NOVEL MICROSTRIP DIRECTIONAL BAND-PASS/BAND-STOP COUPLERS AND FILTERS

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ABSTRACT

A new class of microstrip band-pass/band-stop and periodic couplers and filters are described in this paper. Multi-function performance can be obtained from these components due to their directional properties. The design aspects and the predicted results of these circuits are presented. The theory is verified by an experimental band-pass coupler designed on alumina substrate.

1. INTRODUCTION

The advances in the sophisticated low-power signal processing techniques have a growing demand for multi-function components which simplify system integration problems with improved performance. Many multi-function components are preferably wideband. Recently, the complete design technique for ultrawideband directional couplers have been reported by Uysal et al [1]. These symmetrical MIC components have numerous applications in the microwave engineering field. However, one major drawback of these components has been the out-of-band coupling which is a strong function of frequency. Although this argument is valid for uniform directional couplers, it may not be the same for nonuniform directional couplers. The continuous coupling coefficient distribution function can be modified to minimize the out-of-band coupling. This novel technique will be described in the following sections to design directional band-pass/band-stop and periodic couplers and filters in inhomogeneous media.

2. DESIGN PROCEDURE

The coupled output signal of a nonuniform directional coupler is given by

$$C_{e,o}(\omega) = 2\int_0^{\frac{l}{2}} \sin(2\omega \frac{x}{v_{e,o}})\, p_{e,o}(x)\, dx \qquad (1)$$

where e and o denote the even- and odd-modes, respectively, l is the coupler length, v is the velocity in the guide and $p(x)$ is the reflection coefficient distribution function. For a band-pass directional coupler it can be deduced from [1] that the reflection coefficient distribution function in inhomogeneous media is given by

$$P_{e,o}(x) = -\frac{2}{\pi v_{e,o}} \int_0^{\omega_1} \sin(2\omega \frac{x}{v_{e,o}})\, C_{e,o}(\omega)\, d\omega + \int_{\omega_1}^{\omega_2} \sin(2\omega \frac{x}{v_{e,o}})\, C_{e,o}(\omega)\, d\omega + \int_{\omega_2}^{2\omega_c} \sin(2\omega \frac{x}{v_{e,o}})\, C_{e,o}(\omega)\, d\omega \qquad (2)$$

where e and o denote the even- and odd-modes, respectively, v is the velocity in the guide, $C_{e,o}(\omega)$ is the specified coupling for each section.

The continuous coupling coefficient can then be determined from

$$k(x) = \frac{e^{2\int_0^x p_e(x)\,dx} - e^{2\int_0^x p_o(x)\,dx}}{e^{2\int_0^x p_e(x)\,dx} + e^{2\int_0^x p_o(x)\,dx}} \qquad (3)$$

3. BAND-PASS COUPLERS AND FILTERS

The desired band-pass performance is illustrated in Fig.1. What is shown in this figure, is a multi-function circuit. Equal power division (-3 dB) occurs in the pass-band between f_{B1} and f_{B2}, and the rest of the signal exits from the direct output. A tandem connection of this band-pass coupler would then result in the band-pass/band-stop filter in the design bandwidth.

A perfect cancellation of the coupled signal below f_{B1} and above f_{B2} is not possible. To investigate this, the coupled signal in these bands is set to be equal to zero. The computed performance for this case is shown in Fig.2. There is a finite signal in

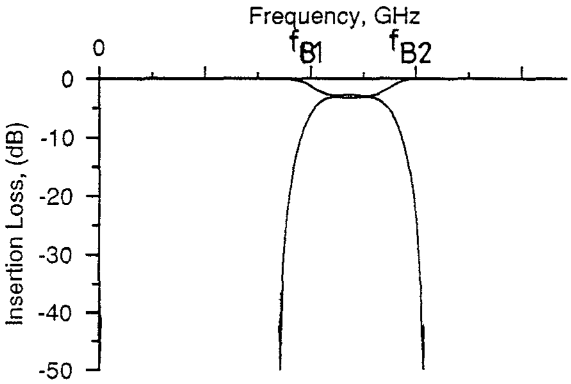

Fig.1 Desired band-pass coupler performance.

