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Design of Substrate Integerated Waveguide Bandpass Filter Based on Metamaterials CSRRs

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Abstract This article presents a band-pass Substrate Integrated Waveguide (SIW) filter based on Complementary Split Ring Resonators (CSRRs). By etching Square Complimentary Split Ring Resonators on the surface of the substrate integrated waveguide. The bandpass filter is treated by two methods. The first method concerns the use of three square single ring CSRRs cells are etched in the top plane of the SIW, the simulated results of this filter have shown that the passband is from 7.267 GHz to 9.933 GHz, while the insertion loss is -1.11 dB within 31% bandwidth around 8.6 GHz and input return loss in the passband is better than -8.91 dB. The second method concerns the use of three square double rings CSRRs cells are etched on the top plane of the SIW, the simulated results of this filter have shown that the passband is from 7.34 GHz to 9 GHz, while the insertion loss is -0.47 dB within 20.31% bandwidth around 8.17 GHz and the return loss in the passband is better than -15 dB. All the structures are designed on a single substrate of RT / Duroid 5880 permittivity 2.2. The compatibility with planar circuits is provided via a specific microstrip transition (microstrip tapered transitions).

Keywords Rectangular Waveguide, Substrate Integrated Waveguide, Microwave Filters, Transition, SIW-Microstrip Technology, Complementary Split Ring Resonators, Band-pass

1. Introduction

The SIW technology is used in the design of systems transmit and receive microwave, for the researchers and the industrialists who wish to integrate metal waveguides into planar circuits without losses of performances of transmission. The SIW appears as a promising candidate for producing a wide variety of components and devices in the field of the microwaves.

The SIW concept associates the use of planar technology microstrip and the functioning of cavities in which are going to exist volume modes [1]. Technically, cavities are included in the substratum and are delimited for the upper and lower faces by the metal plane and for the side faces by rows of metallic holes. This vias have a diameter and spacing small to appear as electric walls [2].

However, the SIW has been applied successfully to the conception of planar compact components for the microwave and millimeter wave applications. Such as couplers [3, 4] and filters [5-8], the advantage of this structure is to have a better quality factor and good compatibility.

On the other, the metamaterials have been one of the popular areas of research in the field of microwaves in the recent past, such that the Split Ring Resonators (SRR) who may exhibit negative permeability and permittivity and hence negative refractive index [9-12]. The Complementary Split Ring Resonators (CSRR) is introduced for big use in structures planar [13].

The CSRR structure is achieved by etching SRR in the background, which can also realize resonance effect and has found great application in the design of wideband bandpass filter [14-20].

In this paper, the resonant properties of CSRR are carefully studied, and the rules of the change of resonant frequency are obtained. The bandpass filter is designed based on the characteristic of CSRR band-stop and characteristic of SIW high-pass. The finite element method (FEM) based on a commercial software package "HFSS" is used for simulations. The results obtained by HFSS simulation are compared and discussed with the results in [20].

2. Design of the SIW Technology and the Transitions

A substrate integrated waveguide (SIW) is made of metallic via-hole arrays in the substrate between top and bottom metal layers replacing the two metal sidewalls are shown in Figure 1.

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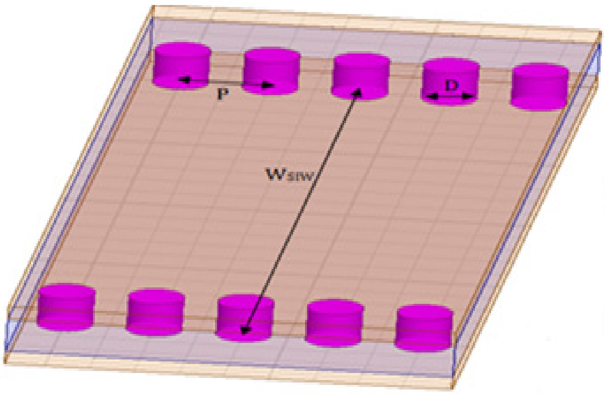
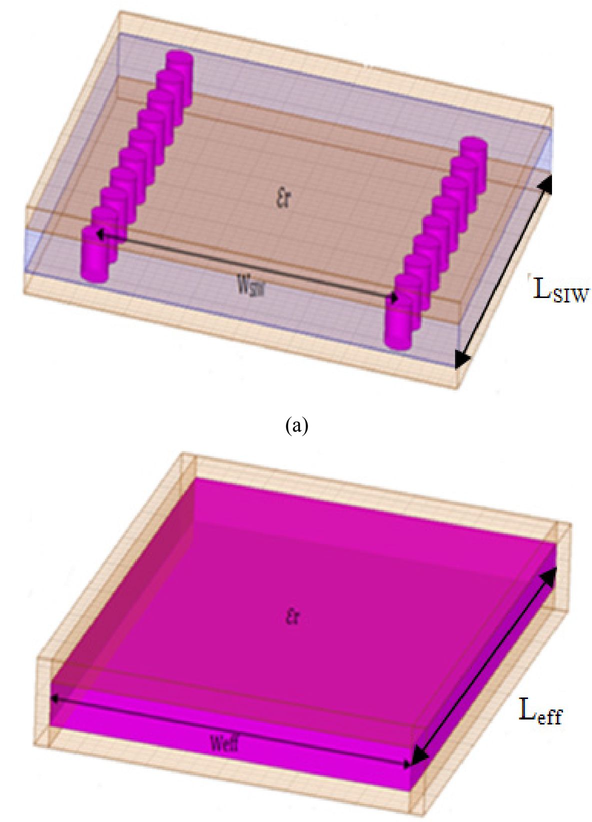


Figure 1. SIW Guide

The parameters D and P are the diameter of the metallic via and the period of via holes respectively and W_{SIW} is the distance between the rows of the centres of via.

