Highly selective filtering power divider using substrate integrated waveguide technique for radar applications

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ABSTRACT

This article exhibits a filtering power divider designed with substrate integrated waveguide (SIW) technique, having the power dividing as well as filtering functionalities. In the design band-pass performance is realized by merging SIW structure having high-pass response and complementary split ring resonator (CSRRs) with parallel tank LC resonant response and the dumbbells shape defected ground structure (DGS) with high out of band rejection characteristics. The anticipated structure serves as both a power divider and a filter, it reduces both the cost and the size of the system. Structure is constructed and tested to confirm the design functionality. The measurement result shows the return loss of -25.94 dB with 3-dB fractional bandwidth of 2.85% at 14 GHz.

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1. INTRODUCTION

In communication systems and miniaturized radars, antennas [1]–[4], filters [5]–[7], and power dividers [8] are the key components. Band pass filters with the high selectivity plays an important role for selection of desired frequencies, while equal or unequal power division is essential for many radio frequency (RF) and microwave circuits and systems, for instance the antenna arrays feeding network, diplexers and power amplifiers [9], [10]. Additionally, the quick growth of wireless communication systems necessitates the use of microwave components that are inexpensive, extremely proficient, and highly integrated. As a result, designing multifunction devices [11], [12] to reduce the size of the communication devices has become a popular research issue in contemporary era. The proposed design is made for the radar application, which operates at a centre frequency of 14 GHz, using the substrate integrated waveguide (SIW) approach. Due to its promising characteristics like large power handling ability, less insertion losses, small weight, and affordable manufacturing, for the designing of microwave circuits, numerous researchers already use SIW technique [13]–[15].

2. RESEARCH METHOD

Primarily, a simple power divider with T-junction configuration has been developed. The cut-off frequency (TE_{10} mode), equivalent length, and width of the SIW structure are each determined by (1)-(3). These equations were derived from [13], [14]. Table 1 provides the planned structure's dimensions. The power divider's inductive post is positioned in the middle, shorting the top, and bottom copper plates. By adjusting the diameter and placement of this inductive post, the parameters of reflection and scattering can be changed. The inductive post is also compatible with the SIW power divider's three ports.

$$f_{cTE10} = \frac{Co}{2\sqrt{\varepsilon_r}}\left(a - \frac{4R^2}{0.95P}\right)^{-1} \quad (1)$$

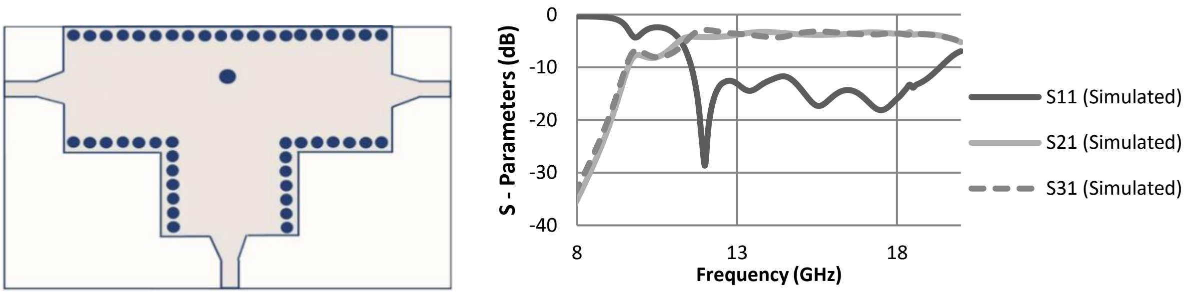
$$L_{eff} = L_{SIW} - \frac{D^2}{0.95P} \quad (2)$$

$$W_{eff} = W_{SIW} - \frac{D^2}{0.95P} \quad (3)$$

Table 1. Proposed power divider's dimensions

Parameters	Dimensions (mm)
Via diameter (D)	1.10
Via pitch (P)	1.30
SIW width (Asiw)	8.20
Microstrip-line width (Wms)	1.60
Microstrip-line length (Lms)	3.00
Taper width (Wtap)	3.60
Taper length (Ltap)	4.95
The distance between the post's and the SIW's centres (Lpost)	0.75
Inductive post diameter (Dpost)	1.50

