DESIGN OF NARROWBAND BANDPASS FILTERS USING DUAL-MODE OPEN-LOOP RESONATORS

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by

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Abstract

A compact dual-mode microstrip open-loop resonator is implemented in stripline technology for the design of compact, sharp-rejection and narrowband bandpass filter (BPF) for space application. The advantage of structure is compact, low cost, and ease of integration. The different characteristics of the dual-mode microstrip open-loop resonator are observed using full-wave electromagnetic simulations using Zeland V14.10 software [10]. From the simulation it is observed that two operating modes (even and odd modes) exist within a single dual-mode resonator. These two modes (currents are mutually excluive in nature) do not couple each other and a finite transmission zero inherently assosiated with the even mode. Variation of parameters of dual-mode resonator loading element leads to asymmetric frequency response used for filter design. Multiple sections of resonator give the sharp rejection after the passband.

The design specifications are center frequency of bandpass filter is at 2GHz, bandwidth of 100MHz (5% relative bandwidth), upper side of bandpass filter should have 70dB isolation from passband to stopband over 50MHz, Return loss shold be atleast 10dB and with low insertion loss. The design has to be implemented in stripline technology with compact in size.

The stripline filter is desinged on substrate namely Woven TFG (substrate having dielectric constant 2.5, substrate thickness of 1.5875mm and loss tangent of 0.0009). Two different Mixed coupling structures are proposed out of which one uses the Non Resonating Node (NRN) coupling element. The advantage of this NRN is we can independently vary the parameters of the individual resonator which will shows neglegible effect of other resonator. Aditional adjustments and corrections were made for satisfactory filter characteristics.

1. Literature Survey

The miniaturization of electronic components has received a lot of attention in the last decades due to the rapid development of the telecommunication industry. Traditional high performance waveguide and dielectric resonator filters are usually too heavy and bulky for most applications like tower-top mounting in base stations [1]. This is also the case in satellite applications where payload costs are elevated, and high performance filters are usually needed. Lately, the accelerated market expansion of portable devices is pushing the needs for miniaturization to its limits. In most modern commercial products there is a very limited use for any large, high performance component. All this is stressed by the fact that most communication systems implemented nowadays operate below 6 GHz where distributed components are physically large.

At lower frequencies the resonators used are Bulk-wave resonators, SAW (surface acoustic wave) filters and helical resonators. All these are used when miniaturization and low loss are strongly demanded. Helical resonators used for high power handling capability. Resonators for RF and MW ranges are Co-axial resonators, Dielectric resonators, Waveguide resonators and Stripline resonators [4]. Co-axial resonators include EM shielding, low-loss characteristics and small-size. The main disadvantage of these is small physical dimensions for greater than 10GHz.

Dielectric resonators include low-loss characteristics, good temperature nature and small-size. The disadvantage of these are high cost for processing technology for less than 50GHz. Waveguide resonators include low-loss characteristics; practical application up to 100GHz. The disadvantage of these is large in size and weight also. Stripline resonators include small size, easy processing by photo-lithography, good affinity with active circuit elements and wide range of frequencies by different substrates. The disadvantages of these are drastic increase in insertion-loss and difficulty to apply for narrowband filters (especially less than 5% bandwidth). Now a day's required properties of filters are low-loss, narrowband, sharp roll-off, small groupdelay and easy integration with active elements like MMIC's. So these are achieved by stripline technology with different substrates here.

The microstrip square open loop resonator is one of the most used structures for filter applications due to its cross-coupling nature, compact size, of approximately $\lambda/8$ by $\lambda/8$, and versatility.

2. Square Open Loop $\lambda_g/2$ Resonators

The microstrip square open loop resonator can be obtained by folding a straight open resonator as shown in Fig. 1. Due to the corners and the fringing capacitance between the open ends, a rigorous calculation of the electromagnetic fields in the square resonator is impractical. However, it is possible to study the main characteristics of the resonant modes of the square open loop resonator by analogy to those of the straight resonator. This qualitative analysis can shed some light on the behavior of the resonator with minimum effort. The conclusions drawn using this approach can then be compared for validation against the actual distribution of the electromagnetic fields obtained with the aid of full wave EM simulators [10].

