A Tight Coupling Microstrip Directional Coupler with High Directivity Performance using FE Calculations

Young-Tae Kim, Sang-Hyuk Kim, Seung-Hoon Song, Jun-Seok Park, Jae-Bong Lim and Hyeong-Seok Kim

Abstract - In this paper, we presented a novel structure of microstrip directional coupler for realizing the high directivity characteristic and tight coupling. The achievement of the high directivity with microstrip configuration was carried out by matching the even and odd mode effective phase velocities. By using 2-dimensional finite element (FE) calculations, the phase velocity for each mode and design parameters were extracted for given dimensions. Based on the extracted design parameter with phase-matched condition, we designed and fabricated 3dB and 4.7dB directional coupler at 2.0GHz. Experimental results of microstrip coupler show good performance with excellent isolation characteristics.

Keywords - effective phase velocities, high directivity, microstrip directional coupler, finite element(FE) calculations

1. Introduction

Directional couplers with parallel microstrip coupled transmission line are widely utilized for various RF and microwave applications because they can be easily incorporated into and implemented with other circuits. However, the microstrip directional couplers suffer from poor directivity due to characteristic of the inhomogeneous dielectric including both dielectric substrate and air in microstrip transmission lines. Thus, the phase velocity of even mode in microstrip is not equal to that of odd mode. The directivity performance of microstrip directional coupler becomes worse when the coupling is decreased or the dielectric permittivity is increased.[1] In addition, it is difficult to achieve tight coupling owing to impractical spacing between the coupled lines in conventional edge coupled microstrip couplers. These are reasons for using the broadside stripline configuration for tight coupling and high directivity, which needs more fabrication cost and efforts than a conventional microstrip line coupler. It is very difficult for the stripline configuration to control the directivity. Furthermore, for the tight coupling cases, the coupling and through losses are increased due to relatively high dielectric loss. Several techniques are available to equalize or compensate for the inequality in the each mode velocity of the coupled microstrip line. The wiggly-line coupler first proposed by Podell suffers from a lack of pertinent design information.[2] Dielectric overlays have also been used to equalize the mode phase velocities by increasing the odd mode effective dielectric constant.[3] The capacitively and inductively compensated microstrip directional couplers with high directivity for loose coupling cases were used to equalize the phase velocities.[4] The capacitively and inductively compensated microstrip directional couplers, which have compensated capacitor or inductor near the ports, employ the printed lumped elements. Re-entrant mode coupler was proposed by S. B. Cohn to obtain tight coupling.[5]

In this paper, a novel structure of microstrip directional coupler is presented to achieve high directivity and tight coupling, which has 3dB coupling and more −30dB isolation To equalize the each mode phase velocity, we used the capacitive compensation method with parallel-coupled microstrip line and additional lumped capacitor fabricated using dielectric substrate. The proposed coupler has a long parallel plate capacitive block with microstrip parallel-coupled line section to achieve the tight coupling characteristic. Simultaneously, the long lumped capacitor of the presented structure can be achieved by reducing the difference between the even and odd mode phase velocities for the coupled microstrip line. Based on 2-D finite element (FE) calculations, the phase velocity for each mode and design parameters were extracted for given dimensions. In order to show the effectiveness of newly proposed coupled line structure with additional capacitance, we designed and fabricated a directional coupler to achieve the tight coupling of 3dB and 4.7dB with excellent loss characteristics and high directivity of 32dB and 31dB, respectively.

2. Design procedure

Fig. 1 shows the schematic of the proposed microstrip directional coupler with additional capacitor for tight coupling and high directivity characteristics. This type of proposed coupler is best suited for tight coupling.

Fig. 2 shows the cross sectional view of the proposed

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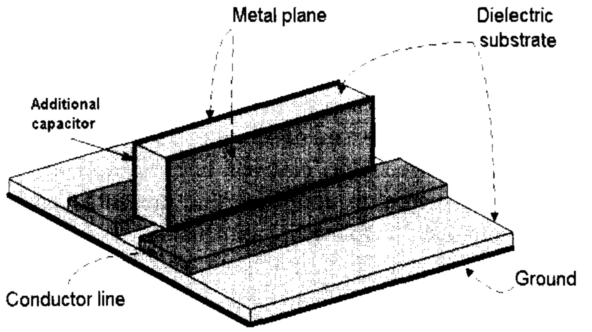

Fig. 1 Schematic of the proposed microstrip directional coupler

microstrip coupler structure with additional lumped capacitor. Dash line indicates electric wall or magnetic wall when even or odd mode excitations were applied to the proposed coupled line structure.