Figure 1 presents the basic T-junction power divider configuration alongside its S-parameter simulation results. Figure 1(a) illustrates the fundamental configuration of the T-junction power divider, while Figure 1(b) displays the corresponding simulation outcomes. It has been discovered that the design suggested exhibits wide band response, with returns losses of 12.5 dB and insertion losses of 1.32 dB, eliminating the basic 3 dB power division loss inside the operational frequency band according to the simulation findings. Figure 1(b) shows that the basic T-junction filtering power divider has a very wideband response. However, for our application required frequency band is narrow.



(a) (b)

Figure 1. Basic T-junction power divider (a) configuration and (b) S-parameter simulation results

Figure 2 shows the configuration of proposed SIW based filtering power divider. As seen in Figure 2(a), complementary split ring resonators (CSRRs) are engraved onto the top metal plane to obtain bandpass response. The layout and equivalent LC tank circuit of CSRR structure is shown in the Figure 2(b). This structure is also described in [16], [17] and can function as a parallel LC resonator with L_r inductance (inductance because of the copper line between the ring gaps) and C_r capacitance (capacitance of a CSRR ring edge to edge). As a result, Baena *et al.* [17] is used to find out the resonance frequency of the CSRR:

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}} \quad (4)$$

From [17]–[19], we can get the formulae for effective inductance and capacitance. Capacitance can be given by (5).

$$C = 4\left(\frac{\varepsilon_0}{\mu_0}\right)L1 \quad (5)$$

Where, ε_0=vacuum permittivity and μ_0=vacuum permeability.
The L_1 is the inductance of the square CSRR, defined as (6).

$$L_1 = \frac{4.86\mu_0}{2}(L - W - S)\left[ln\left(\frac{0.98}{\rho}\right) + 1.84\rho\right] \quad (6)$$

Where L stands for the length of the square's side, W for the conductor's width, S for the distance between the inner and outer conductors, and for the inductance's filling factor can be summed up as (7).

$$\rho = \frac{W+S}{L-W-S} \quad (7)$$

The effective inductance of CSRR can be given by (8).

$$L = 4\left(\frac{\mu_0}{\varepsilon_0}\right)C1 \quad (8)$$

Where C_1 is the capacitance of the square CSRR, which can be defined as (9).

$$C_1 = \left(L - \frac{3}{2}(W + S)\right)C_{pul} \quad (9)$$

Figure 2(c) shows the bottom layer of the proposed filtering power divider, which contains lowpass structures like dumbbell-shaped defected ground structure (DGS). DGS alters the field distribution to produce resonance and has excellent band rejection characteristics. The frequency to be suppressed is determined by the length of the link between the two heads, and the dumbbell structure's head is used to match the structure [20], [21]. To define the equivalent circuit of the dumbbell-shaped DGS, parallel capacitance and series inductance can be utilized in combination. The simulated S-parameters (S11, S21 and S31) results of proposed filtering power divider with DGS and without DGS is shown in Figure 3.

