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PLANAR EIGHT PORT WAVEGUIDE MONO-PULSE COMPARATOR

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Abstract—This paper suggests a new method for the designing of planar eight port waveguide mono-pulse comparator. Planar eight port waveguide mono-pulse comparator acts as a four-way in-phase power divider in a transmitting mode and as a mono-pulse sum and difference combining hybrid in the receiving mode. The short-slot directional coupler is converted to an equivalent magic tee by adding dielectric-slab-filled waveguide phase shifter. Four magic tees are connected appropriately using H-plane bends to form a compact planar eight port waveguide mono-pulse comparator. Simulation results with Ansoft HFSS software are presented, which show good performance.

1. INTRODUCTION

A tracking radar system measures the coordinates of a target and provides data, which may be used to determine the target path and predict its next position. Mono-pulse tracking radar is more popular in modern radar systems because it uses single pulse and thus avoids pulse to pulse fluctuations in echo signal and tracking inaccuracies [1]. Slotted array antennas are most commonly used in airborne applications. A slotted array antenna is divided into four quadrants and the quadrant inputs of the antenna are combined using a mono-pulse comparator, to give sum, azimuth difference and elevation difference signals. The antennas for airborne applications are restricted, in their weight and height due to mechanical scanning limitations. In such situations, the sidewall short-slot directional coupler is found to be the best building block for a mono-pulse comparator, which has minimum height compared to other hybrids like conventional magic tee. The planar nature of side wall hybrid

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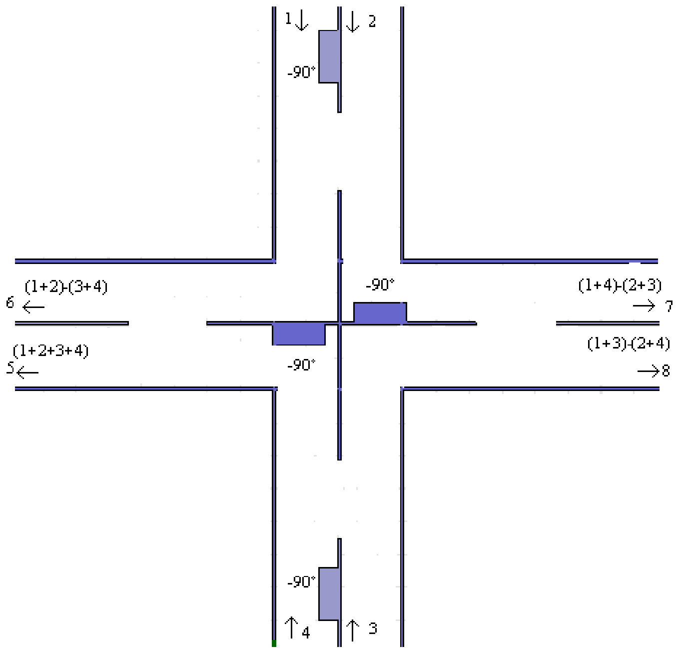

Figure 1. Receive condition of mono-pulse comparator network [3].

has an added advantage in terms of fabrication easiness [2]. The eight-port structure consists of four sidewall short-slot waveguide directional couplers and four phase shifters (Fig. 1). Since the directional coupler led by 90°, phase delays are required at the positions shown shaded to obtain equal-amplitude equi-phased outputs at the terminals to waveguides 1–4 [3]. As shown in Fig. 1, it can be found that port 7 and port 6 provide azimuth and elevation difference signals respectively. In the receive condition, port 5 will receive all the in-phase power from each of the four ports 1–4 with the same amplitude and phase. Output 8 has to be terminated in a matched load. The scattering matrix of the structure is as follows:

$$S = \frac{1}{2}\begin{bmatrix} 0 & M \\ M^t & 0 \end{bmatrix}, \quad M = \begin{bmatrix} 1 & j & -j & -1 \\ 1 & j & j & 1 \\ 1 & -j & j & -1 \\ 1 & -j & -j & 1 \end{bmatrix} \tag{1}$$

The conventional mono-pulse comparators use the four magic tees separately in their designing, so that our structure can be a proper replacement for them. The proposed structure has lower lossless, lower weight, smaller height and easier fabrication. A relative bandwidth of up to 10 percent (for return loss and isolation better than 20 dB) is obtained by directional coupler with matched H-plane impedance steps.