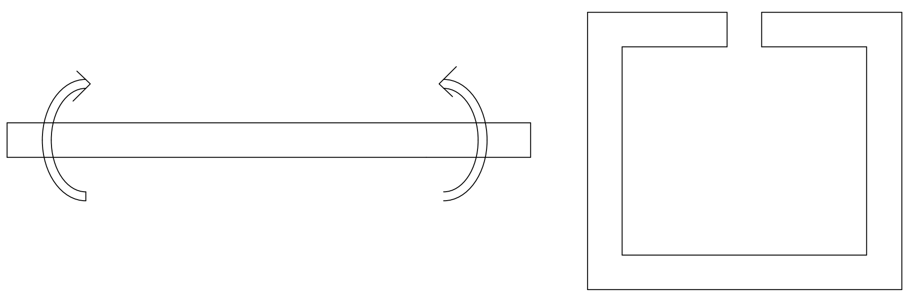


Fig. 1 The square open loop resonator can be obtained by folding a straight open resonator.

3. Feeding methods

There are mainly two types of input/output coupling structures for microstrip resonators. They are tapped-line (direct) feeding and coupled-line feeding (week-coupling) shown in Fig. 2. For tapped-line coupling, a 50 ohm feed line is directly tapped onto I/O resonator, and the coupling or external quality factor is controlled by tapping position t, as indicated in Fig. 2(a). For smaller t, the closer is the tapped line to virtual ground of resonator, which results in weak-coupling or a larger external quality factor. The coupling of the coupled line structure in Fig. 2(b) can be found from the coupling gap g and the line width w. Smaller the gap and a narrow line result in a stronger I/O coupling and a smaller external quality factor.

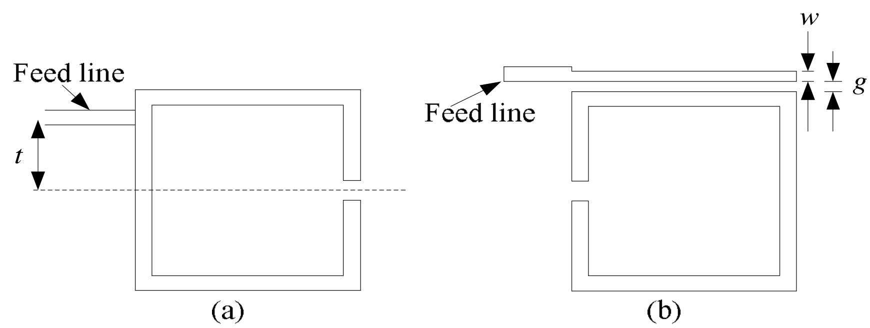


Fig. 2 Typical I/O coupling structures for coupled line resonator filters. (a) Tapped-line coupling. (b) Coupled-line coupling.

4. Parameters of single-mode open-loop square resonator

Main parameters are length of resonator (a), width of resonator (w) and gap of the resonator (g). Since it's an open-loop square resonator length and width of the resonator are almost equal.