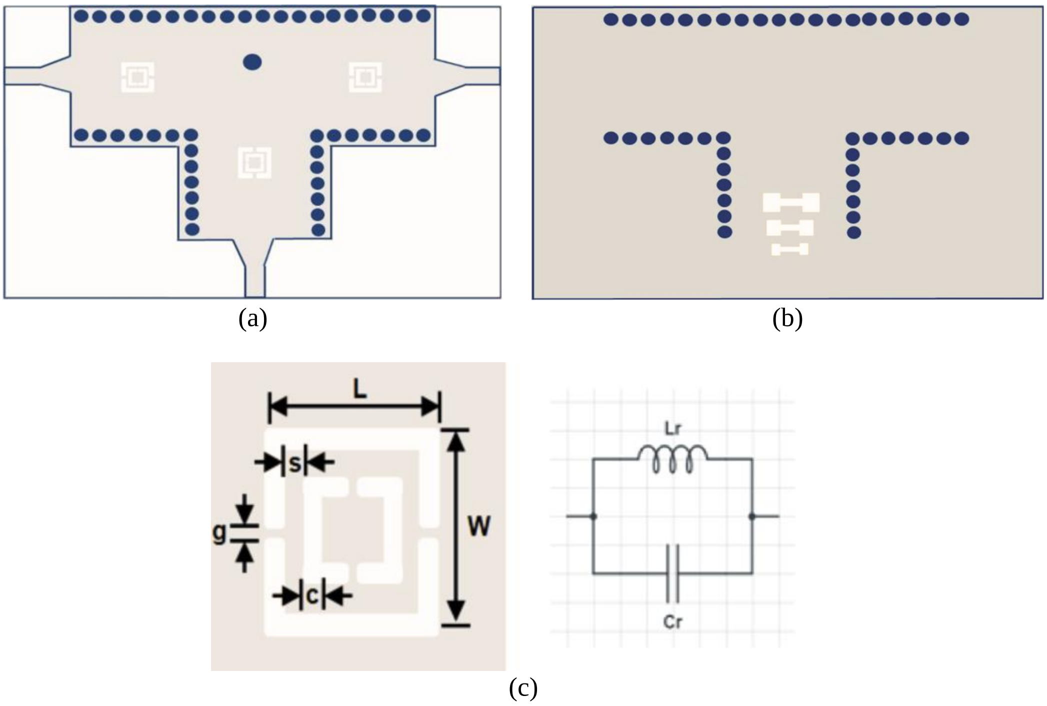


Figure 2. Anticipated filtering power divider with SIW technology (a) top layer, (b) layout and equivalent LC tank circuit of CSRR structure, and (c) bottom layer (accent blue color zone represents metal)

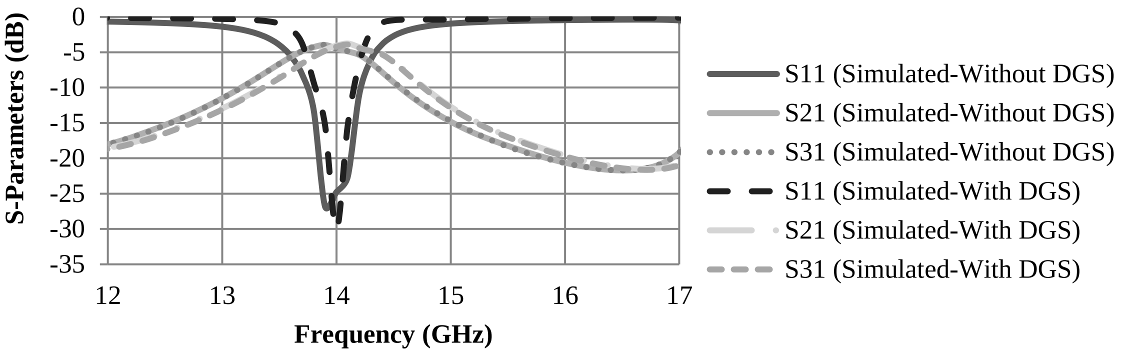
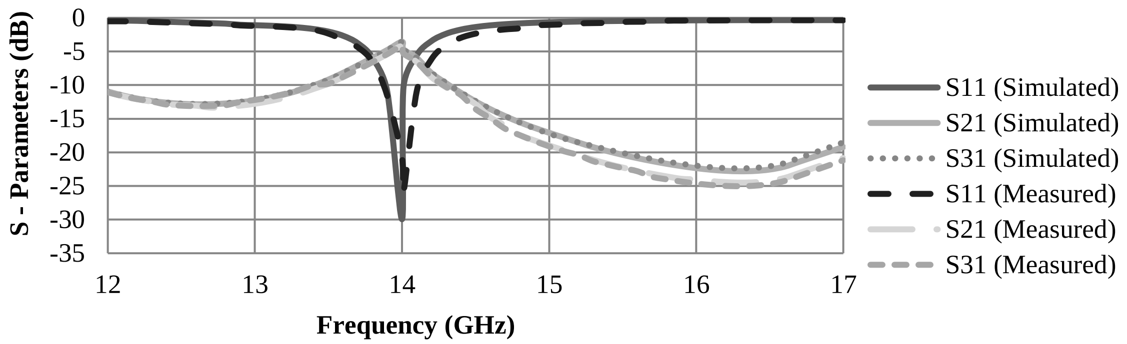