2. DESIGN OF THE DIRECTIONAL COUPLER

There are many directional couplers that utilize continuous coupling between waveguides. The compact Riblet short-slot directional coupler with equal power splitting, high isolation, low VSWR and accurate 90° phasing with 15 percent bandwidth is an example of continuous aperture coupling type [4]. A scheme of widely used Riblet short-slot directional coupler is shown in Fig. 2. An incident TE_{10} wave on port 1 can be considered as the sum of even- and odd-mode signal pairs at port 1 and 4 [5]. For the even mode, the waveguide width in coupling region is $2a$, $\lambda_c = 4a$. Therefore:

$$\lambda_{ge} = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{4a}\right)^2}} \tag{2}$$

where λ_{ge} is even wavelength. Since the input signals of odd-mode pair have 180° out-of-phase in the coupling region, TE_{20} wave is created. For the TE_{20} mode in the coupling region, $\lambda_c = a$ and so:

$$\lambda_{go} = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}} \tag{3}$$

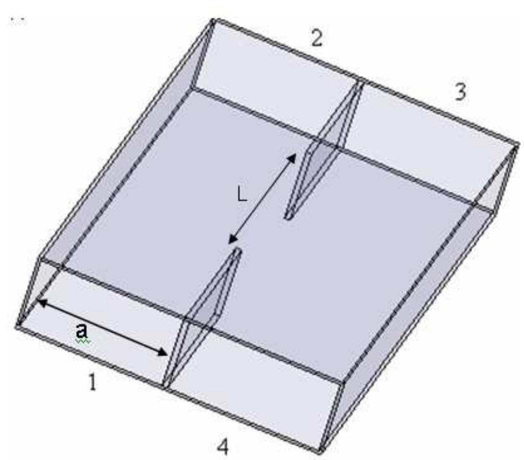

Figure 2. Schematic of Riblet short-slot coupler.

where λ_{go} is odd wavelength. The phase difference between two modes is:

$$\varphi = 2\pi \left(\frac{L}{\lambda_{ge}} - \frac{L}{\lambda_{go}} \right) \tag{4}$$

To obtain $\varphi = 90°$ at $f = 10\,\text{GHz}$, L should be 39.6 mm.

The width of the coupling region must generally be reduced to prevent propagation of the undesired TE_{30} mode [6]. For this purpose, we must use the short-slot coupler with matched H-plane impedance steps. In this paper, a short-slot waveguide coupler with H-plane impedance steps is designed. Fig. 3 shows the configuration of the waveguide directional coupler with matched H-plane impedance steps [7]. Fig. 4 shows the scattering parameters of the short-slot waveguide directional coupler with following parameters: $a = 22.9\,\text{mm}$, $W1 = 20.6\,\text{mm}$, $W2 = 41.57\,\text{mm}$, $W3 = 37.7\,\text{mm}$, $L1 = 13.34\,\text{mm}$, $L2 = 6.68\,\text{mm}$, $L3 = 14.89\,\text{mm}$, $L4 = 28.25\,\text{mm}$, $t = 3.8\,\text{mm}$.

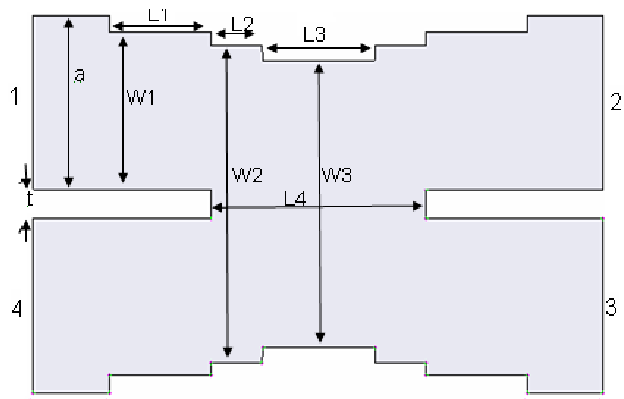

Figure 3. Configuration of the waveguide directional coupler with matched H-plane impedance steps.

