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Design of Directional Coupler Using Synthesis Method on Defected Ground Structure

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***Abstract* - Tight coupling and directivity are always the desirable characteristics of the coupler. This paper proposes a novel tightly coupled directional coupler using defected ground structure by using synthesis method. This coupled-line structure has a rectangular ground-plane aperture and two inserted signal strips in the aperture to improve coupling strength significantly. This structure of the coupler has been simulated on Fr4 substrate and results signify that there is less than 1% error between analytical calculation and simulation. The bandwidth on 20dB coupling is 38 MHz is found by using the FR4 substrate.**

I. INTRODUCTION

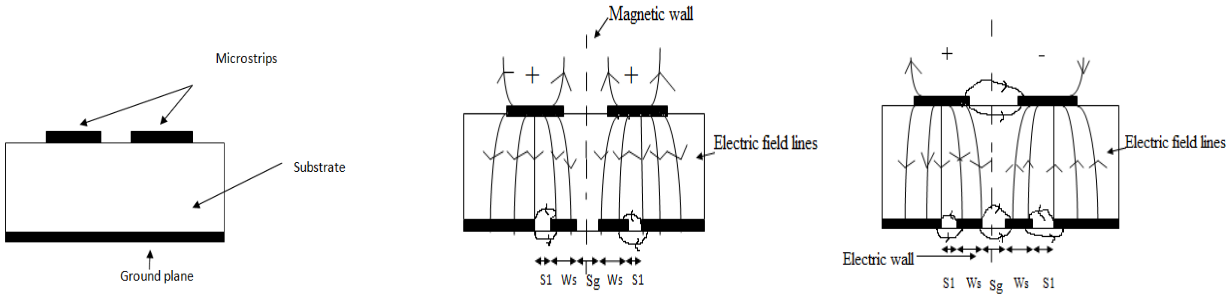
When two transmission lines are close together, because of the interaction of the electromagnetic fields of each line, power can be coupled between the lines. Those coupled lines are used to construct directional couplers. Generally, in design of directional couplers microstrip and stripline forms are used. Although microstrip transmission lines do not support TEM (Transverse electromagnetic mode) and named as quasi-TEM, usually they are assumed to operate in TEM mode. Microstrip directional couplers have been commonly used in microwave systems for measuring transmitted and reflected power with accuracy. Low cost, repeatability and manufacturability are the advantages of such structures. Various approaches have been presented for the design of coupler to achieve tight coupling. The most famous one is the Lange coupler [1]–[3], which is used extensively in the monolithic microwave integrated circuit (MMIC). However, the line width and gap spacing for either a four- or six-line 3-dB Lange coupler will be far below the fabrication limitation of the PCB process if a common substrate is used. The achievement of high directivity and tight coupling with microstrip configuration is carried out by matching the even and odd mode effective phase velocities by using additional capacitance in odd mode [4]. Forward wave directional coupler is presented in [5] which uses periodical ground structures (slots of equal sizes in ground with repetition of itself).

Akhtarzad *et al.* [6] give a design method that seems to reflect the design procedure that finds an application in practice. In [6], the synthesis technique is used, and it has an intermediate step of calculating the strip width of the single microstrip line that corresponds to even- and odd-mode impedances of the coupled lines. However, some critical corrections have to be applied to the formulas given in [6] to have accurate results. There are two separate corrections reported by Hinton [7] and Gupta *et al.* [8] for the work in [6]. Although the error seems to be reduced in comparison to the one in the original work [6] with the application of each correction, the error can still be more than 10% for the low-permittivity materials such as Teflon and FR4 for small values of shape and spacing ratios if the corrections in [7] and [8] are not employed together. We report that when the corrections in [7] and [8] are employed together, the accuracy y of the results increases and the error reduces to within 3%.

In this paper, all corrections presented in [7]-[8] are applied together in synthesis method of [6] with the defected ground structure. Defected ground structures (DGS) are the defects in ground, where the ground plane metal of a microstrip circuit is intentionally modified to enhance performance of the coupler, there are many kinds of defects such as slots, meandered lines, slot variations and dumbbell shapes[9] are, here slots have been taken into effect to realize the tight coupling and the width and the length of the slots varies according to the need ,it simply mean that the coupling can be enhanced by changing the dimensions of the slots in the ground.