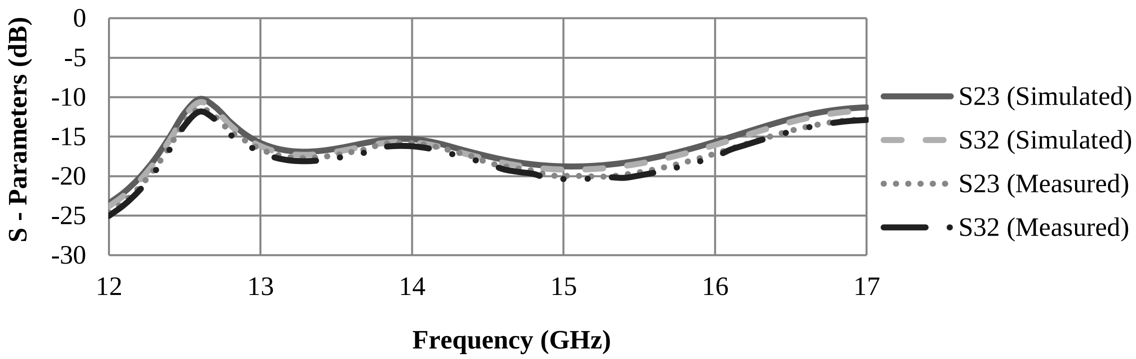
Figure 3. Simulated S-parameters (S11, S21 and S31) results of proposed filtering power divider with DGS and without DGS

3. RESULTS AND DISCUSSION

The anticipated power divider with filtering response has a height of 0.508 mm, a dielectric constants of 3.48, a dissipation factor of 3.7×10-3, and is constructed from RT Duroid 4350. The proposed structures are 25×43 mm (2.32×3.71 λg) in size, where λg is the guided wavelength at the centre frequency. An analysis of the anticipated structure is conducted using a Keysight N5245A vector network analyzer. The results of the suggested filtering power divider's simulation and measurement s-parameters are illustrated in Figures 4. Figure 4(a) shows S11, S21, and S31 parameters while Figure 4(b) shows S23 and S32 parameters. At a central frequency of 14 GHz, the observed insertion loss of 1.07 dB, excluding the inherent 3-dB power division loss and return loss, is -25.94 dB with a 3-dB fractional bandwidth of 2.85%.



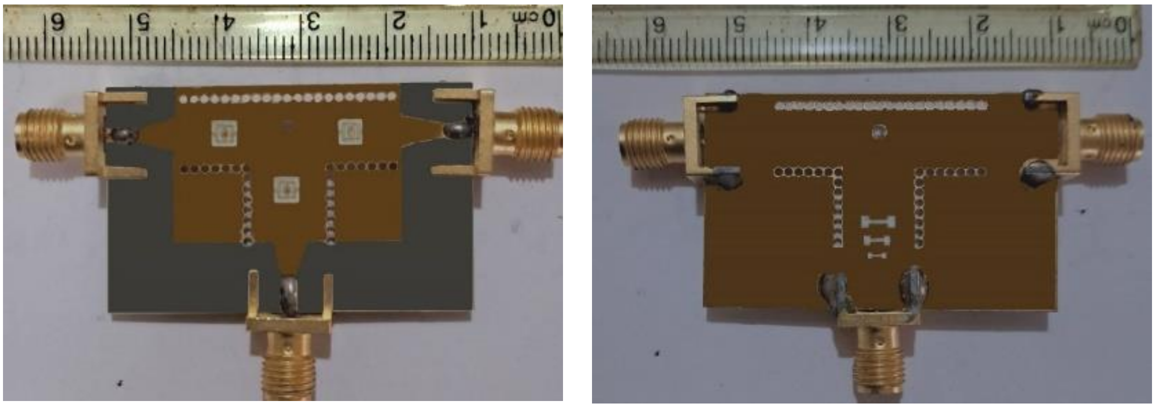
(a)