A comparison between a conventional waveguide and a SIW is given in Figure 2.



(a)

(b)

Figure 2. (a) SIW Guide (b) Equivalent rectangular waveguide

The propagation properties in the SIW and in the conventional metallic rectangular waveguide are very similar. In particular, the electromagnetic field distribution is TE_{10} [1], Thus, the initial dimensions of the SIW resonator cavity can be determined by the conventional resonant frequency formula of metallic waveguide resonator, where the length and width of the metallic cavity, L_{eff} and W_{eff}, should be replaced by the equivalent width W_{SIW} and length L_{SIW} of the SIW cavity because of the presence of vias sidewall.

A SIW cavity can be designed by using the relations 1, 2 and 3 provided that $P < \lambda_0 (\varepsilon_r/2)^{1/2}$ and $P < 4D$ with ε_r relative permittivity [1-3]:

$$f_{c10} = \frac{c}{2W_{eff}\sqrt{\varepsilon_r}} \tag{1}$$

$$W_{eff} = W_{SIW} - \frac{D^2}{0.95P} \tag{2}$$

$$L_{eff} = L_{SIW} - \frac{D^2}{0.95P} \tag{3}$$

Generally, the microstrip transitions are very required to combine SIW and microstrip technologies. Tapered transition shown in Figure 3 has been studied. This kind of transition consists of a tapered microstrip line section that connects a 50 microstrip line and the integrated waveguide. The physical characteristics of microstrip line (the width W_M) and the dimensions (width W_T and length L_T) of a transition are widely detailed in [2, 4].

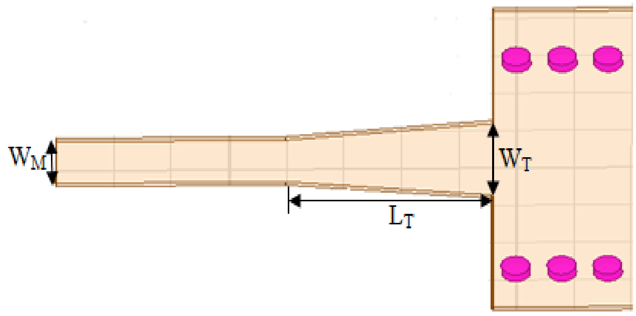


Figure 3. SIW Guide with tapered transitions

3. Complementary Split Ring Resonators «CSRR »

The electromagnetic properties of SRRs have been already analysed in [10-13]. This analysis shows that SRRs behave as an LC resonator.

Split Ring Resonator (SRR) is a well known sub-wavelength metamaterial structure that exhibits negative values of permeability over a narrow frequency band around it resonance frequency. The resonant frequency is determined from the geometrical parameters of SRR. The SRR can have different types of structures (square, circular, Omega ...) with single ring, double ring or multiple ring SRR cells

The Complementary Split Ring Resonator CSRR is the complementary of SRR [12]. The CSRR the rings are etched on a metallic surface and its electric and magnetic properties are interchanged with respect to the SRR. Figure 4 shows the difference between the SRR and the CSRR. In fact, all the conductive part (rings) and the dielectric part of the SRR are respectively replaced by the dielectric and conductive plan of a substrate in the CSRR.

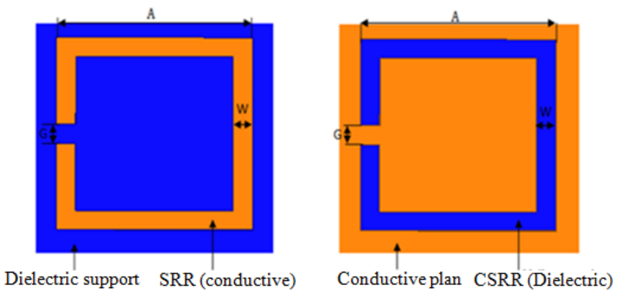


Figure 4. (a) Square-shaped single-ring SRR (b) square-shaped single-ring CSRR

In this work, the square single ring CSRRs cells and the square double rings CSRRs cells are carefully studied for designing the bandwidth filter.

The square double rings CSRR is given in Figure 5.

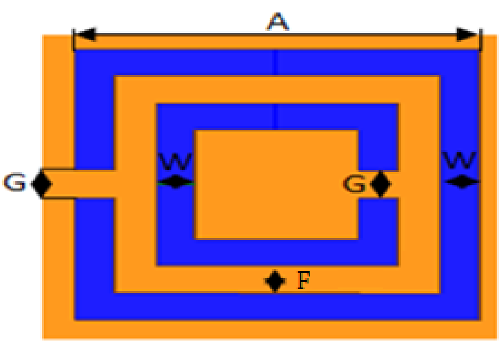


Figure 5. Geometry square CSRR of the double rings

"A" denotes the length of the side of the square, "W" denotes the width of the conductor, "F" denotes the dielectric width between the inner and the outer square and "G" denotes the gap present in the rings. Care is taken that the gap width "G" does not change from the inner ring to the outer ring.

The resonance frequency is obtained by is by using the equivalent circuit analysis method as prescribed in [10, 12]. When a magnetic field is applied perpendicularly to the plane of the ring, the ring begins to conduct and gives rise in current flow. The current flowing through the rings will enable it to act as an inductor and the dielectric gap (F) between the rings will lead to mutual capacitance. Hence the equivalent circuit of the square CSRR with double rings will be a parallel LC resonant circuit in [12]. The resonance frequency is calculated by the relation (4).