II. PROPOSED STRUCTURE

Fig.1 (a) shows the cross sectional view of the coupler with two signal strips on the top and flat ground plane, this structure is the basic structure for the coupler and no modification has been done to improve the coupling. Fig.1 (b) shows the structure of the coupler where we have used the defected ground structure technique; in this type of structure some modifications in the ground plane have been presented with the electric field layout to improve the coupling level. In the ground plane we have inserted two signal strips of width w_s and the spacing between the two inserted signal strips is s_g and the gap of s_1 is taken between the either ends of the inserted strips.



(a) (b) (c)

Fig.1 (a) Shows the cross sectional view of the coupler, (b) Electric field diagram of coupler with DGS

Step-1 The even and odd mode impedances of the coupler is found from

$$Z_{0e} = Z_0\sqrt{\frac{1+10^{C/20}}{1-10^{C/20}}} \qquad 1(a)$$

$$Z_{00} = Z_0\sqrt{\frac{1-10^{C/20}}{1+10^{C/20}}} \qquad 1(b)$$

Where C is the Coupling level in decibels.

Step-2 Find Physical Dimensions s/h and w/h.

The physical dimensions of the directional coupler are found using the synthesis method proposed in [6] and applying the corrections given in [7] and [8]. When the corrections are employed, we get the following equation for the spacing ratio *s/h* of the coupler

$$\frac{s}{h} = \frac{2}{\pi}cosh^{-1}\left[\frac{cosh\left[\frac{\pi}{2}\left(\frac{w}{h}\right)' se\right]+cosh\left[\frac{\pi}{2}\left(\frac{w}{h}\right)' so\right]-2}{cosh\left[\frac{\pi}{2}\left(\frac{w}{h}\right)' so\right]-cosh\left[\frac{\pi}{2}\left(\frac{w}{h}\right)se\right]}\right] \qquad (2)$$

(*w/h*)*se* and (*w/h*)*so* are the shape ratios for the equivalent single case that corresponds to even-mode and odd-mode geometry, respectively. $\left(\frac{w}{h}\right)' so$ is the modified term for the shape ratio and is different from the one that is given in [6, eq. (4)]. The modifications are based on the corrections given in [7] and [8] and are detailed below. (*w/h*) is the corrected shape ratio for the single microstrip line, and it is expressed as

$$\frac{w}{h} = \frac{8\sqrt{[\exp\left(\frac{R}{42.4}\sqrt{(r+1)}\right)-1]\frac{7+(4/r)}{11}+\frac{1+(1/r)}{0.81}}}{[\exp\left(\frac{R}{42.4}\sqrt{(r+1)}\right)-1]} \tag{3}$$

Where

$$R= \frac{Zoe}{2}$$

$$R= \frac{Zoo}{2}$$

Zose and *Zoso* are the characteristic impedances that correspond to single microstrip shape ratios (*w/h*)*se* and (*w/h*)*so*, respectively. They are given as

$$Zose = \frac{Zoe}{2}$$

$$Zoso = \frac{Zoo}{2}$$

$$(w/h)_{se} = (w/h)|_{R=Zose}$$

$$(w/h)_{so} = (w/h)|_{R=Zoso}$$

The corrected term (*w/h*)*so* in (3) is given as [5]

$$(\frac{w}{h})'_{so} = .78(\frac{w}{h})_{so}+.1(\frac{w}{h})_{so} \tag{4}$$

The updated formula in (2) gives accurate results for the spacing ratio *s/h* of the symmetrical two-line microstrip directional coupler when used with (3). After the spacing ratio *s/h* for the coupled lines is found, we can proceed to find *w/h* for the coupled lines, as described in [6]. The shape ratio for the coupled lines is.

$$(\frac{w}{h}) = \frac{1}{\pi} cosh^{-1}(d) - \frac{1}{2}(\frac{s}{h}) \tag{5}$$