3. DESIGN OF E-PLANE DIELECTRIC SLAB WAVEGUIDE PHASE SHIFTER

Dielectric-slab loading of rectangular waveguides is a well known technique to build simple but effective differential phase shifters [8–10]. The phase delay, due to a waveguide length of L in TE_{10}-mode, is given by βL [5], where:

$$\beta = \frac{2\pi}{\lambda_g}, \quad \lambda_g = \frac{\lambda_\circ}{\sqrt{\mu_r \varepsilon_r - (\frac{\lambda_\circ}{2a})^2}} \tag{5}$$

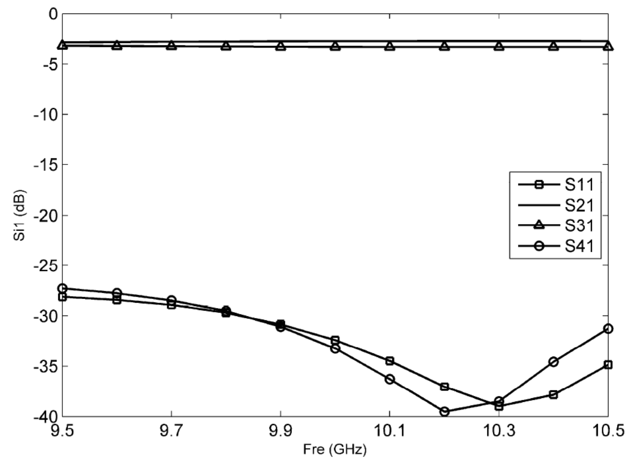

Figure 4. S-parameters of waveguide directional coupler with matched H-plane impedance steps.

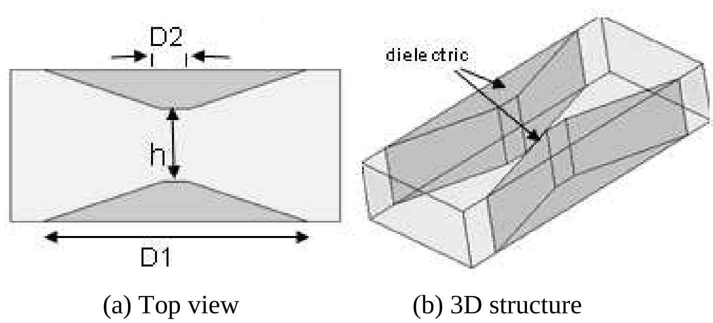

Figure 5. Configuration of the dielectric slab-filled waveguide phase shifter.

where "a" is the waveguide width. Referring to Eq. (5), λ_g is dependent on ε_r (relative permeability). Insertion of the dielectric into the air-filled waveguide increases the effective dielectric constant which causes λ_g to be decreased. In this paper, E-plane dielectric-slab-filled waveguide is utilized to realize phase shifter of 90°. Fig. 5 shows the top view and 3D structure of the phase shifter. The key parameters for designing the phase shifter are dielectric constant and the magnitudes of D_1, D_2 and h.

Figures 6–8 indicate the electric field distribution, reflection coefficient and the phase characteristics of the optimized version of the structure with the following parameters: $D1 = 40\,\text{mm}$, $D2 = 4\,\text{mm}$, $h = 10.9\,\text{mm}$, and $\varepsilon_r = 4$. Tapered form of the dielectric slab in this phase shifter causes the declination of the reflections from the presence of the slab.

