A New Six-port Junction Based on Multilayer Technology

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Abstract

A novel design of compact six-port circuit is proposed for millimeter-wave integrated system design. All the structure is based on the use of an elliptic coupler with certain geometrical characteristics. The prototype circuit occupies only 66.5 % of the size of the conventional six-port junction at the same frequency. To examine the performance of the proposed circuit, the six-port using multilayer technology is simulated using Momentum (ADS) and CST software's. Simulation results of magnitude and phase show a good performance. The results are compared with a six-port circuit using a single-layer and a notable improvement in bandwidth performance is shown.

Keywords: *Elliptic couplers, six-port junction, multilayer technology, millimeter wave.*

1. Introduction

Increasing interest for ultra-high-speed wireless connectivity has pushed the Federal Communications Commission (FCC) to provide new opportunities for unlicensed spectrum usage with fewer restrictions on radio parameters [1].

A six port receiver is a special form of a direct down-conversion receiver [2], offering a very simple architecture and requiring quite low power. The six-port junction is capable of heterodyne or homodyne demodulation of QPSK/QAM signals [3].

The most frequent use of this device is for measuring complex reflection coefficient of an unknown load [2]. The six-port reflectometer has the special feature that phase information can be obtained from amplitude measurements of four different linear combinations of the two signals.

Recently a new class of ultra wideband (UWB) systems for high speed wireless communications operating over frequency band from 3.1 to 10.6 GHz has been introduced. A wideband six-port junction can be used in these systems to achieve transmit or receive diversity. The standard single layer six-port is composed by 2 main components; 3-dB hybrid couplers and 45º phase shifters.

The bandwidth of the whole six-port is much dependent on performance of these components. The elliptic coupler and 45º phase shifter used in conventional six-port have a limited bandwidth [4]. In order to achieve wideband characteristics, Microstrip-Slot Technology is required. Assuming the use of Slot Coupled Directional Coupler [5] and phase shifters, the main goal of the proposed configuration is elimination of losses that normally occur in conventional six-port, but The prototype circuit occupies than 120 % of the size of the conventional six-port junction at the same frequency.

Similar configurations of wideband six-port structure have been reported in [6]. The authors have introduced a multilayer six-port using CPW technology, The reported result shows limited bandwidth and large size.

To resolve these problems, an alternative design of WB six-port circuit is presented. The design is accomplished in multilayer elliptic coupler. This structure provides a broad band width and a compact size.
Possible applications of the developed device in communications, microwave imaging and metrology field have been pointed out.

2. Design Procedures

The block diagram of a six-port using multilayer technology is shown in Fig. 1.

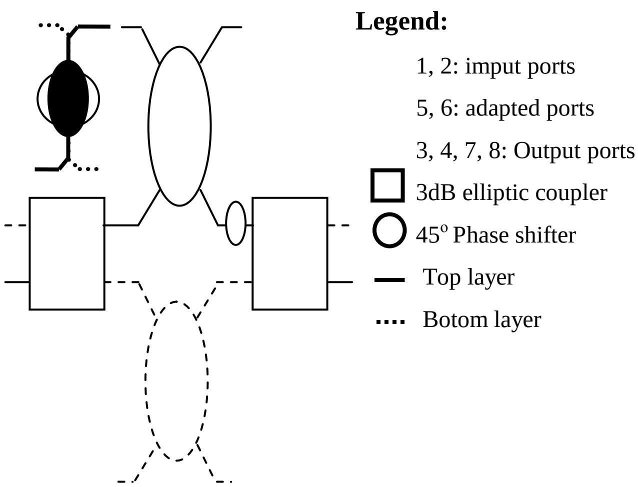


Fig. 1 Block diagram of multilayer six-port circuit based on Slot Coupled Directional Coupler.

The six-port circuit is composed of microstrip-slot coupled 3-dB couplers [7], elliptic coupler [8] and 45 phase shifters. The use of microstrip-slot technique decreases the size present in the conventional planar six-port design.

The prototype of six-port junction is implemented on two double sided Rogers RO4003C substrate featuring a dielectric constant of 3.38 and a loss tangent of 0.0027, 0.508-mm thickness and is designed using ADS and CST software's. The challenge is to obtain a compact circuit, which would operate over the desired frequency band of 3-6 GHz.

As the performance of the six-port depends critically on the bandwidth of elliptic coupler and slot coupled directional coupler, they are designed independently using ADS simulation software.