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{4}$$

The expressions for effective inductance and capacitances can be obtained from [10, 12] as follows:

The capacitance is given by

$$C = 4\left(\frac{\varepsilon_0}{\mu_0}\right)L_1 \tag{5}$$

With L_1 present the inductance of the equivalent circuit proposed for square SRR in [10].

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

Where,

A, W, F are the notations prescribed in the previous section,

ρ is the filling factor of the inductance and is given by

$$\rho = \frac{W + F}{A - W - F} \tag{7}$$

The inductance is given by

$$L = \left(\frac{\mu_0}{4\varepsilon_0}\right)C_1 \tag{8}$$

With C_1 present the capacitance of the equivalent circuit proposed for square SRR in [10].

$$C_1 = \left(A - \frac{3}{2}\left(W + F\right)\right)C_{pul} \tag{9}$$

Where,

C_{pul} is the per-unit-length capacitance between the rings which is given as below

$$C_{pul} = \varepsilon_0\varepsilon_{eff}\frac{K\left(\sqrt{1-k^2}\right)}{K\left(k\right)} \tag{10}$$

Here, ε_{eff} is the effective dielectric constant which is expressed as

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{11}$$

K (k) denotes the complete elliptical integral of the first kind

$$K\left(k\right) = \frac{\pi}{2}\sum\left[\frac{\left(2n\right)!}{2^{2n}\left(n!\right)^2}\right]^2 \alpha^{2n} \tag{12}$$

With k expressed as

$$k = \frac{F}{F + 2W} \tag{13}$$

The square single ring CSRR is shown in Figure 4 (b), this resonance frequency is determined by the same relation the square double rings CSRR, with the dielectric width between the inner and the outer square is null.

4. Results

In this work, all the structures are designed on a single substrate of RT / Duroid 5880 permittivity ε_r =2.2 and height h = 0.254 mm.

Generally to determine the parameters of SIW guide, designed in the X-band [8.2-12.4] GHz from a conventional wave guide with dimensions a= 22.86 mm and b= 10.16 mm, using the formulas given by equations 1, 2 and 3. With the diameter of the metallic via D = 0.8 mm and the period of the vias P = 1.6 mm. Following this approach, the distance between the rows of the centres of via is W_{SIW} =16 mm and the length of SIW guide is L_{SIW} =L_{eff} =80 because does not bring significant change in the propagation phenomenon.

A microstrip transition (taper) is used to interconnect SIW to the planar transmission lines. There is a tapered section which is used to match the impedance between a 50Ω microstrip line and the SIW. The 50Ω microstrip line, in which the dominant mode is quasi-TEM, can excite well the dominant mode TE_{10} of the SIW, as their electric field distributions are approximate in the profile of the structure.

The parameters (the width W_M) of the microstrip line and (the width W_T and the length L_T) the transitions are determined from several formulas given in [2, 4].

The dimensions retained are W_M=0.8 mm, W_T =5.2 mm and L_T =14 mm.

A schematic view of a SIW with two tapered transitions is shown in Figure 6.

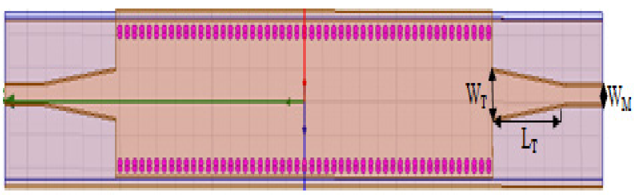


Figure 6. SIW with two tapered transitions

This structure is simulated by using HFSS. The simulated S-parameters of SIW with two tapered transitions in the frequency band 8.2 – 12.4 GHz are shown in Figure 7.

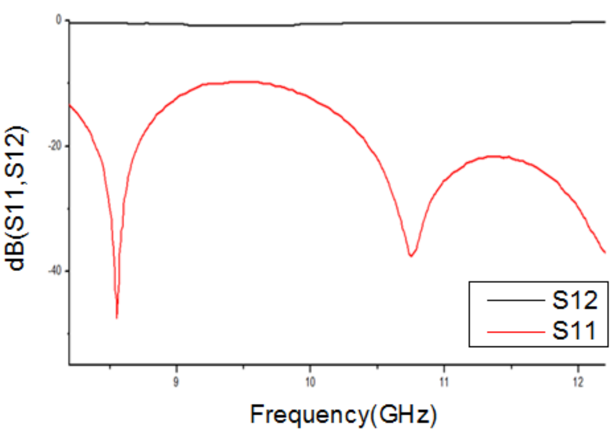


Figure 7. Transmission coefficient S12 and reflection coefficient S11 of SIW with two tapered transitions

The results illustrated in the figure 7, indicate that the reflection coefficient S11 remains below-15dB over 32% of the frequency band and the transmission coefficient S12 is around -0.9 dB across the entire band.

The SIW bandpass filter based on metamaterials (CSRRs) is designed by two methods.

The first method concerns the use of three square single ring CSRRs cells are etched in the top plane of the SIW.

Before beginning the study of the proposed filter, the resonant properties of square single ring CSRR are carefully studied starting with a single CSRR etching in the top plane of the SIW is shown in Figure 8.