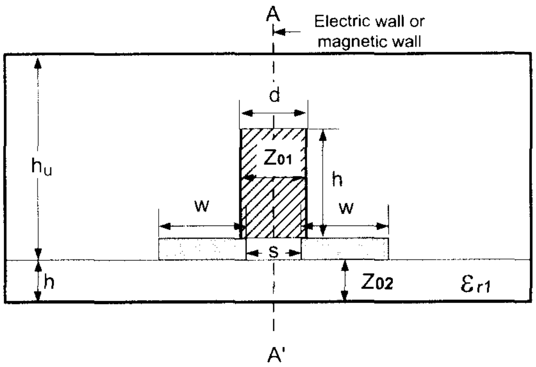

Fig. 2 Cross section view of the proposed microstrip coupler

All parallel-coupled lines, which are supported by any TEM, have the even and odd mode property. The even mode characteristic impedance Z_{oe} and odd mode characteristic impedance Z_{oo} can be extracted by calculating the characteristic impedance under each mode excitations, respectively. Since the structure can be bisected through its vertical symmetric plane when the even and odd modes are excited as shown Fig. 2, the characteristic impedances of even and odd modes can be derived as follow

$$Z_{oe} = Z_{02} \tag{1}$$

$$Z_{oo} = Z_{02} + \frac{Z_{01}}{2} \tag{2}$$

where Z_{01} means characteristic impedance between additional metal planes above microstrip line, Z_{02} is characteristic impedance between ground plane and microstrip line in Fig 2. This means that the microstrip line section mainly affects to the even mode operation and the additional long parallel capacitive block dominantly determines the odd mode operation of coupler due to higher capacitance value of additional capacitive block than that of microstrip section. In/output matching condition and coupling factor for any directional coupler are given by

$$Z_o = \sqrt{Z_{oe}\,Z_{oo}} \tag{3}$$

$$k = \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}} = \left|\frac{-Z_{01}}{4Z_{02} + Z_{01}}\right| \tag{4}$$

$$Z_{oe} = Z_0\sqrt{\frac{1+k}{1-k}} \quad \text{and} \quad Z_{oo} = Z_o\sqrt{\frac{1-k}{1+k}} \tag{5}$$

where Z_0 and k mean the characteristic impedance and the voltage coupling coefficient, respectively. In the above analysis, it was assumed that the even and odd modes of the coupled line structure have the same velocities of propagation, so that the line has the same electrical length for both modes. For a coupled microstrip, or other non-TEM, this line condition will generally not be satisfied. Generally, the effective permittivity of even mode is greater than that of odd mode in a conventional microstrip coupled line. Thus, the phase velocities for each mode become different. The disagreement of phase velocities gives rise to deterioration in isolation characteristic for conventional microstrip couplers. In order to improve the isolation characteristic in microstrip, the difference in phase velocities should be considered. Fortunately, From Eq.(2) the odd mode impedance Z_{oo}, which is related to odd mode phase velocity by Eq.(7), can be adjusted by changing Z_{01}, which is determined by the distance between the metal planes and the height shown in Fig.2. It is possible to control odd mode impedance Z_{oo} and coupling factor k without any effect for Z_{oe}. Thus, the even and odd mode phase velocity can be well matched.

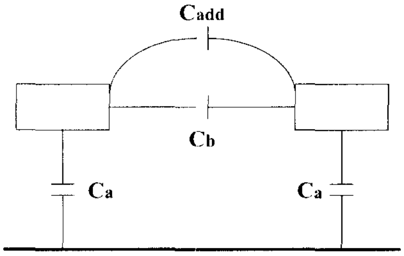

Fig. 3 The equivalent capacitances of proposed structure

Fig 3. shows the equivalent capacitances of presented structure. Capacitance '*Cadd*' indicates capacitance between additional metal planes above microstrip line as shown Fig. 2. In the presented equivalent capacitance circuit, we can control the odd mode phase velocity by additional capacitance '*Cadd*'. Furthermore '*Cadd*' is available to solve the problem for achieving tight coupling owing to impractical spacing between the coupled lines in conventional edge coupled microstrip couplers.