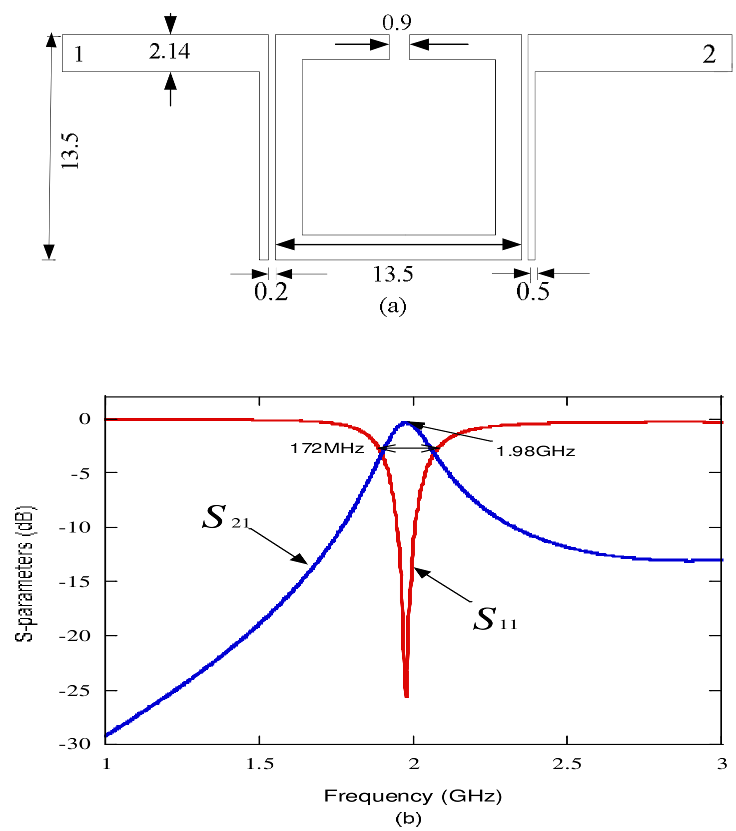


Fig. 3 Single mode open-loop square resonator. (a) Simulation diagram showing week I/O coupling to the resonator (all units are in mm). (b) Frequency response.

Fig. 3(a) shows the structure of the open-loop resonator with week-coupling. The length of the resonator is 13.5mm, width of the resonator is 1.5mm and open-loop gap is 0.9mm. The port sizes are 2.14mm width and length is 10.5mm. The spacing is 0.2mm between resonator and coupled line and coupled line width is 0.5mm. This structure is implemented on Woven TFG substrate having relative dielectric of 2.5, substrate height of 1.5875mm and loss tangent of 0.0009 in stripline technology.

Using the EM simulator [10], the structure is simulated and response is shown in Fig. 3(b). From the response it is observed that the center frequency is 1.98GHz, quality factor is 11.5 and bandwidth is 172MHz for the open-loop resonator.

5. Dual mode open-loop resonator

Each single-mode resonator is equal to an LC circuit, which produces a pole at the resonance frequency. But in order to design a filter with sharp rejection no of single-mode resonators are to be connected in cascade structures and this leads to increase in size of the filter. Each Dual mode resonator is a doubly tuned resonant circuit. So no of resonators for a given degree of filter is reduces by half. Here proposed design has the same size as single mode resonator with the help of loading element leads to compact in size. A loading element with a variable parameter $'W'$ is tapped from inside onto the open loop.

Change of width of loading element $'W'$ leads to mode splitting. Two modes exists odd mode and even mode. The resonance frequency which is not affected by change of width of loading element is called odd-mode. The resonance frequency which is affected by change of width of loading element is called even-mode.

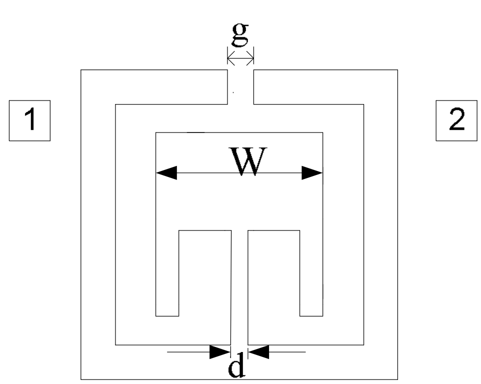


Fig. 4 Dual mode open-loop square resonator.

Odd mode exhibits the same characteristics that of single mode resonator, since in the odd mode at the tapping point its short circuit. So the loading element does not contribute any coupling here. Hence the odd mode resonance frequency is dependent only on square open-loop parameters (i.e. length of resonator (a), width of resonator (w) and gap of open loop (g)). But in the even mode it causes the resonant frequency with varying the width of loading element ($'W'$), and width of tapping element ($'d'$). Next diagram shows here the variation of even mode resonant frequency with $'W'$ and $'d'$.

To excite the resonator, weakly coupled ports are used. For a single value of 'W' the two modes exhibits same resonance frequency. As $'W'$ increases/decreases, the two modes split. Smaller $'W'$ shifts resonance frequency of even mode to right. Larger $'W'$ shifts even-mode resonance frequency to left. Due to short circuit at tapped point no charge or current in the odd mode case in the loading element, and maximum current in the even mode case in loading element. There is a finite frequency transmission zero as the modes split. Transmission zero is on right side if even mode frequency is more than odd mode frequency and on left side if odd mode frequency is more than even mode frequency.

The transmission zero is related to the even mode case only. There are two properties of dual-mode resonator. It exhibits a transmission zero for filter design of asymmetric response. Two modes are not coupled to each other even after they split. From the theory of asynchronous tuned coupled resonator, two split mode frequencies are equal to two self-resonant frequencies and no coupling between these two resonators. To find these separate frequencies response place a magnetic/electric wall along the line of symmetry leads to two self-resonant frequencies.