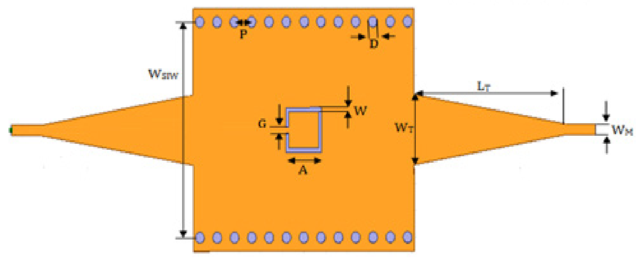


Figure 8. SIW guide with square single ring CSRR

The dimensions of the CSRR structure are chosen to have resonant frequency at 10.78GHz. They are A = 3 mm, W = 0.3 mm and G = 0.4 mm for a RT/Duroid 5880 substrate (dielectric constant εr = 2.22, thickness h = 0.254mm and tan δ = 0.002). The CSRR structure is etched in the top plane of the SIW exactly the center of a conductor plane of the SIW guide as shown in Figure 8.

The characteristics of square single ring CSRR on the surface of the substrate integrated waveguide are studied by varying the value of one parameter while the rest of the dimensions are being kept constant. The analyses of the performances are based on the centre stopband frequency, attenuation, passband frequency, fractional bandwidth and insertion loss.

First case:

The dimensions of the SIW guide and the transition are:

D = 0.8 mm, P = 1.6 mm, W_{SIW} =16 mm, W_M=0.8, W_T =5.2 mm and L_T =14 mm.

The dimensions of square single ring CSRR are:

W = 0.3 mm and G = 0.4 mm.

With the length of the side of the square "A" is varied in three different values (A = 3 mm, A = 3.1mm and A=3.2mm)

The Figure 9 shows the transmission coefficient S12 and the reflection coefficient S11 of the SIW guide with square single ring CSRR in three different values of the length of the side of the square "A".

The results simulated by HFSS of the SIW guide with square single ring CSRR in three different values of the length of the side of the square "A" are shown in Table 1.

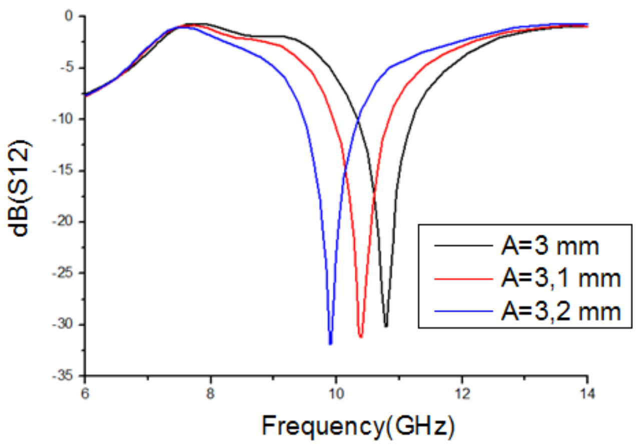
The results show that an increase in the length of the side of the square "A" a resulted in a decrease in the centre stopband frequency with the increased attenuation, passband bandwidth is decreased and insertion loss is increased.

Second case:

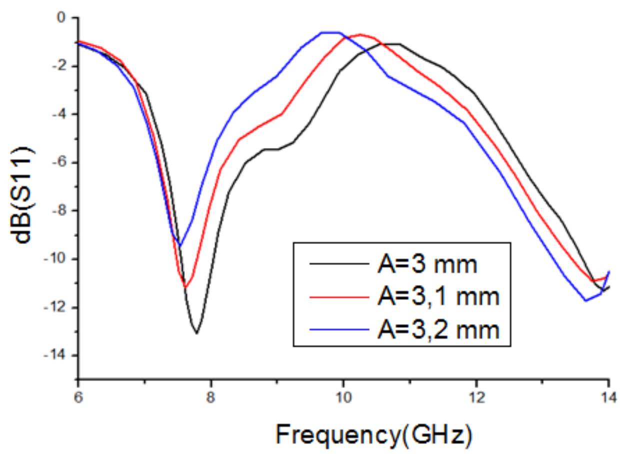
The dimensions of the SIW guide with square single ring CSRR are:

D = 0.8 mm, P = 1.6 mm, W_M=0.8, W_T=5.2 mm, L_T=14 mm, A=3.2mm, W=0.3 mm and G=0.4 mm.

With the width SIW guide "W_{SIW}" is varied in three different values (W_{SIW}=16 mm, W_{SIW}=15 mm and W_{SIW}=14 mm).



(a)

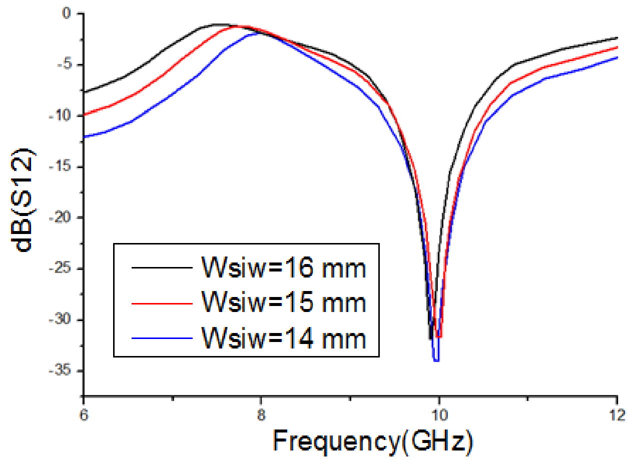


(b)