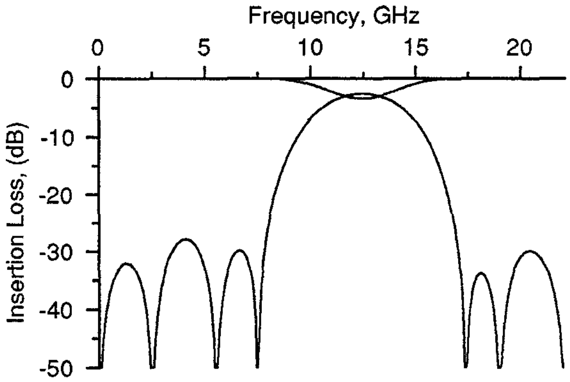

Fig.2 Computed band-pass coupler performance with specified zero out-of-band coupling.

the out-of-band regions and this signal has several null points (the number of nulls depends on the coupler length). Fig.3 shows the coupling coefficient

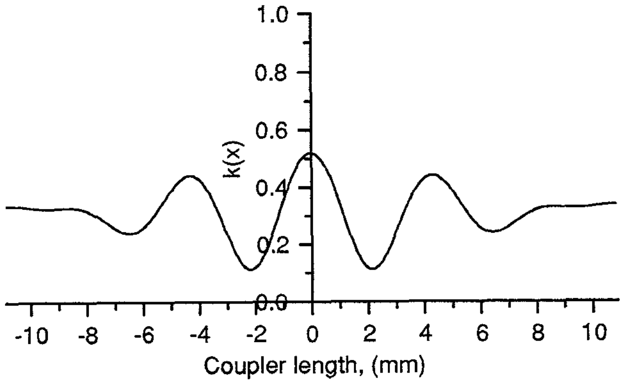

Fig.3 Computed coupling coefficient along the coupler length.

along the coupler length for this design. The computations are carried out with the following specifications:

Impedance level, $Z_o = 50\ ohm$
Substrate : Alumina
Dielectric constant, $\varepsilon_r = 9.9$
Thickness, $h = 0.635\ mm$
Phase velocities with $N = 2$
Even-mode, $v_{2e} = 99.10^9\ mm/sec$
Odd-mode, $v_{2o} = 99.10^9\ mm/sec$
Phase velocities with $N = 4$
Even-mode, $v_{4e} = 110.10^9\ mm/sec$
Odd-mode, $v_{4o} = 120.10^9\ mm/sec$
Band-pass coupler design bandwidth:
lower band-edge, $f_{B1} = 10\ GHz$
upper band-edge, $f_{B2} = 14\ GHz$
Number of sections, $N_x = 10.0$
The total coupler length can be found from:

$$l = \frac{v}{4f_c}(N_x - N_y) + \frac{v_{4e} + v_{4o}}{8f_c} N_y \tag{4}$$

where $v = v_{2e} = v_{2o}$, $f_c = \frac{f_{B1} + f_{B2}}{2}$ and N_y is an adjustable variable which determines the length of the interdigitated section.

The coupling in the out-of-band regions can be set to non-zero but very small values. This can be done in several ways as illustrated in Fig.4. From

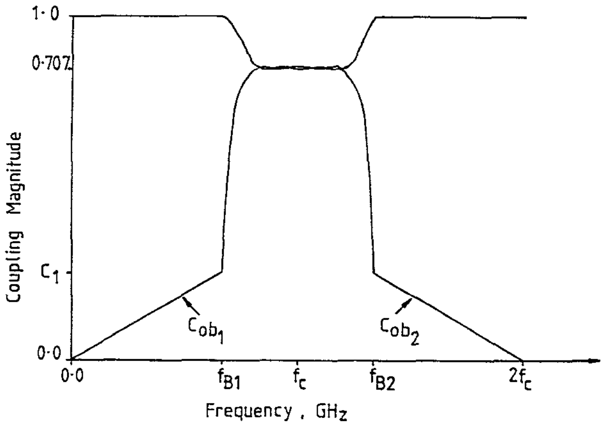

Fig.4 Specified band-pass coupler performance with non-zero out-of-band coupling.

this figure the equation defining C_{ob_1} can be deduced as

$$C_{ob_1} = \frac{C_1}{(f_{B1})^{\frac{1}{q}}} f^{\frac{1}{q}} \tag{5}$$

where C_1 is the maximum allowable out-of-band coupling and with $q = 1$, C_{ob_1} is linear and as $q \to \infty$, $C_{ob_1} \to C_1$. A similar formulation is valid for C_{ob_2}.

The aim of specifying non-zero coupling values in the out-of-band regions is to ease the coupling requirements along the coupler length. Sharp coupling variations may cause some errors in the physical realization. Therefore, the coupling requirements can be varied according to the design bandwidth, the number of sections and the physical realizability of the design.

4. PERIODIC COUPLERS AND FILTERS

Periodic channeling filters are used in the minimization of single-tone intermodulation products [2], baseband conversion for detection, analysis and sorting for EW and satellite applications.