(b)

Figure 4. S-parameter simulation and measurement results of the anticipated power divider with filtering response (a) S11, S21, and S31 and (b) S23 and S32

The manufactured structure of anticipated power divider is shown in Figure 5. Figure 5(a) shows top layer and Figure 5(b) shows bottom layer photograph of fabricated structure. Additionally, the suggested structure exhibits isolation of greater than 15 dB; the highest amplitude and phase inequality are, respectively, 0.12 dB and 1.42° throughout a 3-dB bandwidth of 400 MHz spanning from 13.8 to 14.2 GHz.



(a) (b)

Figure 5. Manufactured structure of anticipated power divider with filtering response (a) top layer and (b) bottom layer

Figure 6 depicts the anticipated filtering power divider's simulated and measured phase response. In Table 2, a comparison with the alternative filtering power divider is shown. The anticipated power divider with filtering response has benefits such as improved selectivity (2.85% FBW), less insertion loss, and fewer amplitude and phase inequality.

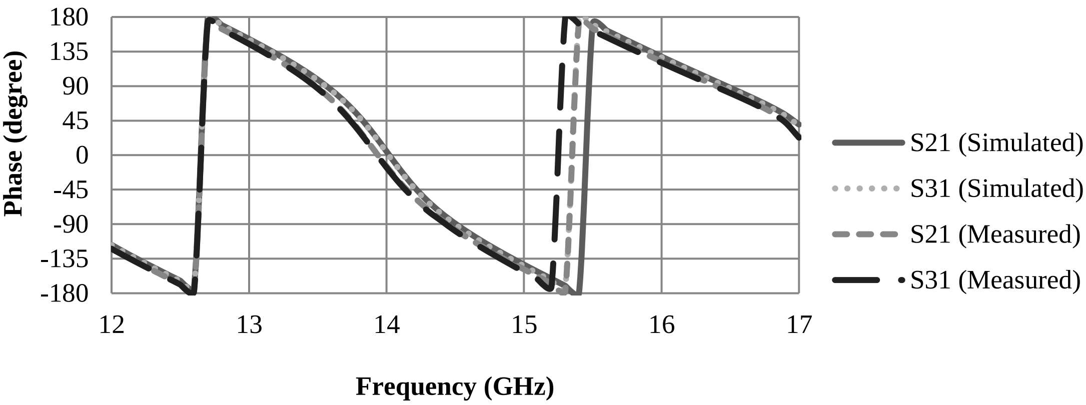


Figure 6. Simulation and measurement phase response of the anticipated power divider with filtering response

Table 2. Performance evaluation of this work in comparison to other scholarly articles

Reference	Frequency (GHz)	Fractional bandwidth (FBW) (%)	Amplitude imbalance (dB)	Phase imbalance	Size
He *et al.* [22]	9	22.3	<0.2	<2°	1.09×1.0 λg
Chen *et al.* [23]	4.3	38	NG	NG	0.79×1.1 λg
Danaeian *et al.* [24]	5.47	8.41	~0.05	<10°	0.25×0.17 λg
Li *et al.* [25]	10.6	4.62	<0.5	0°-4°	NG
This work	14	2.85	<0.20	<1.25°	2.32×3.71 λg

4. CONCLUSION

A very selective filtering power divider is suggested in this research. In the design, DGS having dumbbell-shaped is applied to the SIW cavity, and CSRRs are etched onto the top metal surface. A suggested structure was created and put to the test. The simulation and measurement findings show a high degree of consistency. The results of the measurements indicate that the reflection coefficient value is better than 20 dB and that the insertion loss value is less than 1.07 dB. The suggested structure also exhibits great selectivity when compared to previously designed filtering power dividers using SIW technology. Given that the proposed structure's 3 dB fractional bandwidth is 2.85% at 14 GHz. The anticipated structure is appropriate for different millimeter-wave and microwave applications and satisfies the specifications of our radar system.

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