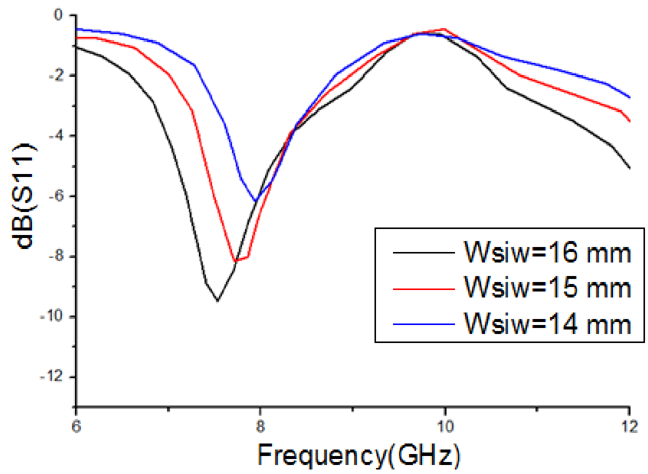
(A=3 mm, A=3.1 mm and A=3.2 mm)

Figure 9. Frequency response of the SIW guide with square single ring CSRR (a) Transmission coefficient S12 as a function of frequency (b) Reflection coefficient S11 as a function of frequency

The Figure 10 shows the transmission coefficient S12 and the reflection coefficient S11 of SIW guide with square single ring CSRR in three different values of the width SIW guide "W_{SIW}".



(a)



(b)

(W_{SIW}=16 mm, W_{SIW}=15 mm and W_{SIW}=14 mm)

Figure 10. Frequency response of the SIW guide with square single ring CSRR (a) Transmission coefficient S12 as a function of frequency (b) Reflection coefficient S11 as a function of frequency

The results of SIW guide with square single ring CSRR in three different values of the width SIW guide "W_{SIW}" are shown in Table 2.

The results show that a decrease in the width SIW guide "W_{SIW}" a resulted in a decrease in passband bandwidth with increased Insertion loss, the centre stopband frequency is fixed and attenuation is increased.

Table 1. Frequency response of variation of *"A"* for SIW guide with square single ring CSRR with dimensions D = 0.8 mm, P = 1.6 mm, W_{SIW} =16 mm, W_M=0.8, W_T =5.2 mm, L_T =14 mm, W = 0.3 mm and G = 0.4 mm

A(mm)	Centre stopband frequency (GHz)	Attenuation (dB)	Passband frequency (GHz)	Fractional bandwidth	Insertion loss (dB)
3	10.78	-30.3	7 to 9.71	32.4%	-1.54
3.1	10.38	-31.4	6.88 to 9.35	30.4%	-1.57
3.2	9.9	-32.27	6.8 to 8.8	25.6%	-1.58

Table 2. Frequency response of variation of "W_{SIW}" for SIW guide with square single ring CSRR with dimensions D = 0.8 mm, P = 1.6 mm, W_M=0.8, W_T=5.2 mm, L_T=14 mm, A=3.2mm, W=0.3 mm and G=0.4 mm

W_{SIW} (mm)	Centre stopband frequency (GHz)	Attenuation (dB)	Passband frequency (GHz)	Fractional bandwidth	Insertion loss (dB)
16	9.9	-32.27	6.8 to 8.88	25.6%	-1.58
15	9.9	-33.23	7.1 to 8.77	21.04%	-1.62
14	9.9	-34.44	7.42 to 8.65	15.3%	-2.1

Table 3. Frequency response of variation the dimensions of transition for SIW guide with square single ring CSRR with dimensions D = 0.8 mm, P = 1.6 mm, W_{SIW} =14 mm, W_M=0.8, A=3.2mm, W=0.3 mm and G=0.4 mm

L_T and W_T (mm)	Centre stopband frequency (GHz)	Attenuation (dB)	Passband frequency (GHz)	Fractional bandwidth	Insertion loss (dB)
14 and 5.2	9.9	-34.44	7.42 to 8.65	15.3%	-2.1
5.5 and 2	9.9	-34.44	6.69 to 8.47	23.7%	-1.6

Third case:

The dimensions of the SIW guide with square single ring CSRR are:

D = 0.8 mm, P = 1.6 mm, W_{SIW} =14 mm, W_M=0.8, A=3.2mm, W=0.3 mm and G=0.4 mm.

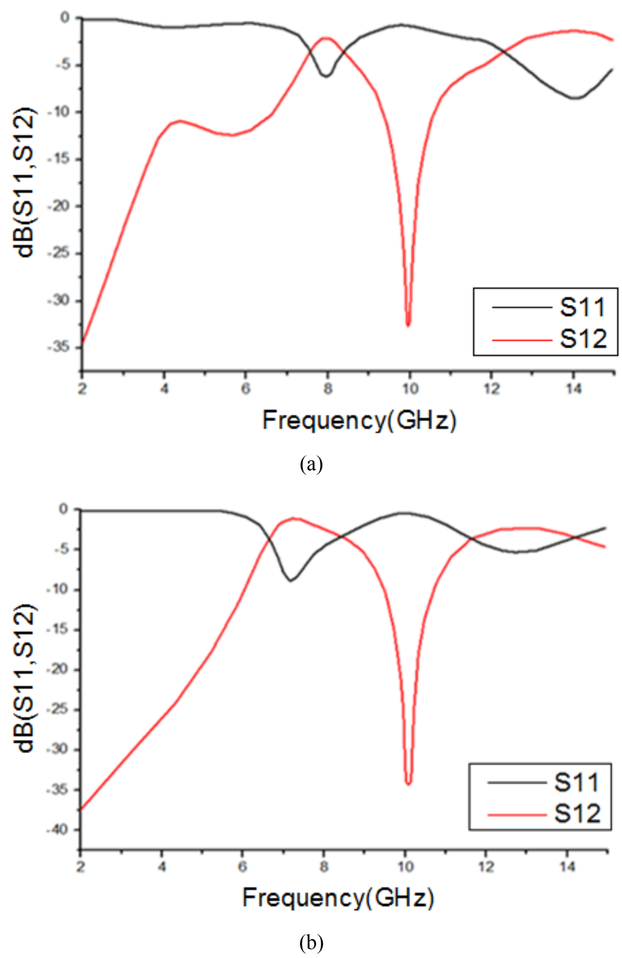


Figure 11. (a) Frequency response of the structure (SIW guide with square single ring CSRR) with L_T=14 mm and W_T =5.2 mm (b) Frequency response of the structure (SIW guide with square single ring CSRR) with L_T=5.5 mm and W_T =2 mm