$$v_{pe} = \frac{1}{Z_{oe}C_a} \tag{6}$$

$$v_{po} = \frac{1}{Z_{oo}(C_a + 2C_b + 2C_{add})} \qquad (7)$$

In this paper, design parameters of proposed structure shown in Fig.1 were investigated using numerical calculations based on FEM algorithm. Goals of calculation procedures for the extraction of design parameters are intended to find the acceptable geometric dimensions when the difference of effective permittivities between the even and odd mode become zero. Dielectric constant of substrate for simulations and fabrication was chosen to be 3.05 with 60mils thick and 2.17 with 10mil for additional capacitor.

3. Simulation and Measurement

To make even and odd-mode effective permittivity be equal for high directivity, the effective microstrip permittivities are calculated as followings;

$$\varepsilon_{effe} = \frac{C_e}{C_{e1}} \qquad (8)$$

$$\varepsilon_{effo} = \frac{C_o}{C_{o1}} \qquad (9)$$

where the second subscript 1 refers to a free-space ('air') line.

In order to get the capacitance of even and odd mode in microstrip directional coupler as show in Fig. 2, we firstly have to calculate the stored energy within the coupler using FE calculations.[6],[7] Regardless of the dielectric media involved, the stored energy is given by

$$W = \frac{1}{2}\int \varepsilon_0 \varepsilon_r \nabla u \cdot \nabla u \quad dS \qquad (10)$$

where ε_0, ε_r are the permittivity of free space, relative permittivity and u means the electric potential. From the energy W, the capacitance is then found as

$$C = \frac{2W}{(\Delta u)^2} \qquad (11)$$

where Δu means the potential difference between the two conductors.

The even and odd mode characteristic impedances are then

$$Z_{0e} = (c\sqrt{C_e C_{e1}})^{-1} = \frac{\sqrt{\varepsilon_{effe}}}{cC_e} \qquad (12)$$

$$Z_{0o} = (c\sqrt{C_o C_{o1}})^{-1} = \frac{\sqrt{\varepsilon_{effo}}}{cC_o} \qquad (13)$$

where c is the velocity in free space. From Eq. (12) and (13), voltage coupling coefficient factor k can be calculated by using (4). In order to show the validity of this structure for tight coupling and high directivity, microstrip directional coupler with additional capacitor was designed and fabricated in case of coupling value 3dB and 4.7dB. It is very difficult to achieve 3dB coupling owing to impractical spacing between the coupled lines in conventional edge coupled microstrip couplers. The presented coupler was implemented by following dimension; 1) in case of 3dB, w=1.25mm, s=0.2mm, h=0.8mm, and d=0.254mm, 2) in case of 4.7dB, w=1.77mm, s=0.2mm, h=0.5mm, and d=0.254mm.

Fig. 4 and 5 show simulation results of microstrip coupler with 3dB and 4.7dB coupling, which was done by Ansoft HFSS, respectively. Simulation results show that the designed directional coupler has the directivity of 29dB and 31dB at center frequency 2GHz with excellent matched characteristic

