIONAL COUPLER

In the following, we interest to the design of a broad band homogeneous rectangular coaxial-to-microstrip directional coupler. The figure 5 presents the structure of a four port coupler.

All the ports of the coupler are matched with Z_{co}=50Ω. For s/h=0,2 and a length l=10,5 mm, the resulting scattering parameters (with respect to 50Ω) are plotted in figure 6 in the band frequency [1-9]GHz.

Where:

$$[L]=\begin{bmatrix}224,4 & 24,09\\ 24,09 & 300,6\end{bmatrix}\quad\left(\frac{nH}{m}\right)$$

$$[C]=\begin{bmatrix}100,6 & -8,06\\ -8,06 & 75,15\end{bmatrix}\quad\left(\frac{pF}{m}\right)$$

Figure 6 shows the desired 20dB coupling from about 3GHz to 6GHz, with a high directivity (22 dB).

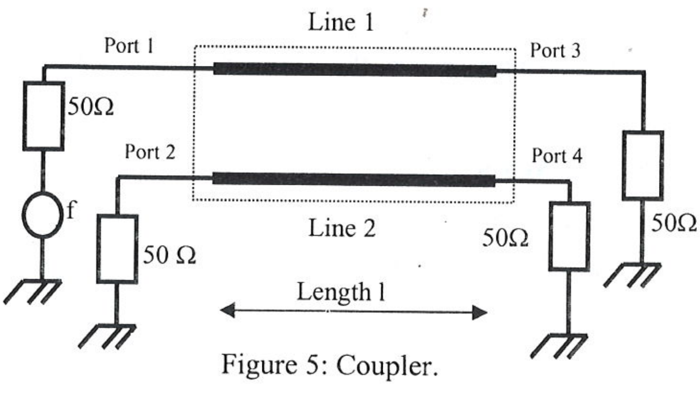

Figure 5: Coupler.

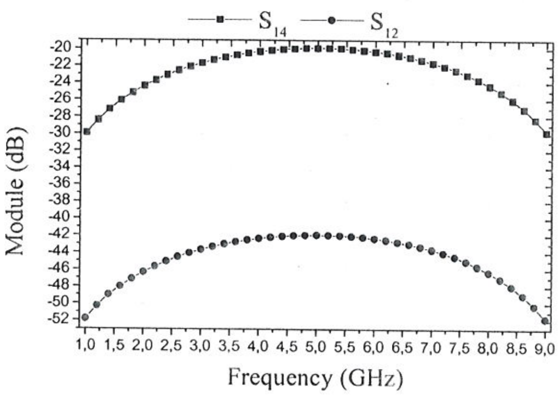

Figure 6: Scattering parameters of the rectangular coaxial-to-microstrip coupler as functions of frequency.

5. CONCLUSION

An homogeneous and an asymmetrical rectangular directional coupler using coaxial-to-microstrip coupling structure has been analyzed and designed, in order to overcome the main drawbacks of coaxial, waveguide, and stripline couplers. This structure represents a great improvement for high power measurement systems, since it has broad-band, good directivity, and can be easily designed and fabricated.

To reach this objective, it was necessary to determine the electromagnetic parameters of the structure (([L], [C], k). In the frequency range [1-9] GHz, the resolution of the problem is based on the quasistatic assumption and was made by the finite element method.

The results of the CAD program which was developed is highly correlated to those obtained by MoM [4]. We dispose for the asymmetrical and homogeneous coupled lines one precious tool for the characterisation of the primary and secondary parameters.

All the curves presented in this paper, taking into account the influence of the metallic diaphragm (s/h ratio) on the electromagnetic parameters of the studied coupler, prove the interest of the CAD program developed.

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