With the dimensions of transition are varied in two values. (L_T=14 mm, W_T =5.2 mm) and (L_T=5.5 mm, W_T =2 mm)

The Figure 12 shows the frequency response of SIW guide with square single ring CSRR in two different dimensions of transition (the width L_T and the length W_T).

The results of SIW guide with square single ring CSRR in two different dimensions of transition (the width L_T and the length W_T) are shown in Table 3.

The results show that a decrease in the dimensions of transition a resulted in an increased in passband bandwidth with insertion loss lower, the centre stopband frequency and attenuation are fixed.

Finally, the results showed the most important parameters to influence on the central frequency of the stop band attenuation, frequency bandwidth and insertion loss, to achieve a narrow bandwidth with very low insertion loss.

The proposed design of SIW bandpass filter based of three square single ring CSRRs cells is shown in Figure 12.

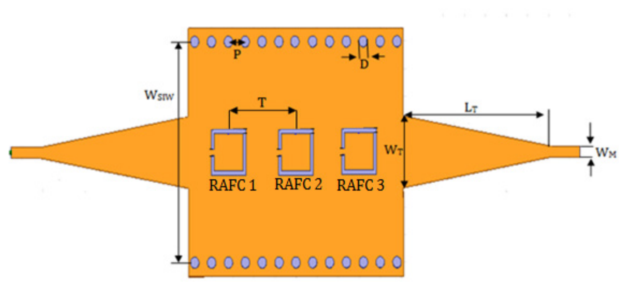


Figure 12. SIW bandpass filter based of three square single ring CSRRs cells

The dimensions of the SIW guide, the transition and the microstrip line are:

D = 0.8 mm, P = 1.6 mm, W_{SIW} =14 mm, W_T =1.72 mm and L_T =5.5 mm, W_M=0.8.

The dimensions of square single ring CSRR1 are:

A=2.7 mm, W=0.3 mm and G=0.4 mm.

The dimensions of square single ring CSRR2 are:

A=2.9 mm, W=0.3 mm and G=0.4 mm.

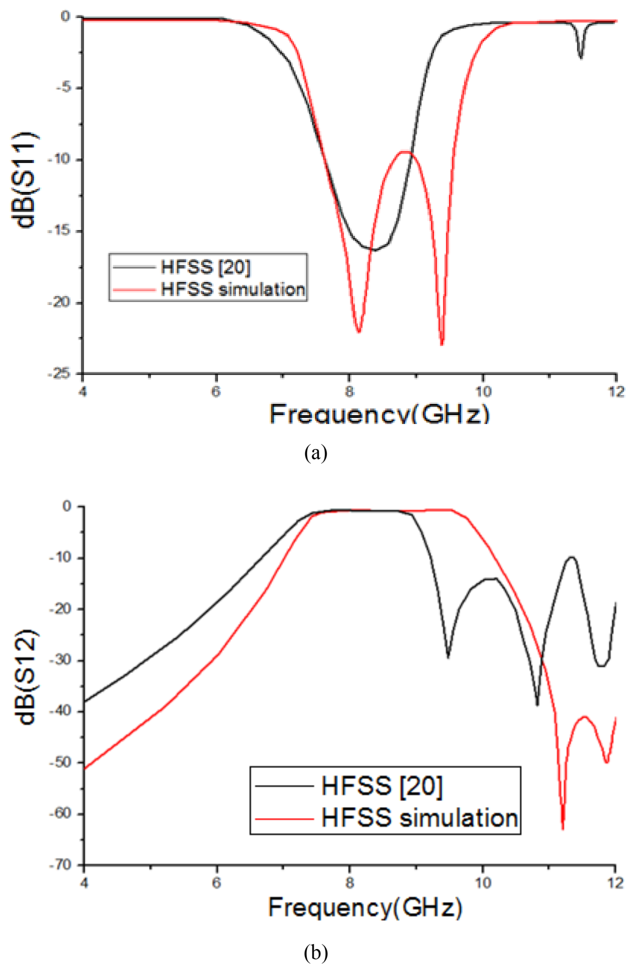
The dimensions of square single ring CSRR3 are:

A=2.8 mm, W=0.3 mm and G=0.4 mm.

The distance between two adjacent square single ring CSRRs is T =7.4 mm

The figure 13 illustrated the reflection coefficient S11 and the transmission coefficient S12 of SIW bandpass filter based of three square single ring CSRRs cells and also the results in [20].

The result simulated by HFSS shows that the full frequency passband is from 7.267 to 9.933 GHz. the center frequency f_0= 8.6 GHz, the absolute bandwidth 2.67GHz and the relative bandwidth FBW= 31%. The insertion loss around 8.6 GHz is approximately -0.81 dB, the return loss in the passband is better than -8.91 dB.