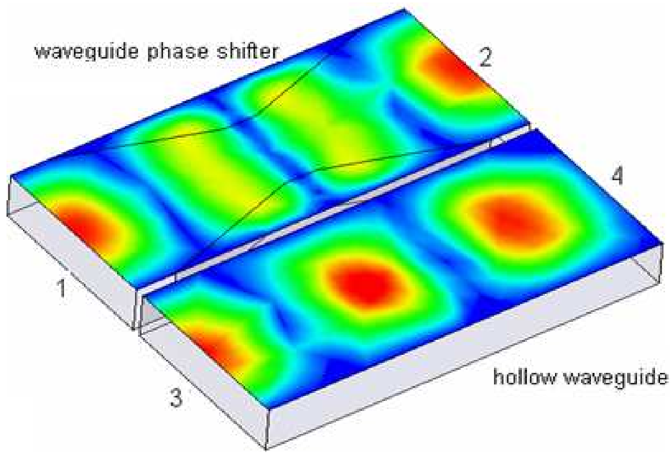

Figure 6. E field distribution of dielectric-slab-filled waveguide phase shifter and a hollow waveguide with the same length.

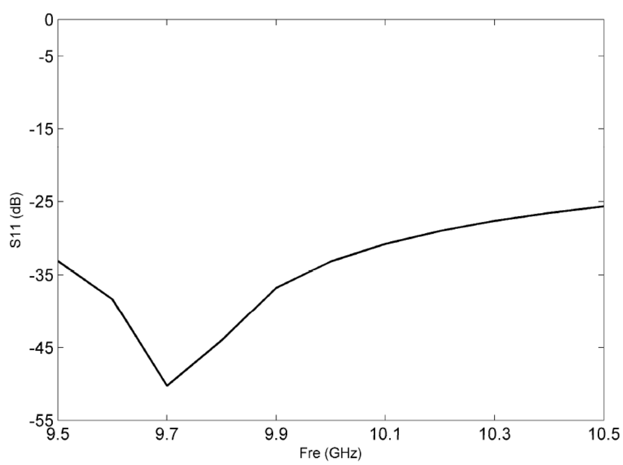

Figure 7. Reflection coefficient of the designed phase shifter.

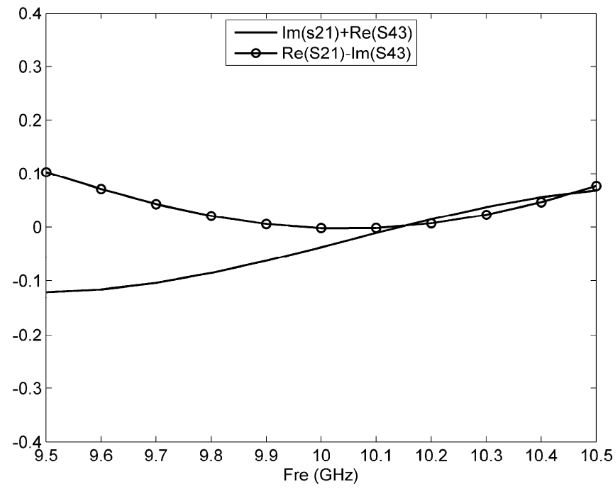

Figure 8. Phase characteristic of the designed phase shifter.

4. PLANAR MAGIC TEE

By adding a waveguide phase shifter equivalent to 90 degree phase, we can convert directional coupler into planar magic tee, which will give the sum and difference of two inputs as shown in Fig. 9. The whole scattering parameters of the magic tee can be obtained by direct combination of the scattering parameters of the two parts [11]. Figs. 10 and 11 indicate the scattering parameters and the phase characteristics of the structure.

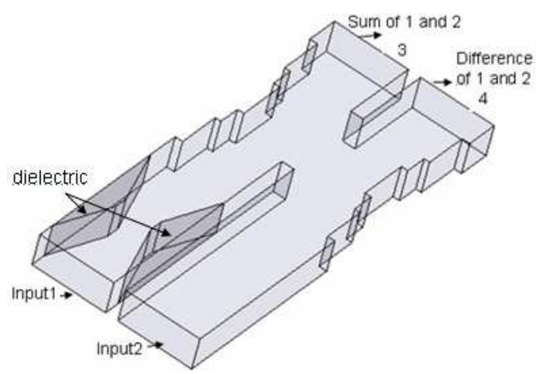

Figure 9. Configuration of the planar magic tee.

