growth rate $a = 0.65$ and $1.05$, substrate thickness $h = 0.5$ mm, and relative dielectric constant $\varepsilon_r = 9.8$.

4. SIMULATED AND MEASURED RESULTS

The antenna with the proposed feed and a shallow cavity was fabricated, and its return loss was measured by using the vector network analyzer HP8722ES. The simulated and measured results are shown in Figure 5. The measured return loss is less than $-10$ dB from 0.75 GHz to 8 GHz. The simulated axial ratio is less than 3.5 dB from 0.95 GHz to 8 GHz as shown in Figure 6. The simulated radiation patterns are shown in Figure 7, showing that the forward radiation is enhanced by using the back cavity.

The diameter of proposed antenna is $50$ mm, whereas for an ordinary spiral antenna it is about $D = \lambda/2 \approx 200$ mm when operating at $0.75$ GHz. Therefore, it is only one fourth of that of the ordinary one, and the area of the proposed antenna is only as small as 6.25% of the conventional spiral antenna. So the antenna size is greatly reduced.

5. CONCLUSION

A planar compound spiral antenna has been introduced. The antenna has good impedance characteristics from 0.75 GHz to 8 GHz (10.7:1) with a simple feed and a shallow back cavity, whereas the area of the antenna is only about 6.25% of that of the conventional spiral antenna. Therefore, this antenna is promising for SWB CP antenna applications.

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SYMmetric MICROstrip INTERdigital CAPACitor-Compensated HIGH DIRECTivity DIRECTIONal-COUpler

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Received 15 March 2008

ABSTRACT: This article describes a symmetric capacitor-compensated microstrip directional-coupler design with very high directivity. The compensation capacitors are incorporated between the coupling lines as interdigital type on the PCB board. The prototype directional-coupler
shows 19.6 dB coupling factor and achieves very high directivity of more than 45 dB at 1.9 GHz; © 2008 Wiley Periodicals, Inc.
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Key words: directivity; interdigital; capacitor; directional; coupler

1. INTRODUCTION

A microstrip directional coupler is an elemental building block in hybrid microwave circuit and system. One of main design concern is the directivity, which is originated from the mismatch of even and odd mode phase velocities due to the inhomogeneous dielectric constant [1]. These inconsistent dielectric constants between two modes can be compensated by attaching an overlay material with high dielectric constant on top of the coupler [2]. However, adding reactive elements on the coupled lines is easier to implement and more effective for equalizing even and odd modes phase velocity. The reactive elements can be capacitive [3] or inductive components [4]. The distributed implementation is also reported [5]. But these techniques request some additional lumped elements or dedicated fabrication procedure.

In this letter, a directional coupler using symmetric microstrip interdigital-capacitors is proposed, which is very simple to fabricate for loosely coupled directional coupler and can provide very good directivity performance without additional component and size increment.

2. COUPLER DESIGN

Figure 1 shows the schematic diagram of a symmetric capacitor-compensated directional-coupler. The coupler design goal is to obtain the target coupling, low return loss, and high directivity simultaneously at the wanted frequency, which can be described by the reflection and transmission coefficients that are derived from ABCD matrix. As noted in Ref. 4, the minimum return loss and maximum directivity can be achieved at conditions of $r_e = -r_o$ and $T_e = T_o$, where $r_e$, $r_o$, $T_e$, $T_o$ are the reflection and transmission coefficients of even and odd modes.

These two requirement can be met when $A_o = A_e = D_o = D_e = 0$ and $B_o D_e = B_e D_o$. Because the uncompensated coupler or asymmetrical coupler cannot satisfy these conditions, the directivity or the return loss cannot be simultaneously optimized. However, addition of symmetric capacitors on the edges modifies odd mode characteristic to comply with these demands, when even mode remains unchanged. The ABCD parameter of the symmetric capacitor-compensated directional-coupler can be described as follows:

$$
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}_e = \begin{bmatrix}
\beta_e & jZ_o \alpha_e \\
-jV_o \alpha_e & \beta_e
\end{bmatrix} \begin{bmatrix}
A & B \\
C & D
\end{bmatrix}_o
$$

where $\alpha_e = \sin(\theta_e)$, $\alpha_o = \sin(\theta_o)$, $\beta_e = \cos(\theta_e)$ and, $\beta_o = \cos(\theta_o)$. Assuming $\theta_e = \pi/2$, $C_e$ for zeroing the value of $A_e$ and $D_e$ can be found in (2), and the compensated characteristic impedance at odd mode is described as follows:

$$
C = \frac{\cot(\theta_e)}{2\omega Z_o \alpha_o} Z_{oc} = Z_o \sin(\theta_o),
$$

and the coupling factor, $k$ is determined by characteristic impedances as follows:

$$
k = \frac{Z_{oc}^2 - Z_o^2}{Z_{oc}^2 + \alpha_o^2 Z_o^2}
$$

The compensation capacitors shift the frequency when $k$ is maximized to a little lower than that of uncompensated coupler. Therefore, the compensation capacitance slightly increases compared with (2). The compensating capacitors are implemented using microstrip interdigital type as shown Figure 1(b). Interdigital type is effective in loosely coupled application because it provides moderate capacitance in small area, which can be embedded between two coupled lines as shown in Figure 1(b) [6]. The required capacitance is around 70 fF for the exemplary 20 dB coupler.

Figure 1 Schematic diagram for analysis of the directional-coupler (a) capacitor-compensated (b) microstrip interdigital capacitor compensated
The simulation is performed in schematic level using precalculated parameters and through 2.5D EM simulation the geometric parameters are tuned. Figure 2 shows the simulation results of 20 dB directional coupler with and without compensation capacitor. The directivity improves more than 50 dB compared with that of uncompensated coupler. And also low return loss is achieved when meeting required coupling factor at the center frequency of 1.9 GHz.

3. EXPERIMENT RESULT
The proposed directional-coupler is implemented using a Duroid substrate with relative dielectric constant of 3 and the thickness 3 mil (Figure 3). The measurement of the exemplary 20 dB coupler centered at 1.9 GHz was done using an HP8753 vector network analyzer. For accurate measurement, the narrow resolution bandwidth is set to 2 kHz. Figure 4 shows measured frequency response of the directional-coupler. The coupling factor is around 19.6 dB, and the return loss is less than 35 dB. And also very high directivity of more than 45 dB is achieved at the center frequency. Because the frequency where the directivity is minimized is sensitive to the interdigital capacitor width, $W_1$ and gap size, $G_1$, the pattern was carefully patterned. However, the average measurement data on the directivities of several samples shows more than 40 dB. Table 1 summarizes the physical dimension of the proposed directional-coupler

4. CONCLUSION
This letter presents a microstrip directional coupler with high directivity using microstrip interdigital capacitor compensation, which is useful to obtain high directivity as well as low return loss. The introduced coupler shows very high directivity of more than 40 dB without additional components or size increment.

ACKNOWLEDGEMENT
This research was partially supported by the Chung-Ang University Excellent Researcher Grant in 2008.

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