2.1 Slot coupled Elliptic Coupler

Many implementations of the directional coupler is presented: Microstrip branch-line couplers [9] presenting narrow bandwidth, a circular disc couplers [10], and ring couplers [11].

Fig. 2 shows a UWB multilayer elliptic coupler [12] for use in the UWB six-port circuit and other applications.

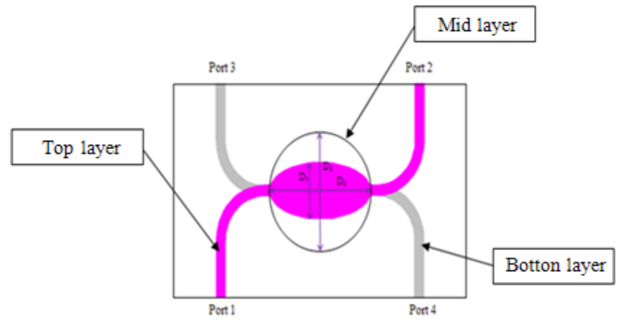


Fig. 2 Elliptical coupler using multi-layer technology.

As shown in Fig. 2, the coupler is constructed on three conductor layers interleaved by two dielectric layers [13]. A common ground is present between the two dielectrics. Port 1 and Port 2 are on the top layer while Port 3 and Port 4 are on the bottom dielectric layer. The 3dB quadrature of signals at Port 2 and Port 3 is achieved by controlling the width of elliptical patches and ground slot.

The odd and even mode characteristic impedances of the elliptic coupler of Fig. 2 were calculated using (1) and (2) as follows:

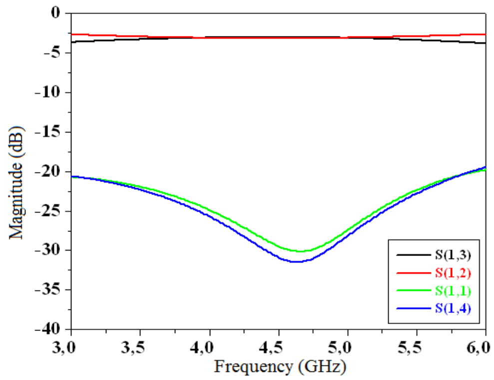
$$Z_{oe} = Z_o \left(\frac{1+10^{-C/20}}{1-10^{-C/20}}\right)^{0.5} \quad (1)$$

$$Z_{oo} = Z_o \left(\frac{1-10^{-C/20}}{1+10^{-C/20}}\right)^{0.5} \quad (2)$$

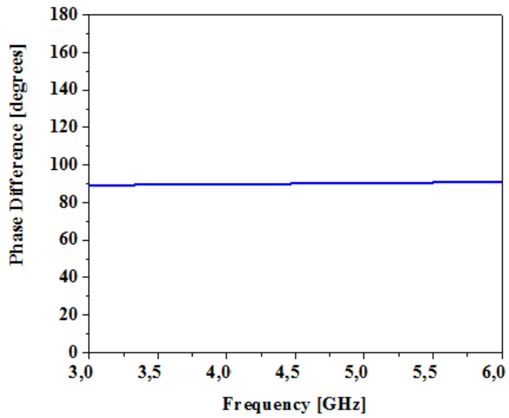
Where Z_o is the characteristic impedance of the microstrip ports of the coupler.

Before commencing the design, we consider the operation of this coupler for the odd and even modes. When the odd modes exited, the slot can be replaced by a perfect electric conductor.

To determine the initial dimensions, the expressions shown in [14] are used. Next, the elliptical patch and slot dimensions are optimized using ADS optimization tool. The aim is to have the input signal at port 1 divided equally to Port 2 and 3, minimize power reflected back to port 1 and isolate port 4. The final dimensions of the elliptical patch and slot are found to be D1=4.8 mm, D2=7.4 mm and D3=7.2 mm. The simulated results for return loss, coupling, and isolation of the designed coupler are shown in Fig. 3.



(a)



(b)

Fig. 3. Simulation results of S-parameter of the multi-layer elliptical coupler. (a) Magnitude (b) Phase Difference.

The coupling is 3 ± 0.3dB for the 3-6GHz band, and the return loss and isolation is better than 20dB, around the center frequency, as shown in Fig. 3(a). The coupler provides 90±1 phase difference between its two output ports in the same band, as illustrated in Fig. 3(b).