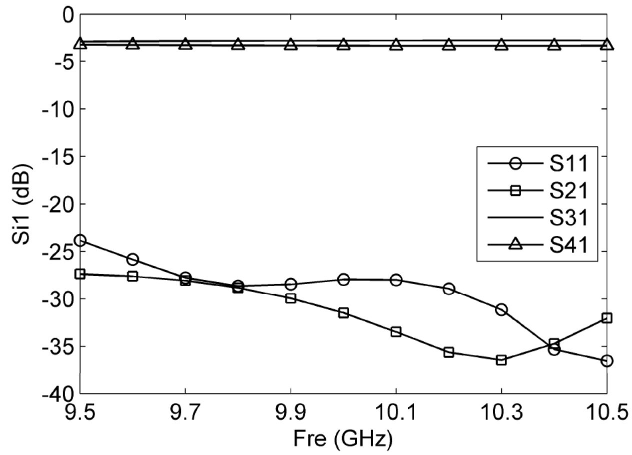

Figure 10. S-parameters of the planar magic tee.

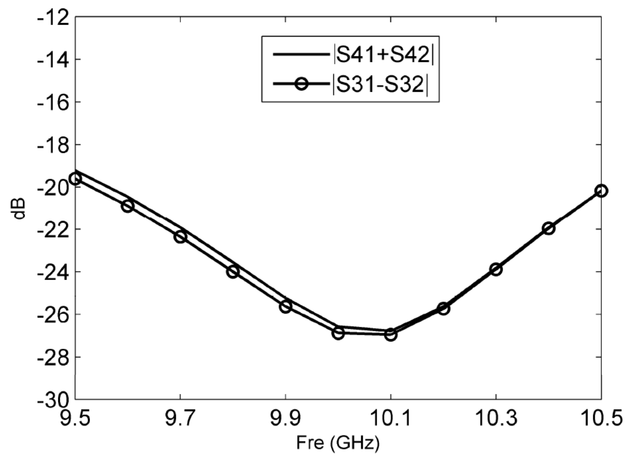

Figure 11. Characteristic of the planar magic tee.

5. DESIGN OF PLANAR EIGHT PORT WAVEGUIDE MONO-PULSE COMPARATOR

Four planar magic tees and four H-plane bends are connected to build a compact planar eight port waveguide mono-pulse comparator, which configuration is shown in Fig. 12. The scattering parameters of the compact planar mono-pulse comparator network are shown in Fig. 13. The parameters of $|(S_{71} + S_{72}) - (S_{73} + S_{74})|$ and

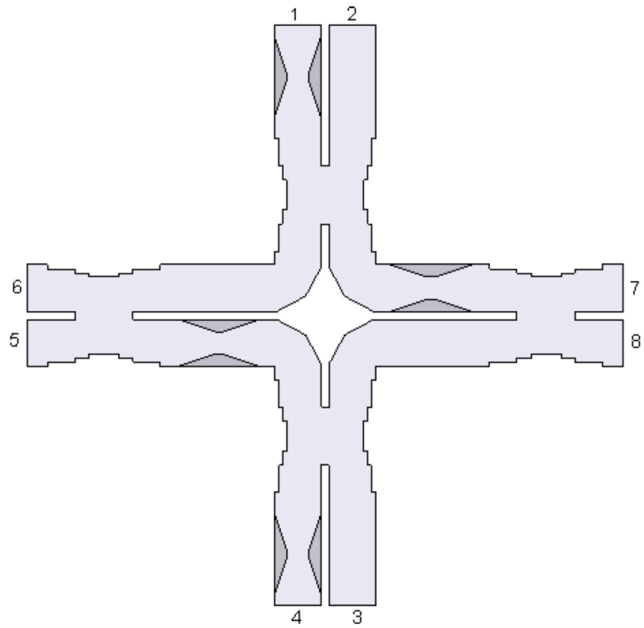

Figure 12. Configuration of the compact waveguide eight port mono-pulse comparator.