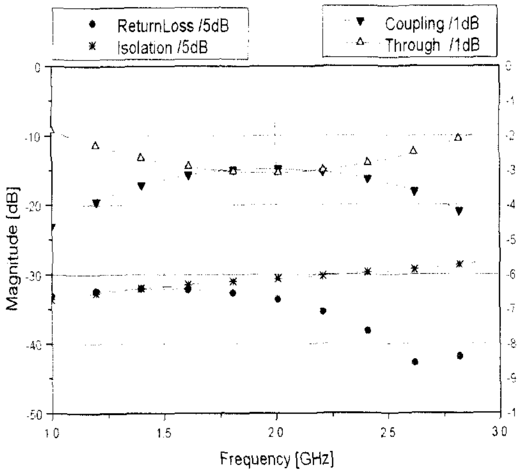

Fig. 4 Simulation result of 3dB microstrip coupler

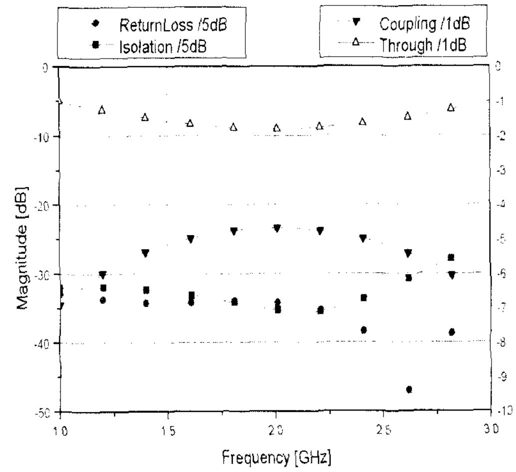

Fig. 5 Simulation result of 4.7dB microstrip coupler

The measured results of fabricated microstrip directional coupler are shown in Fig.6 and 7. Measured results show about 3.15dB and 4.87dB of coupling, less 30dB of return loss, and 32dB and 31dB of directivity at center frequency 2.0GHz, respectively. Measured performances show excellent agreement with predicted results.

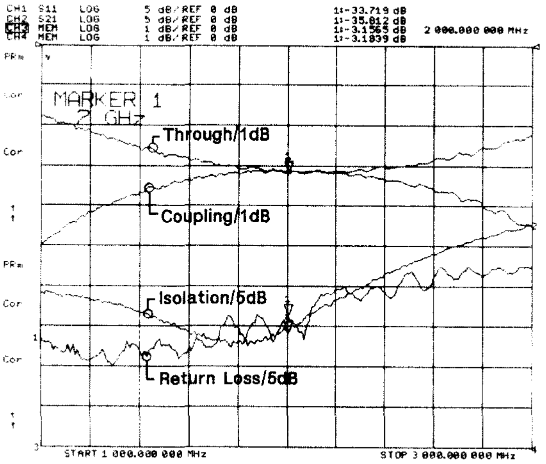

Fig. 6 Measured result of 3dB microstrip coupler

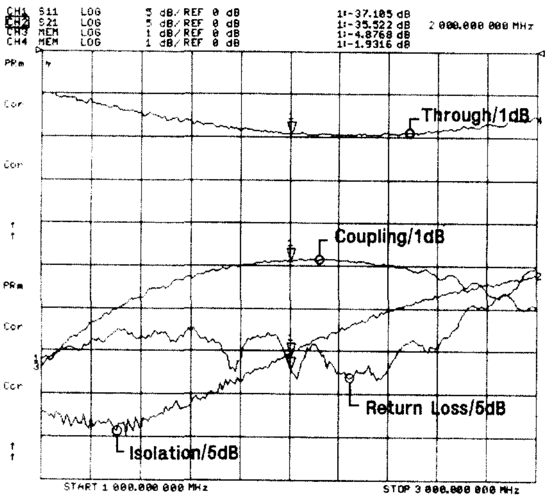

Fig. 7 Measured result of 4.7dB microstrip coupler

4. Conclusions

In this paper, we proposed a new structure of microstrip directional coupler with additional long capacitor block to obtain high directivity and tight coupling characteristics, simultaneously. The design procedure is based on the 2-dimensional FE calculations. By changing geometric dimensions of the proposed directional coupler, we can adjust the effective permittivity of odd mode to be equal with that of even mode for the achievement of an identical phase velocity ratio. The proposed tight coupling directional coupler could provide excellent loss characteristic with high directivity. Experimental results on the fabricated microstrip directional coupler showed the validity of the proposed structure and design procedure. Improvements of poor isolation characteristic and impractical spacing for a conventional microstrip directional coupler with tight coupling can be achieved by using the proposed structure and design procedure. Furthermore, the manufacturing cost and efforts are more improved than the stripline configuration because that the proposed tight coupling directional coupler can be easily implemented by simple soldering process between the microstrip section and the additional parallel plate capacitor block.

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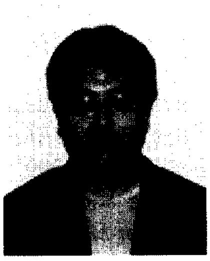

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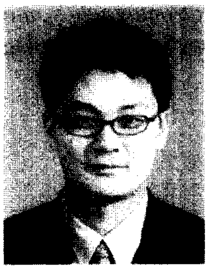

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