(a)

(b)

(—— HFSS simulation, —— HFSS [20])

Figure 13. Frequency response of SIW bandpass filter based of three square single ring CSRRs cells (a) Reflection coefficient S11 as a function of frequency (b) Transmission coefficient S12 as a function of frequency

On the other side, the result simulated by HFSS in [20] shows that the full frequency passband is from 7.34 to 9 GHz. the center frequency f0= 8.17 GHz, the absolute bandwidth 1.66 GHz and the relative bandwidth FBW= 20.31%. The insertion loss around 8.17 GHz is approximately -0.57 dB, the return loss in the passband is -15 dB.

The results simulated by HFSS in [20] show the frequency responses better than the results simulated of SIW bandpass filter based of three square single ring CSRRs cells, owing to the use of resonators CSRRs more specific about the achievement of narrow bandwidths with very low insertion loss. To improve the characteristics of the bandpass filter, other resonators CSRSS are used in the second method.

The second method concerns the use of three square double rings CSRRs cells are etched on the top plane of the SIW.

As the first method, the resonant properties of square double ring CSRR are carefully studied starting with a single CSRR etching in the top plane of the SIW is shown in Figure 14.

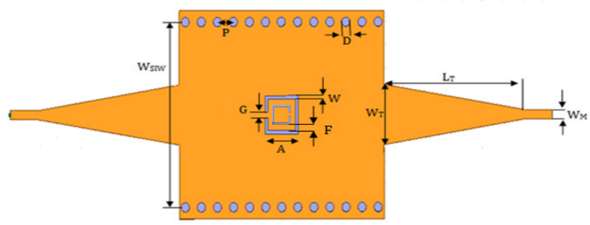
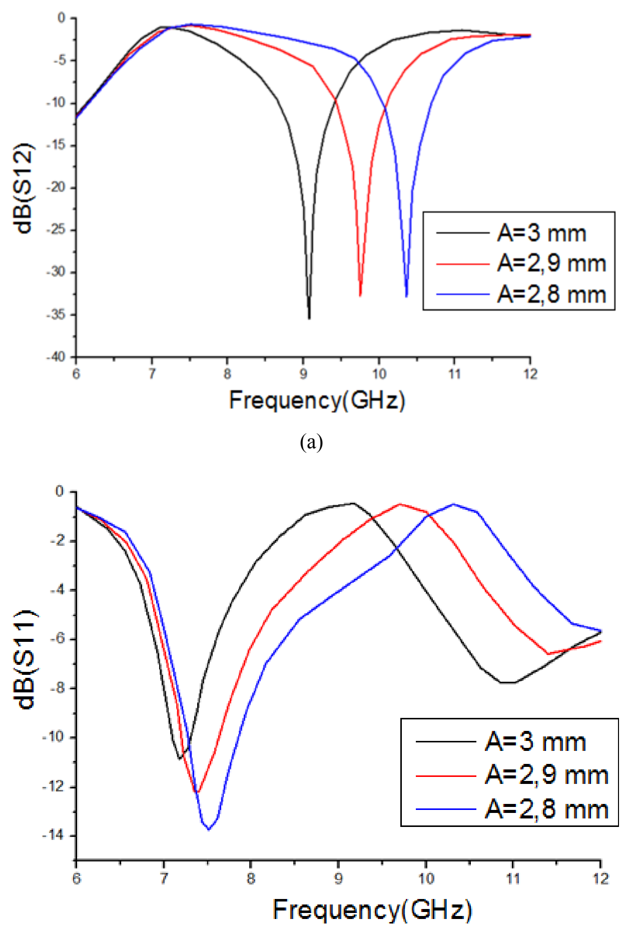


Figure 14. SIW guide with square double rings CSRR



(a)

(b)

(—— A=3 mm, ——A=2.9 mm et ——A=2.8 mm)

Figure 15. Frequency response of the SIW guide with square double ring CSRR (a) Transmission coefficient S12 as a function of frequency (b) Reflection coefficient S11 as a function of frequency

The dimensions of the CSRR structure are chosen to have resonant frequency at 9.08GHz. They are A = 3 mm, W = 0.3 mm, G = 0.4 mm and F=0.3 mm for a RT/Duroid 5880 substrate (dielectric constant εr = 2.22, thickness h = 0.254mm and tan δ = 0.002). The CSRR structure is etched in the top plane of the SIW exactly the center of a conductor plane of the SIW guide as shown in Figure 14.

As the first method, the characteristics of square double ring CSRR on the surface of the substrate integrated waveguide are studied by varying the value of one parameter while the rest of the dimensions are being kept constant.

The dimensions the SIW, the transition and the microstrip line are:

D = 0.8 mm, P = 1.6 mm, W_{SIW} =14 mm, W_T =1.72 mm, L_T =5.5 mm and W_M=0.8

The dimensions of square double ring CSRR are:

W = 0.3 mm, G = 0.4 mm and F=0.3 mm

With the length of the side of the square "A" is varied in three different values (A = 3 mm, A = 2.9mm and A=2.8mm)

The Figure 15 shows the transmission coefficient S12 and the reflection coefficient S11 of the SIW guide with square double ring CSRR in three different values of the length of the side of the square "A".

The results simulated by HFSS of the SIW guide with square double ring CSRR in three different values of the length of the side of the square "A" are shown in Table 4.

The results show that a decrease in the length of the side of the square "A" a resulted in a increase in the centre stopband frequency and decreased attenuation, passband bandwidth is increased and insertion loss is decreased.

The proposed design of SIW bandpass filter based of three square double ring CSRRs cells is shown in Figure 16.