A periodic filter can separate input channel frequencies $f_1+f_2+f_3+f_4+f_5++......$ into $f_1+f_3+\cdots$ and $f_2+f_4+\cdots$, alternately. The main components for these filters are -3 dB hybrids and band-pass filters. Several of these components are usually required to divide the input signal into proper channels. Breuer et al [3] have reported a channeling filter which divides 26-42 GHz signal into contiguous 4 GHz wide channels by using six -3 dB waveguide couplers and seven band-pass waveguide filters. Recently, a microstrip periodic filter using four -3 dB directional couplers and phase-shifting elements in the 2-18 GHz with, again, 4 GHz wide channels, is reported by Uysal et al [4]. Other forms of channeling filters have also been reported in the literature [5-6]. However, one common noticeable feature of these filters is the extensive use of circuitry to achieve the desired channelization of the input signal.

This study significantly advances the state of the art of the realization of channelization filters both at microwaves and millimetre waves. This novel technique uses two frequency selective -3 dB directional couplers connected in tandem thereby eliminating any additional circuitry in the realization of periodic channeling filters.

4.1 Design Principles and Computations

When two -3 dB symmetrical couplers are connected in tandem, 0 dB coupling value is obtained from the coupled output and no signal exits from the direct output. If the coupler is designed strictly for -3 dB coupled output in a specified bandwidth, then the rest of the signal exits from the "subtracting output" of the tandem coupler. Periodic coupling can be obtained from nonuniform coupled lines. This requires the reflection coefficient distribution function to be divided according to the desired number of subbands in the entire design bandwidth. The reflection coefficient distribution function in inhomogeneous media for the channelized coupler can be deduced as

$$P_{e,o}(x) = -\frac{2}{\pi v_{e,o}} \int_0^{\omega_1} \sin(2\omega\frac{x}{v_{e,o}})\, C_{e,o}(\omega)\, d\omega + \int_{\omega_1}^{\omega_2} \sin(2\omega\frac{x}{v_{e,o}})\, C_{e,o}(\omega)\, d\omega + \int_{\omega_2}^{\omega_3} \sin(2\omega\frac{x}{v_{e,o}})\, C_{e,o}(\omega)\, d\omega + \int_{\omega_3}^{\omega_4} \sin(2\omega\frac{x}{v_{e,o}})\, C_{e,o}(\omega)\, d\omega + \int_{\omega_4}^{\omega_5} \sin(2\omega\frac{x}{v_{e,o}})\, C_{e,o}(\omega)\, d\omega \quad (6)$$

The design procedure given in [1] can be employed to optimize eqn.(1) with $C_{e,o}(\omega)$ set to zero in the appropriate channels. For the computations the previous specifications with $N_x = 16.0$ are used with the following channel crossover frequencies: Channel crossovers: $f_1 = 2.0\ GHz$, $f_2 = 6.0\ GHz$, $f_3 = 10.0\ GHz$, $f_4 = 14.0\ GHz$, $f_5 = 18.0\ GHz$.

The predicted result for the periodic coupler is shown in Fig.5.

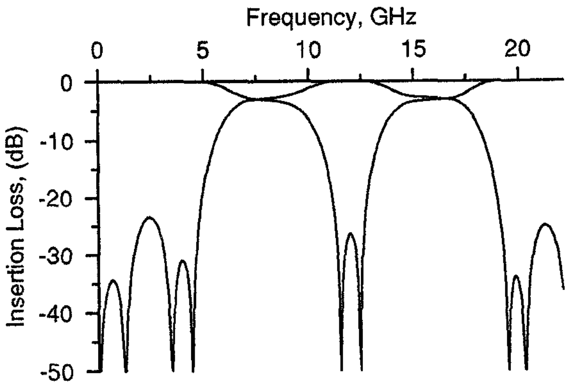

Fig.5 Computed performance of the periodic coupler.

5. EXPERIMENTAL RESULTS

For the experimental verification of the theoretical work presented in this paper, the band-pass coupler designed on 1x1x0.025 $inch^3$ alumina substrate is used. This band-pass coupler is specifically designed to fit the available box dimensions. The schematic diagram of this circuit is shown in Fig.6.

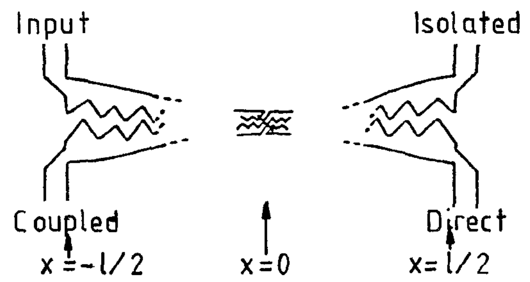

Fig.6 Schematic diagram of band-pass coupler.