6. Parameters of dual-mode open-loop square resonator

The dual-mode resonator parameters are single-mode resonator parameters (a, w and g), width of the loading element (W) & Height of the loading element (h_1), width of the connected stub (d) & Height of the connected stub (h_2) and additional stub to the loading element width and height (sw and sh). All the parameters are indicated in Fig. 5.

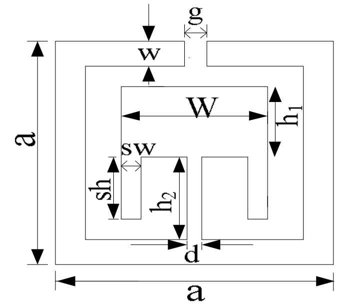
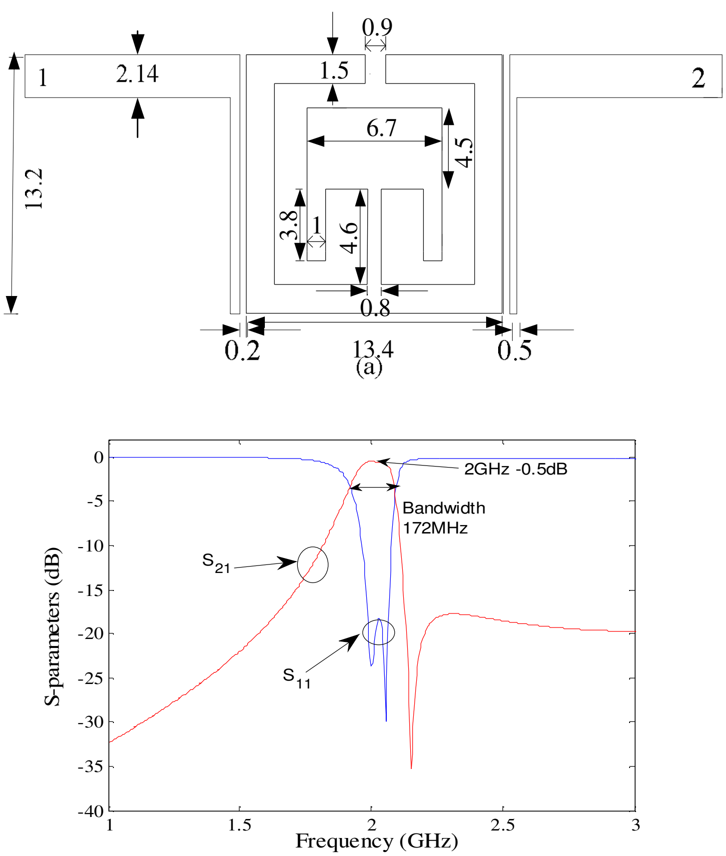


Fig. 5 Dual mode resonator showing different parameters.

Here dual mode single section open-loop resonator is used for the bandpass filter design. Since the resonator provides asymmetric structure we are getting response in upper side of bandpass filter. The even-mode and odd-mode resonant frequencies are bring to close each other and the transmission zero is taking near to passband so that narrowband filter is provided. The filter is exited by coupled line structure. The response is plotted in this section along with the filter design diagram.



(b)

Fig. 6 Dual mode open-loop filters [8]. (a) Simulation diagram showing week I/O coupling to the resonator (all units are in mm). (b) Frequency response.

The filter is designed using EM simulator [8] and the response of the design is plotted in Fig. 6(b). The length of the resonator is 13.4mm, width of the resonator is 1.5mm and open-loop gap is 0.9mm. The port sizes are 2.14mm width and length is 10.5mm. The spacing is 0.2mm between resonator and coupled line, and coupled line width is 0.5mm. The loading element width is 6.7mm and length is 8.3mm. This structure is implemented on Woven TFG substrate having relative dielectric of 2.5, substrate height of 1.5875mm and loss tangent of 0.0009 in stripline technology.

The resonant frequency of the proposed design is 2 GHz, quality factor is 11.6 and bandwidth is 172MHz. This is showing asymmetric frequency response of the bandpass filter in the upper passband. The level of the transmission zero of the filter in the upper-side of pass band is -35dB. The same structure with increasing the width of the loading element brings the transmission zero to the left side (lower pass band side). So combination of these two asymmetric responses produces the symmetric bandpass filter design for narrowband application.