2.2 Single layer Elliptic Coupler

The design start-up from data given in the literature [15] since they do not conform to the central frequency of the desired band, a scaling procedure is using [16]. By using a multivariable optimization procedure under constraints on the desired central frequency, 4.5GHz, the bandwidth and the form of the designed coupler is given in Fig. 4

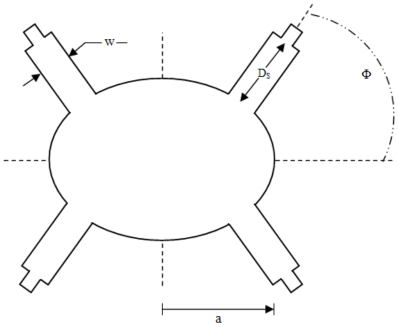


Fig. 4. Elliptical coupler using single layer.

The impedance matrix for the elliptic patch consists of even and odd parts. So from [17], the even and odd elements of the impedance matrix Z for an elliptic patch with ports at the periphery (Fig. 4) are given as:

$$Z_{ij}^{e} = \frac{jw\mu d l^2}{w_i w_j} \sum_{n=0}^{\infty} \frac{Je_n(h, \cosh u_1)\, I\, Se_n(h, v_i, \Delta_i, u_1)\, I\, Se_n(h, v_j, \Delta_j, u_1)}{M e_n(h)\, Je_n'(h, \cosh u_1)} \quad (3)$$

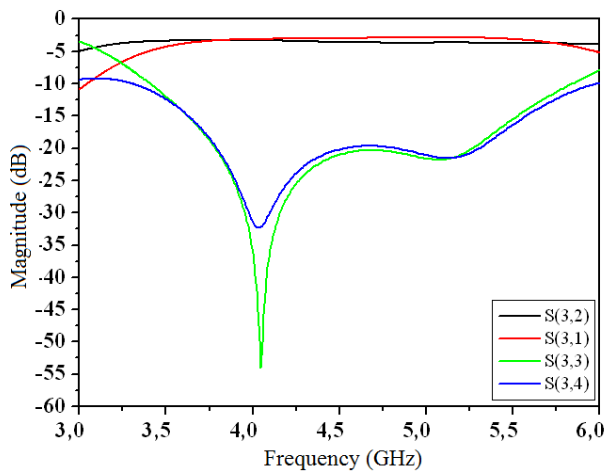
$$Z_{ij}^{o} = \frac{jw\mu d l^2}{w_i w_j} \sum_{n=1}^{\infty} \frac{Jo_n(h, \cosh u_1)\, I\, So_n(h, v_i, \Delta_i, u_1)\, I\, So_n(h, v_j, \Delta_j, u_1)}{M o_n(h)\, Jo_n'(h, \cosh u_1)} \quad (4)$$

Where $Jo_n(h, \cosh u)$ and $Je_n(h, \cosh u)$ are odd and even first kind radial Mathieu function, respectively. The dimensions of patch coupler are determined and are shown in Table 1.

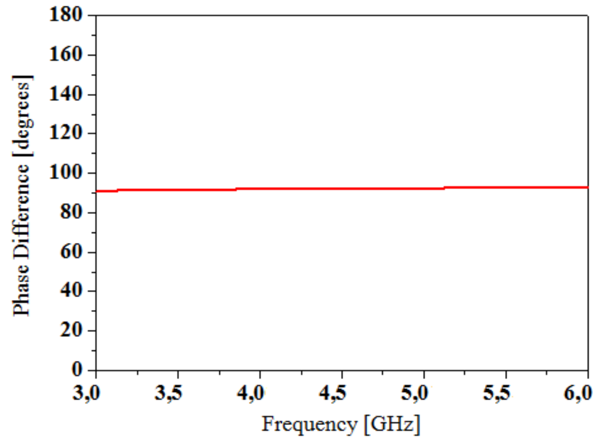
Table 1: Parameters of the Single layer elliptical coupler (mm)

Parameter	***Initial values***	Optimum values
a (Semi major elliptical axis)	11.3	12.9
e (Eccentricity)	0.47	0.64
Ds (length of the impedance Steps)	15	7.8
W (width of the impedance steps)	1	3.3
Φ (the port angle)	51°	51°

The simulated performance of the elliptic patch is shown in Fig. 5.



(a)



(b)

Fig. 5. Simulation results of S-parameter of elliptical coupler with ADS momentum. (a) Magnitude (b) Phase Difference.

In Fig.5 (a) it is observed that the coupling is 3 ± 0.5dB for the 3-6GHz band. The isolation and return los are better than 20dB and 22dB. Respectively, around the center frequency.