Where $$d= \frac{cosh\left[\frac{\pi}{2}(\frac{w}{h})se\right](g+1)+g-1}{2}$$

$$g = \cosh\left[\frac{\pi}{2}(\frac{s}{h})\right]$$

Step 3—Find the Physical Length of the Directional Coupler

The physical length of the directional coupler is obtained using

$$l = \frac{\lambda}{4} = \frac{c}{4f\sqrt{eff}} \tag{6}$$

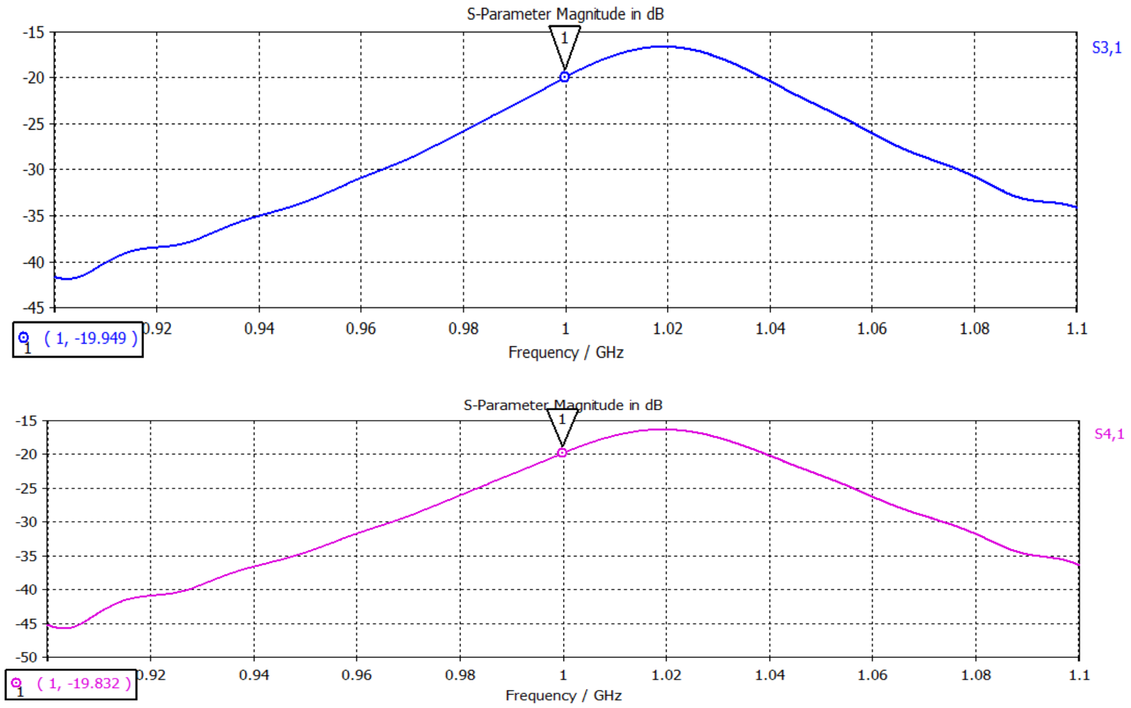
Where c = 3*10^8 m/s, and f is operational frequency in hertz. Hence, the length of the directional coupler can be found if the effective permittivity constant $_{eff}$ of the coupled structure.

$$_{eff} = \left[\frac{\sqrt{_{effe}}+\sqrt{_{effo}}}{2}\right]^2$$

$_{effe}$ and $_{effo}$ depend on even- and odd-mode capacitances *Ce* and *Co*.

III. SIMULATION RESULT

For the structure of coupler shown in Fig.2 calculation of shape ratios is done and then the structure has been implemented on CST SUITE 2010.The simulation results of the coupler verifies the calculation of shape ratios.



(c)

Fig.3 shows (a) shows coupling (S13) (b) shows directivity (S14).

IV. CONCLUSION

This paper presents a practical and complete method to have a symmetrical two-line microstrip directional coupler by analytically introducing a three-step design procedure. The design procedure requires knowledge of the port termination impedances, the coupling level, and the operational frequency, which are the three parameters that are known at the beginning of the design in practice. Results are validated with a CST Studio Suite 2010 simulation tool for FR4 materials that are widely used in microwave applications. Further results are then experimentally verified with analytical results for FR4 substrate. The complete design of a symmetrical two-line microstrip directional coupler can be obtained with minimum error (< 1%) using our result.

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