7. Dual-mode coupling mechanism

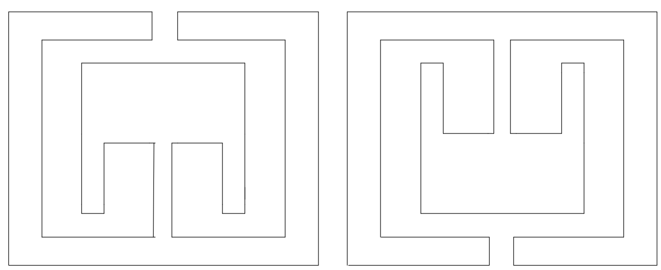


Fig. 7 Mixed couplings of dual-mode resonators separated by distance $'s'$.

Shown in Fig. 7 is the one of basic coupling structures encountered in the type of cross-coupled filters. It follows that the electric coupling can be obtained if the open sides of two coupled resonators are proximately placed, while the magnetic coupling can be obtained if the sides with the maximum magnetic field of two coupled resonators are proximately placed. For the coupling structure in Fig. 7, the electric and magnetic fringe fields at the coupled sides may have comparative distributions so that both the electric and the magnetic couplings occur. In this case the coupling may be referred to as the mixed coupling. So in our discussion we are using mixed coupling schemes.

8. NRN Coupling Element

The two dual-mode resonators without any direct coupling between them are cascaded through the two non resonating nodes, as shown in the diagrams. The advantage of this method is we can vary the parameters of the each dual-mode resonator independently. Generally this method is used for the symmetric frequency response to get at the both sides of the passband.

9.1. Quad-Section Mixed Coupling using NRN Coupling Elements (on Woven TFG substrate)

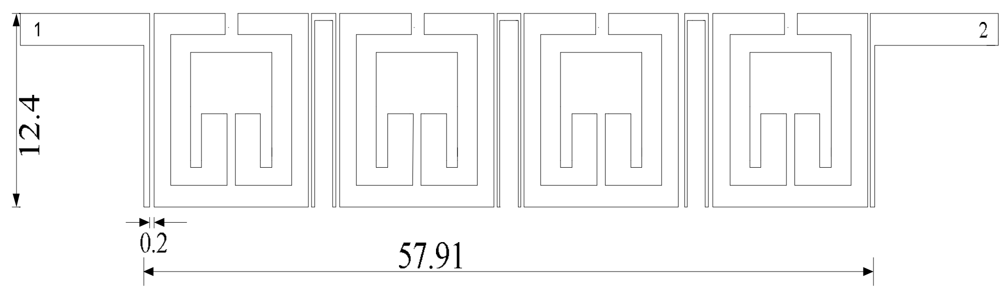


Fig. 8(a) Quad-section using NRN coupling element (all dimensions are in mm).

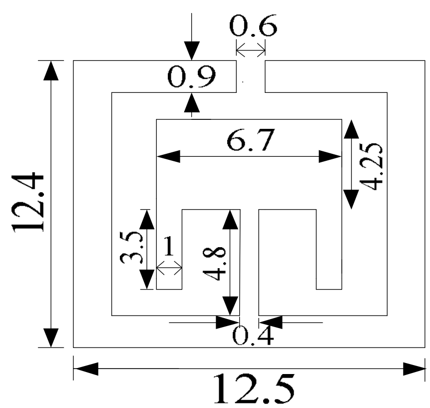


Fig. 8(b) Single unit dimensions (all dimensions are in mm).

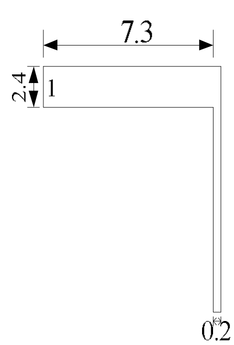


Fig. 8(c) Port Dimensions (in mm)

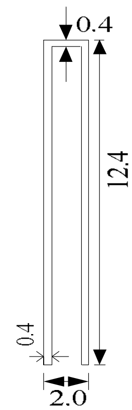


Fig. 8(d) NRN (first and third NRN are equal length of 2 mm, second NRN is 1.91mm length) (all dimensions are in mm).

