Compact capacitive compensated directional coupler using planar artificial transmission lines

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A novel compact directional coupler based on planar artificial transmission lines is proposed. Interdigital capacitors are introduced to compensate for the odd-mode phase velocity in order to achieve a high directivity. The size of this proposed coupler is about 25% that of a conventional one. A 20 dB directional coupler at 900 MHz has been designed and fabricated. The directivity reaches 36 dB at the centre frequency. The design, simulation and measurements are presented.

Introduction: Compact microwave components have been required in many applications in recent years. Directional couplers are widely used in communication and measurement systems. Conventional microstrip directional couplers are realised by a pair of coupled transmission lines. They are easily realised on a standard printed-circuit board, but are not compact owing to the length (quarter-wave) of the coupled transmission lines. A few high directivity directional couplers have been proposed [1, 2]. The capacitance compensation is a valid method to enhance the directivity with shunt or coupling capacitors [3–5].

A novel weak coupling compact directional coupler is proposed in this Letter. It is composed of two planar artificial transmission lines with interdigital capacitors in between. A 20 dB directional coupler is designed and measured. The size is reduced greatly, while low insertion loss, high return loss and high directivity are obtained.

Principles: Novel planar artificial transmission lines (ATLs) have recently been proposed to miniaturise conventional microstrip lines. They are composed of microstrip quasi-lumped elements and their discontinuities with PCB techniques. Transmission lines may be synthesised with a wide range of characteristic impedances and electrical lengths. Three meandered-line inductors, two interdigital capacitors and four parallel-plated capacitors are applied to building a symmetric ATL unit. If both the series inductance and the shunt capacitance increase proportionally, the phase constant increases but the characteristic impedance remains unchanged. The design and realisation of ATLs and the equivalent circuit analysis can be found in [6].

The direct coupling between two ATLs is very weak. The meander lines are applied to be the coupling components, as shown in Fig. 1*a*, in which the ATLs are non-symmetric structures. Also, an interdigital capacitor is introduced between ATLs to enhance the directivity further.

As a coupled line coupler, the required even- and odd-mode characteristic impedances Z_{0e} and Z_{0o} are related to the voltage coupling factor k as follows:

$$\begin{cases} Z_{0e} = Z_0\sqrt{\dfrac{1+k}{1-k}} \\ Z_{0o} = Z_0\sqrt{\dfrac{1-k}{1+k}} \end{cases} \tag{1}$$

In practical couplers, the phase velocities of the even- and odd-mode are usually different. The capacitive compensation is a valid method to achieve high directivity by equalising the phase velocities of both modes. We introduce an interdigital capacitor in the proposed coupler to affect the odd-mode phase velocity and Z_{0o} without effects to even-mode parameters. The interdigital capacitor C_{comp} is [7]

$$C_{comp} = \frac{1 - \tan^2 \theta_o/2}{\omega_0 Z_{0o}} \tag{2}$$

where θ_o is the electrical length of the odd mode at the desired operating frequency ω_0. Then, the even- and odd-mode phase velocities are well matched.

The design procedure is concluded as follows: (a) design two ATLs with $Z_c = 50\ \Omega$ and $\theta_{ALT} = \pi/4$ at ω_0, and obtain Z_{0e} and Z_{0o} by (1) for a given coupling factor k; (b) determine the gap between two ATLs from Z_{0e}, since Z_{0e} is not changed by the compensative capacitor, and calculate θ_o by EM simulation; (c) introduce an interdigital capacitor between ATLs with capacitance obtained from (2). The interdigital capacitor is designed from [8].

Simulation and measurements: A coupler with 20 dB coupling factor at $f_0 = 900$ MHz has been designed and fabricated. A photograph of the fabricated coupler is shown in Fig. 1*b*. The overall dimensions are 30 by 23 mm or, equivalently, $0.09\lambda_0$ by $0.07\lambda_0$, which is about 25% of a conventional directional coupler, where λ_0 is the free space wavelength at ω_0. It was realised on F4B substrate of 1 mm thickness with dielectric constant of 2.65 and loss tangent 0.001. The characteristic impedance of each ATL is Z_0, and the phase delay remains $\pi/2$. The 50 Ω microstrip line at each port has a width of 2.7 mm. The layout was designed from the above procedure, in which C_{comp} is 0.56 pF. The parameters are given by $l_1 = 6.5$ mm, $l_2 = 6.4$ mm, $l_3 = 2.8$ mm, $l_4 = 1.6$ mm, $l_5 = 0.9$ mm, $l_6 = 1.3$ mm, $s_1 = s_2 = w_2 = 0.4$ mm, $s_3 = 1.4$ mm, $s_4 = 0.2$ mm, and $w_1 = 5.4$ mm.