In Fig. 5 (b), the phase difference between port 1 and 2 is $90° \pm 2°$dB over the band. Having obtaining this basic structure our next step is simply to integrate the two prototype couplers.

3. Multilayer Six-Port Junction

Fig. 6 shows the layout of conventional six-port circuit and layout of the proposed multilayer six-port circuit.

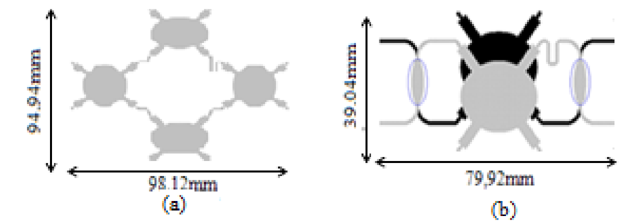


Fig. 6. (a). Layout of proposed six-port junction, (b). Layout of conventional six-port junction.

Combining the components presented in II.A and II.B, the proposed six-port circuit presented in figure 6 (b) was designed using elliptic coupler and slot-coupler directional coupler.

The dark color represents the top layer while the light color represents the bottom layer.

Let us assume that there are two normalized wave inputs a_5(LO) and a_6 (RF) with different amplitude and phases.

$$a_5 = a.\exp\left[j\left(w_0.t + \varphi_5\right)\right] \quad (5)$$

$$a_6 = \alpha(t).a\, exp\left[j\left(wt + \varphi_6\right)\right] \quad (6)$$

Therefore, we can calculate the normalized wave outputs using six-port S-parameters [18].

$$b_i = a_5.S_{5i} + a_6.S_{6i} \qquad \text{for i= 1, 2, 3, 4} \quad (7)$$

The low IF outputs signals are obtained using for power detectors connected to the six-port outputs. Comparing the dimensions of both six-port junction excluding the connectors, it can be shown that the proposed structure is more compact compared to the conventional one with (66,5% % of compactness).

In this device, signals at input port 1, 2 (port 5, 6 adapted at 50Ω) are divided into output ports 3, 4, 7 and 8 with equal amplitude and appropriate phase difference.

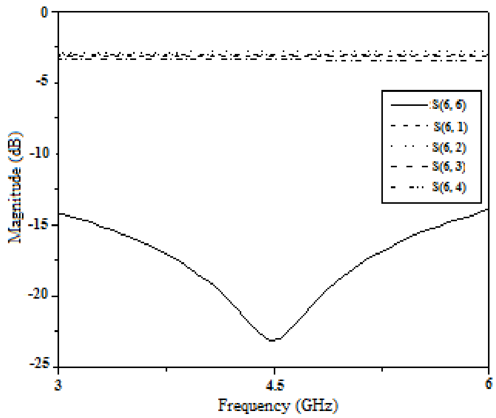
Each RF output signal is a different linear combination of the two RF input signals, depending on the circuit architecture.

The six-port circuit is implemented on two double sided Rogers RO4003C substrate featuring a dielectric constant of 3.38 and a loss tangent of 0.0027, 0.508 mm thickness. The challenge is to obtain a compact circuit, which would operate over the desired frequency band of 3-6GHz.

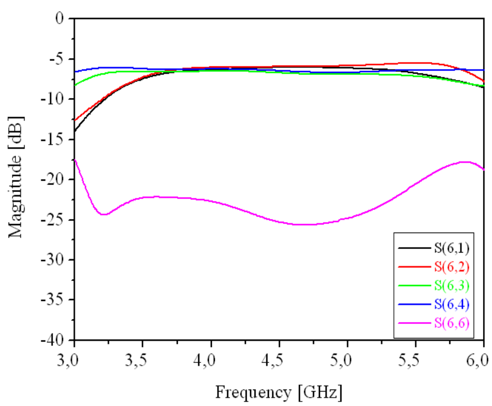
In order to obtain a best solutions in terms of magnitude and return loss of multilayer six-port circuit, we apply two software's: Momentum ADS and CST.

3.1 Simulation results

The six-port circuit is designed at a frequency range of 4. 5 GHz. Fig. 7 shows the simulated S-parameters of the proposed six-port junction with two software's (ADS and CST).