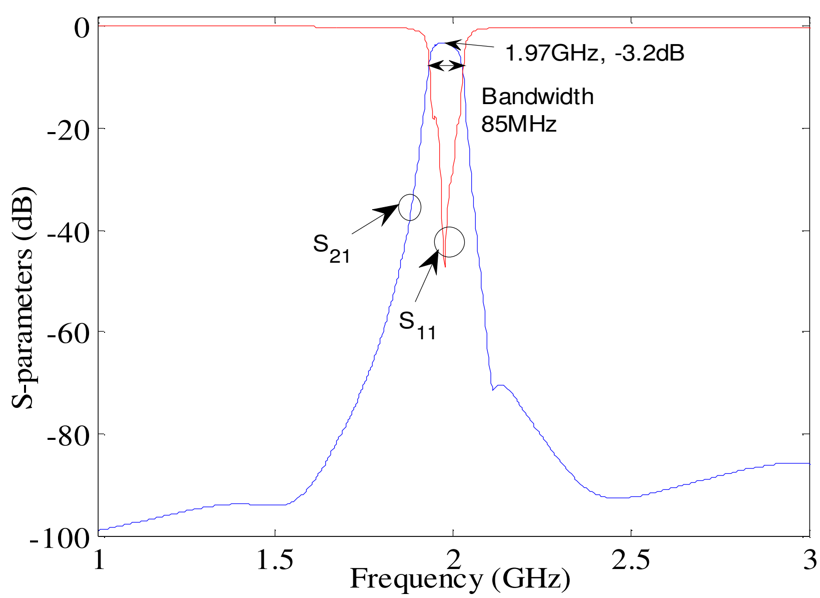


Fig. 9 S-parameters of the Quad-section using NRN coupling element.

Discussion

From the Fig. 9, insertion loss in pass band at 2GHz is 3.2dB. The frequency band separation between the pass band and stop band at 2.05 GHz is 29.26dB, at 2.10GHz is 66.41dB and at 2.11GHz is 73.36dB. Here 37.1dB isolation is achieved between 2.05 GHz and 2.10GHz, and 70dB isolation is achieved between 2.0GHz and 2.11GHz. The filter roll-off rate = 636 dB/GHz on the upper side of the pass band. The return loss in pass band is better than 18 dB. The upper band rejection of insertion loss is greater than 70 dB from 2.11 GHz to 3 GHz.

The quad-section asymmetric response is obtained using the Woven TFG substrate having relative dielectric of 2.5, substrate height of 1.5875mm and loss tangent of 0.0009 in stripline technology. The metal strip is shown in the Fig. 8(a) for the entire quad section. In Fig. 8(b) individual section of resonator is shown. Each resonator is separated by NRN coupling element here. The port dimensions are given in Fig. 8(c) and the NRN coupling element is shown in Fig. 8(d) along with dimensions. At last in Fig. 9 shows the frequency response of the given design in Fig. 8 using EM software [10] and the response is plotted here.

9.2. Quad-section direct mixed coupling

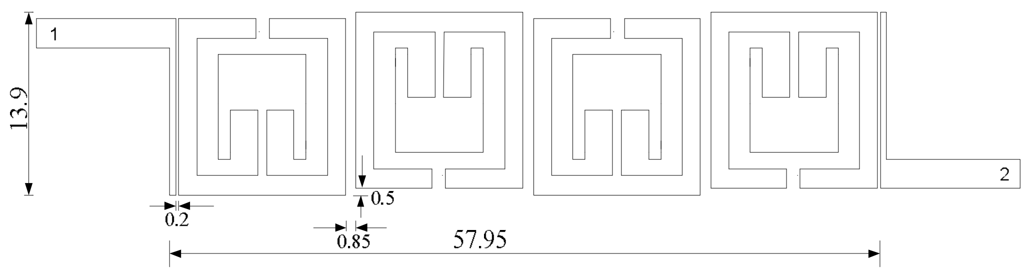


Fig. 10(a) Quad-section direct mixed coupling (all dimensions are in mm).

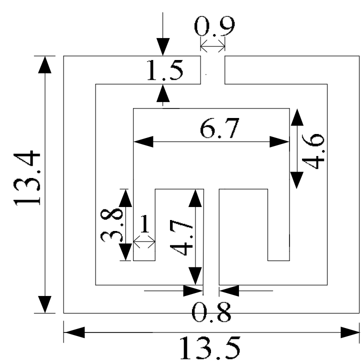


Fig. 10(b) Single unit dimensions (all dimensions are in mm).