The band-pass coupler is measured on an HP8510B Network Analyser. The measured results are shown in Fig.7(a-d). The out-of-band coupling is measured to be -12 dB. The passband is sharp with excellent coupling balance within 0.5 dB. The measured isolation and return loss are both less than -15 dB in the 0.1-18.1 GHz band. The phase quadrature is good and changes sign at zero coupling values.

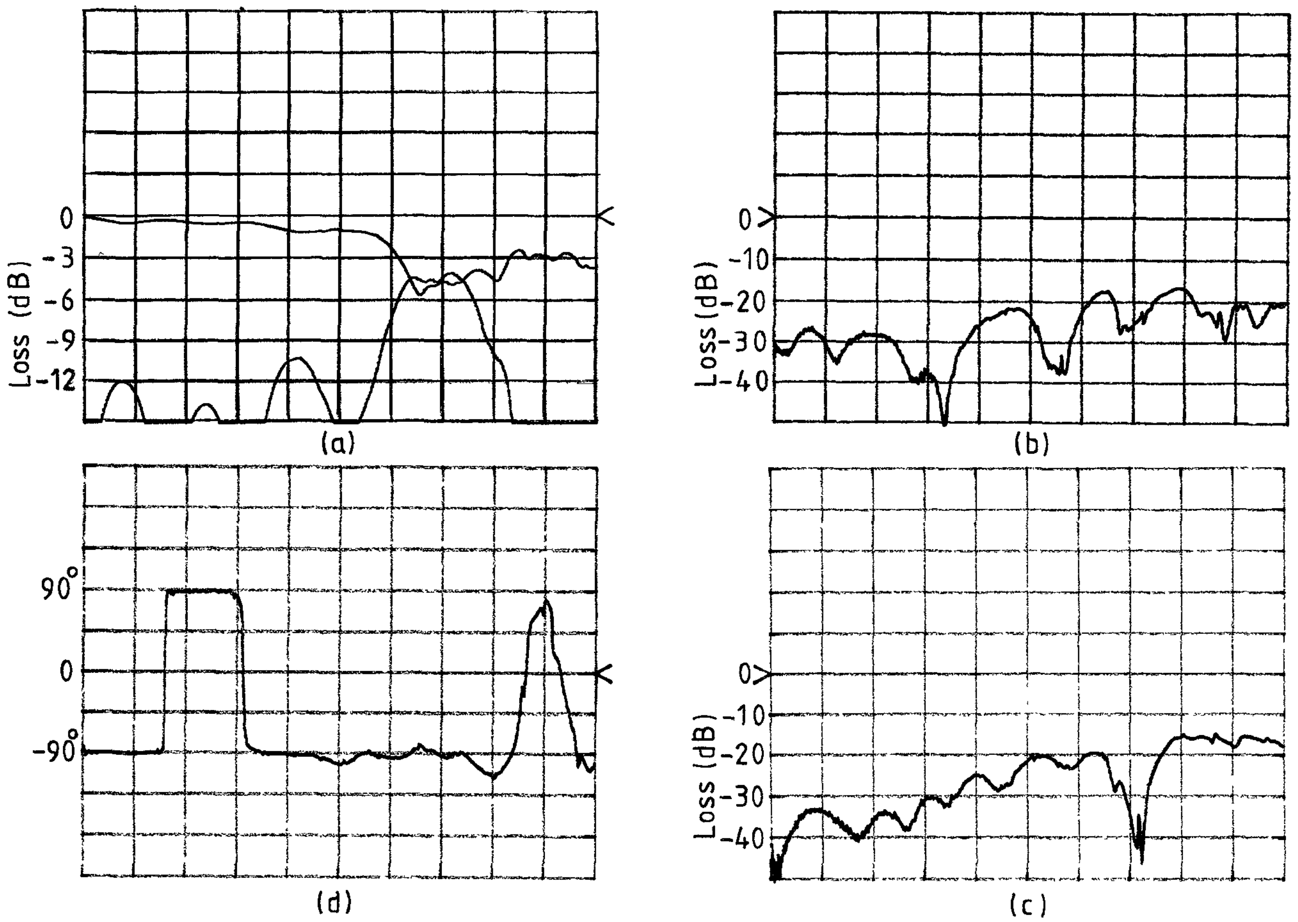

Fig.7 Measured band-pass coupler performance, (a) coupled and direct ports, (b) return loss, (c) isolation, and (d) phase quadrature.

START 0.100000000 GHz
STOP 18.100000000 GHz

6. CONCLUSIONS

The design of novel band-pass/band-stop and periodic couplers/filters are presented in this paper. This new class of multi-function components can be used in many applications with improved performance due to their directional properties.

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