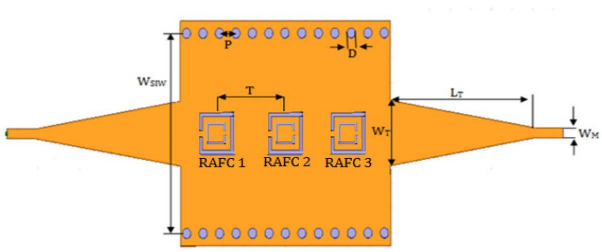


Figure 16. SIW bandpass filter based of three square double ring CSRRs cells

The dimensions of the SIW guide, the transition and the microstrip line are:

D = 0.8 mm, P = 1.6 mm, W_{SIW} =14 mm, W_T =1.72 mm, L_T =5.5 mm and W_M=0.8.

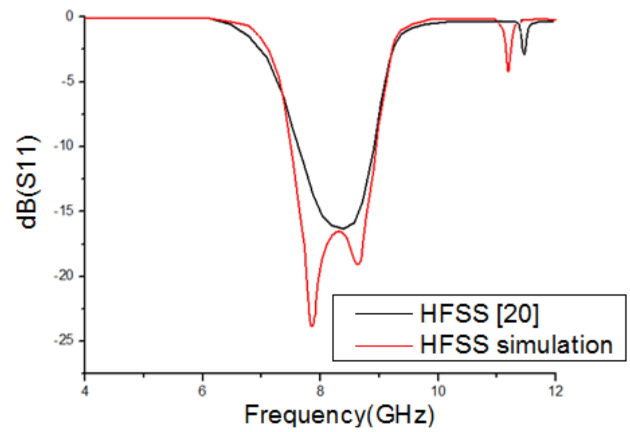
The dimensions of square double ring CSRR1 are:
A=2.7 mm, W=0.3 mm, G=0.4 mm and F=0.3 mm

The dimensions of square double ring CSRR2 are:
A=2.9 mm, W=0.3 mm, G=0.4 mm et F=0.3 mm

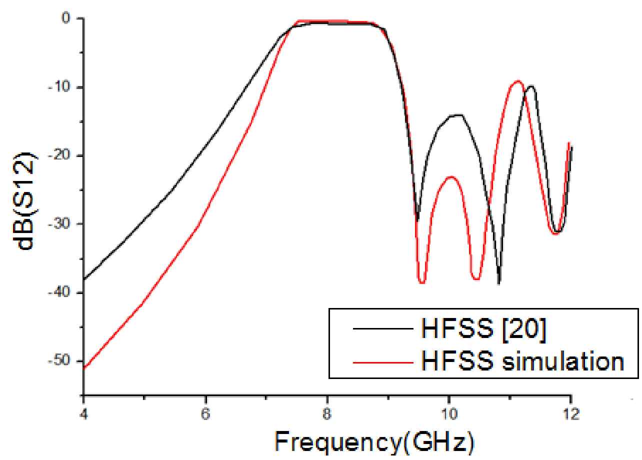
The dimensions of square double ring CSRR3 are:
A=2.8 mm, W=0.3 mm, G=0.4 mm and F=0.3 mm

The distance between two adjacent square double ring CSRRs is T =9 mm

The figure 17 illustrated the reflection coefficient S11 and the transmission coefficient S12 of SIW bandpass filter based of three square double ring CSRRs cells and also the results in [20].



(a)



(b)

(—— HFSS simulation, ——HFSS [20])

Figure 17. Frequency response of SIW filter based of three square double ring CSRRs cells (a) Reflection coefficient S11 as a function of frequency (b) Transmission coefficient S12 as a function of frequency

Table 4. Frequency response of variation of *"A"* for SIW guide with square double ring CSRR with dimensions D = 0.8 mm, P = 1.6 mm, W_{SIW} =14 mm, W_T =1.72 mm, L_T =5.5 mm, W_M=0.8, W = 0.3 mm, G = 0.4 mm and F=0.3 mm

A(mm)	Centre stopband frequency (GHz)	Attenuation (dB)	Passband frequency (GHz)	Fractional bandwidth	Insertion loss (dB)
3	9.08	-37.11	6.66 to 8.06	19.02%	-1.19
2.9	9.73	-35.5	6.7 to 8.7	25.97%	-1.09
2.8	10.33	-33.5	6.8 to 9.4	32%	-0.97

The results simulated by HFSS are in good agreement with the results in [20]. The results simulated by HFSS shows that the full frequency passband is from 7.34 to 9 GHz. the center frequency f0= 8.17 GHz, the absolute bandwidth 1.66 GHz and the relative bandwidth FBW= 20.31%. The insertion loss around 8.17 GHz is approximately -0.57 dB, the return loss in the passband is better than -15 dB.

This filter have a small size can be directly integrated with other circuits. This makes them favorable for microwave and millimeter-wave applications.

5. Conclusions

In this work, two bandpass SIW filter based on Complementary Split Ring Resonators (CSRRs) were presented for X-band applications. Which are designed by two methods, The first method concerns the use of three square single ring CSRRs cells are etched in the top plane of the SIW, the simulated results of this filter have shown that the passband is from 7.267 GHz to 9.933 GHz, while the insertion loss is -1.11 dB within 31% bandwidth around 8.6 GHz and input return loss in the passband is better than -8.91 dB. The second method concerns the use of three square double rings CSRRs cells are etched on the top plane of the SIW, the simulated results of this filter have shown that the passband is from 7.34 GHz to 9 GHz, while the insertion loss is -0.47 dB within 20.31% bandwidth around 8.17 GHz and the return loss in the passband is better than -15 dB.

These filters are easy for integration with other planar circuit compared by using conventional waveguide. The design method is discussed; the results from our analysis are in good agreement with previous research done on this topic. These bandpass SIW filters based on Complementary Split Ring Resonators (CSRRs) are suitable for practical applications.

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