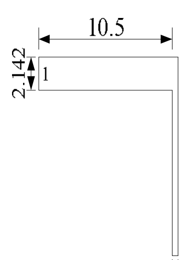


Fig. 10(c) Port Dimensions (all dimensions are in mm).

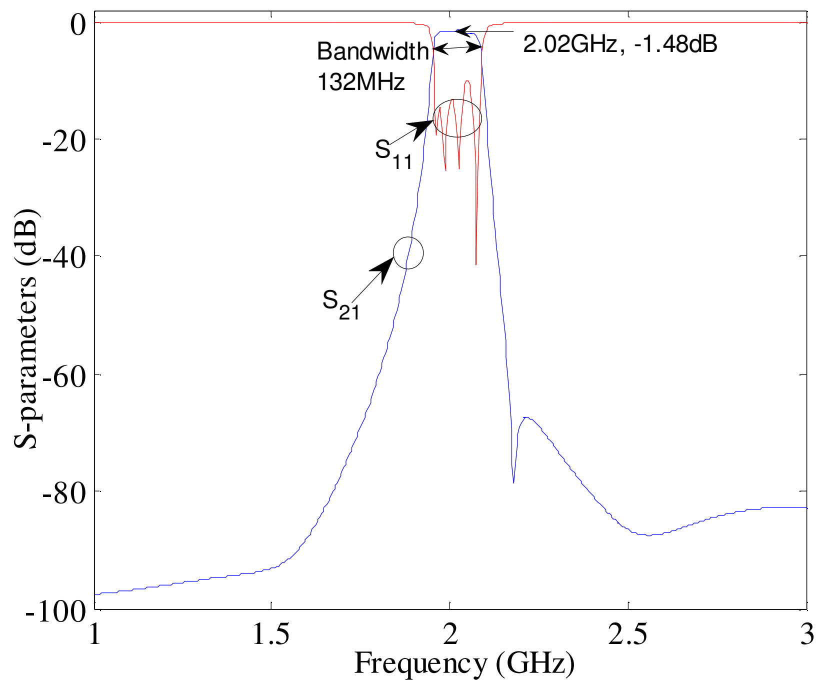


Fig. 11 S-parameters of the Quad-section direct mixed coupling.

Discussion

The quad-section asymmetric response is obtained using the Woven TFG substrate having relative dielectric of 2.5, substrate height of 1.5875mm and loss tangent of 0.0009 in stripline technology. The metal strip is shown in the Fig. 10(a) for the entire tri-section. In Fig. 10(b) individual section of resonator is shown. The port dimensions are given in Fig. 10(c) along with dimensions.

At last in Fig. 11 shows the frequency response of the given design in Fig. 10 using EM software [10] and the response is plotted here. The center frequency of the structure is at 2.02GHz, with insertion loss value of 1.48dB, the transmission zero is frequency 2.18GHz, with insertion loss value of 78.51dB. The return loss maximum over passband is 9.99dB. The flat region is over 1.96 GHz to 2.07 GHz. The bandwidth of the quad-section filter is 132MHz. The over-all tri-section size is $0.611\lambda g\times 0.1412\lambda g$.

10. Conclusions

The miniaturization of microwave filters below 3 GHz remains an active area of research due to the relatively large physical size of traditional resonators and the great demand from the wireless communication industry within this band. One of the most popular structures for microstrip implementations is the square open loop resonator due to its compact size and versatility. Here design of narrowband bandpass filter using dual-mode open-loop resonators is studied. The design procedure includes the ease of fabrication, high performance.

The center frequency of the structure is at 2.02GHz, with insertion loss value of 1.48dB, the transmission zero is frequency 2.18GHz, with insertion loss value of 78.51dB. The return loss maximum over passband is 9.99dB. The flat region is over 1.96GHz to 2.07GHz. The bandwidth of the quad-section filter is 132MHz. The over-all tri-section size is $0.611\lambda g \times 0.1412\lambda g$.

11. Future work

Verify the simulated results with measured data. Any another structure leads to compact size and produce improved insertion loss in pass-band for the given design problem. The design can be extended to fractal structure so that size will be further reduced. The work can be extended to different substrates with proper design of the resonator. Multi layer design can also be possible.

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