(a)

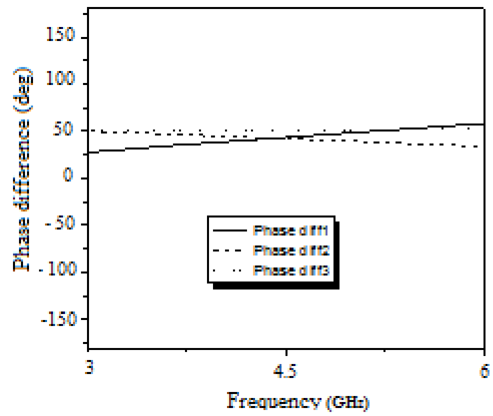


(b)

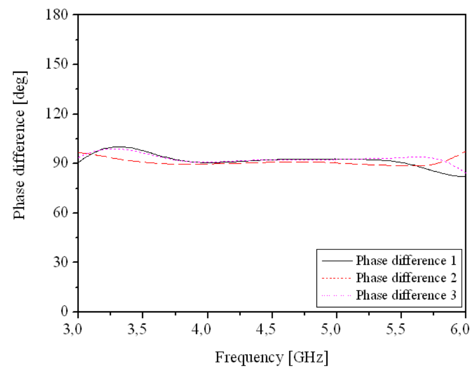
Fig. 7. Simulated S-parameters, (a). Simulation with CST. (b). with ADS.

The return loss is better than 20dB over the entire operating frequency band (3-6GHz). It is found that the simulated results of transmission coefficients are close to the theoretical predicted value of 6dB. From these results, it can be seen that the proposed six-port provides a bandwidth from 3-6GHz.

Fig. 8 illustrates the simulated results of the phase shift of the outputs ports with two software's CST and ADS:



(a)



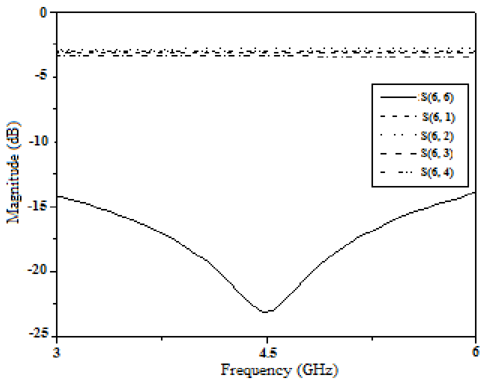
(b)

Fig. 8. Phase difference simulated, (a). Simulation with CST (b). with ADS.

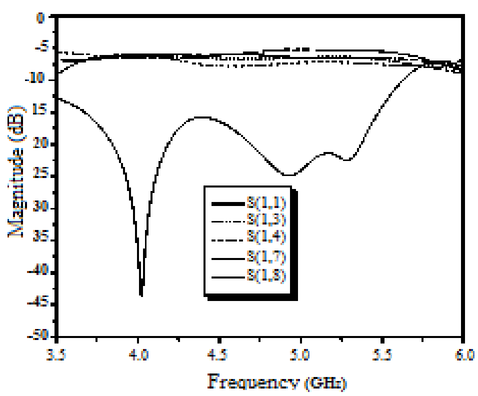
Phase difference 1= Phase(S (6, 2)) - Phase(S (6, 4))
Phase difference 2= Phase(S (6, 3)) - Phase(S (6, 4))
Phase difference 3= Phase(S (6, 1)) - Phase(S (6, 3))

The phase differences of the output ports over the operating frequency band are close to the theoretical predicted value 90°.

The best simulation results of multi-layer six-port junction proposed is compared with a six-port formed by four single layer elliptical coupler.



(a)



(b)

Fig. 9. Simulated S-parameters, (a). Proposed six-port junction. (b). conventional six-port junction.

Results obtained in terms of magnitude S-parameters show clearly that multi-layer six-port junction provides a large bandwidth from 3-6GHz, compared to single layer six-port junction.

Another important advantage of this new six-port circuit, from the dimensions of both six-port junction in Fig. 6, it can be seen that the proposed structure is more compact compared to the six-port junction shown in Fig. 6 (a).

4. Conclusions

A compact six-port junction on a multi-layer with relatively negligible cost has been designed. The circuit is compact with 66.5% of size reduction compared with conventional structure. In the proposed design, elliptic coupler has been used as a key component of new topology, which leads to significant size reduction and loss minimization.

Simulated results are validated by using the software tools CST and Momentum ADS. The performances in terms of magnitude and phase shift of the proposed six-port are better than the six-port single-layer.

Results obtained have the advantages of low cost, small volume, and light weight.

These features make the proposed six-pot structure suitable for different applications at 4.5 GHz.

Acknowledgments

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