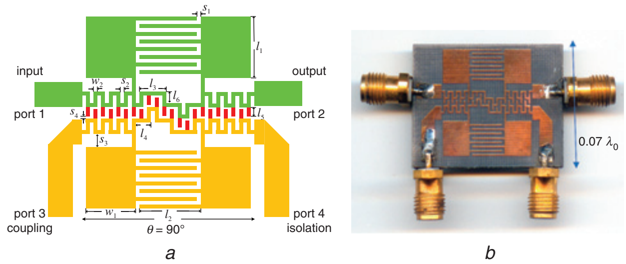

Fig. 1 *Circuit layout and fabricated directional coupler*

a Circuit layout
b Photograph

The simulated Z_{0e} and Z_{0o} from IE3D with and without the capacitive compensation are shown in Fig. 2*a*, Z_{0o} is greatly dependent on the capacitive compensation, while Z_{0e} is not. Fig. 2*b* shows the normalised propagation constant β/β_0 of the even- and odd-mode, which are well matched at ω_0. There is a noticeable difference between them if the capacitive compensation is not applied.

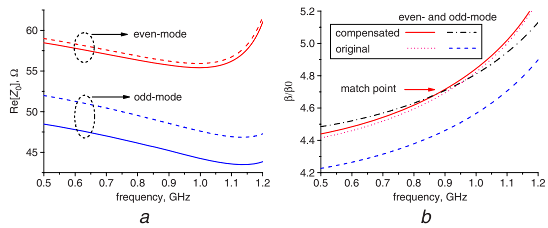

Fig. 2 *Characteristics of even- and odd-mode*

a Characteristic impedance
——— with capacitive compensation
- - - - - without capacitive compensation
b Propagation constant

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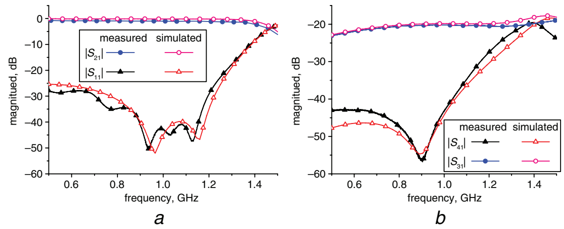

Fig. 3 *Simulated and measured S-parameters*

a $|S_{11}|$ and $|S_{21}|$
b $|S_{31}|$ and $|S_{41}|$

Measurements were performed by an Agilent E8263B vector network analyser. The simulated and measured *S*-parameters are illustrated in Figs. 3*a* and *b*. At 900 MHz, the insertion loss is less than 0.7 dB, and the best return loss is 55 dB. $|S_{11}|$ is less than −20 dB from 0.5 to 1.2 GHz. The coupling factor is 20.3 dB at 900 MHz, and the maximum isolation reaches 56 dB, which gives a directivity of 36 dB. The bandwidth of the proposed coupler is 360 MHz (from 0.67 to 1.03 GHz) with directivity higher than 20 dB and a coupling factor variation within −1 to +0.2 dB. Another two couplers with coupling factors of 26 and 30 dB were fabricated. Measurements agree well with designs, and high directivities are achieved by introducing the capacitive compensation as well

Conclusions: A novel weak coupling directional coupler using ATLs is presented. A high directivity is obtained by capacitive compensation with an interdigital capacitor introduced between two ATLs. The size is only 25% of that of a conventional one. The couple-shows good return loss, reasonable bandwidth and high directivity. It can greatly miniaturise the conventional directional couplers in low frequency microwave systems.

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One or more of the Figures in this Letter are available in colour online.

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