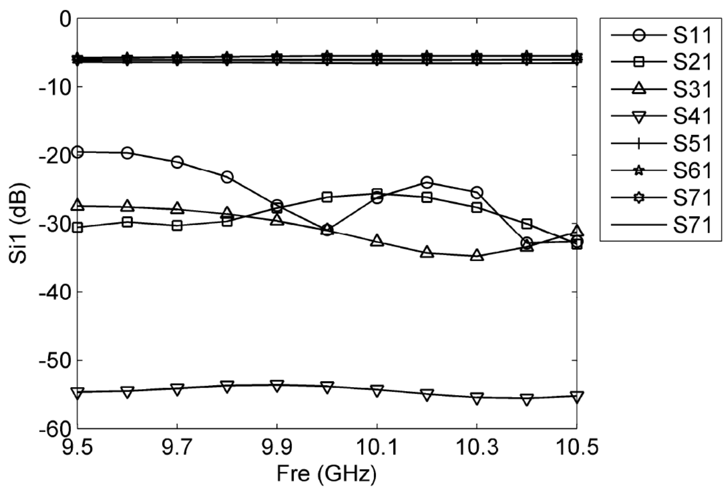

Figure 13. S-parameters of the waveguide mono-pulse comparator.

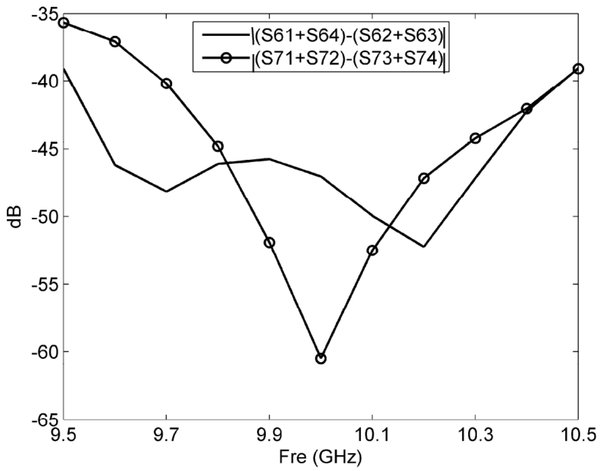

Figure 14. Characteristic of the mono-pulse comparator.

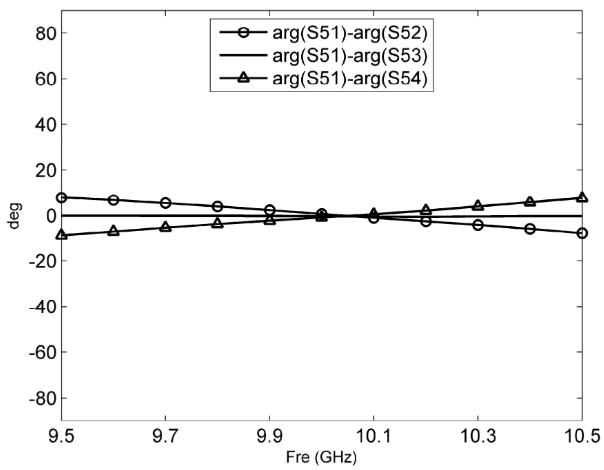

Figure 15. Phase characteristic of the mono-pulse comparator for port 5.

$|(S_{61} + S_{64}) - (S_{62} + S_{63})|$ in Fig. 14 indicate that outputs of ports 7 and 6 are azimuth and elevation difference signals of inputs, respectively. Fig. 15 indicates that port 5 will receive all the in-phase power from each of the four ports 1–4 with the same amplitude and phase.

6. CONCLUSION

In this paper, a planar waveguide eight port mono-pulse comparator is designed and then optimized at X-band. Our structure is composed of directional coupler, phase shifter and H-plane bend. The comparator has low weight and height and therefore it can be used specially for airborne application. The planar nature of this comparator is easy to fabricate. The comparator also has 10% bandwidth at X-band.

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