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Designing a Two-Band Micro-Strip Filtering Antenna for Use in Wi-Max Telecommunication Systems and the Fifth Generation Mobile Cellular Communication Network

Elnaz Ghanadian[1,2], Mohamad Amin Honarvar[1,2]

[1]Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[2]Digital Processing and Machine Vision Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran

Abstract

The proposed structure is a closed-loop dual-band filtering antenna, in which the antenna and the resonator are combined together. The filtering antenna consists of two triangular resonators and a rectangular loop micro-strip antenna. The surface structure of a Rogers RO-4003 substrate with dielectric (εr) equal to 3.55 and insulation loss tangent (tgδ) equal to 0.0027 and a thickness of 32 mm is placed at frequencies of 3.4, 5.28 and 8 5.5 GHz, which indicates a return loss below 10 dB. This structure is suitable for Wi-Max and the fifth-generation mobile communication network, and the filter antenna proposed for these applications has a suitable bandwidth and radiation pattern in its resonance frequencies. The design and analysis of the structure has been done using HFSS software. To confirm the correctness of the simulation results, a laboratory sample of the proposed filtering antenna is made and it shows the correctness of the measured values of the design and simulation.

Keywords: Rectangular ring micro-strip antenna, filtering antenna, bandwidth, multimode resonator, band-pass filter
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1. Introduction

Antennas with multi-purpose capability, such as filtering antennas, have attracted the attention of designers in recent years [1,2]. Filtering antennas avoid separate design, and also improve antenna and filter performance in the passband [3,4]. A common way to design filtering antennas, which results in high integration, is to replace the radiating antenna at the end of the filter network. One of the widely used structures for the design of wideband filters is the use of multi-mode resonators [5,6]. Filters designed based on the multimode technique operate by creating resonators at different frequencies, as well as by having multiple resonant frequencies within the desired bandwidth, and by using transmission lines with characteristic impedances and coupling. Appropriate, the desired pass band and stop band are formed [7,8].

One of the important parameters in the design of filtering antennas is low transmission loss in the pass band, having a suitable frequency response, in other words, a suitable filtering power and also a wide stop band [9,10]. Therefore, different micro-strip resonators can be used to design an integrated filtering antenna, which does not require a pre-filter and reduces the dimensions of the circuit [11-16].

In [17], the design of a dual-band array antenna is mentioned, in which both radiating elements are fed using a micro-strip line, and it has two separate bands of 2.4 and 5.8 GHz, each corresponding to They are one of the radiating elements of the array antenna. Then, two antenna elements are designed, each of which is connected to the end of a filter, and the passband filters have a similar shape and structure. The gains of the filtering antenna for the frequencies of 2.4 and 5.8 GHz are equal to 6.7 and 7.4 dB, respectively.

In [18], a quasi-elliptical wideband dipole filtering antenna is designed, which consists of a feed network, a feed patch and an H-shaped patch, which is 0.09 λ (λ is the wavelength) above the main patch, Composed. The feeding network consists of two orthogonal H-shaped lines. Since the feed lines are well designed, it not only increases the isolation between the two ports, but also helps to have sharper edges. On the other hand, the patch placed above improves the high stopband and also increases the gain of the antenna in the passband. Therefore, a small dipole antenna with satisfactory filtering performance in the 2.49 and 2.69 GHz band is obtained without using additional circuits. This structure is suitable for use in the LTE band, and the radiation pattern does not seem appropriate in this structure.

In [19], a broadband filtering slot antenna with multimode resonators is presented, two types of slot resonators are investigated to excite different resonance modes. Also, amplifiers have increased the bandwidth impedance of the antenna. In this research, an equivalent multipole network is proposed for frequency band filtering, and the antennas in this structure not only have a wide bandwidth impedance, but also have a very sharp frequency response at the upper and lower edges of the band. The filtering antenna is placed on the substrate with a height of 0.8 mm, a relative dielectric coefficient of 2.55 and an insulation loss tangent of 0.0029. Also, the radiation pattern shows that the out-of-band radiation is lower than the reference antenna level.

In [20], a two-stage bipolar filter antenna with high selectivity is proposed, which by creating four slits on each side of a square radiation patch, dual performance bands and a radiation perpendicular to the radiating surface between the two observation bands. It can be Also, two more radiation zeros are produced by introducing a feed structure, which consists of a micro-strip line with open-circuit stepped impedance resonators. The measured results show that the antenna element has dual operating bands of 3.28, 3.71, 4.8 and 5.18 GHz for a voltage standing wave ratio of less than 1.5.

A compact micro-strip filter antenna consisting of three segments with modified slots to improve the impedance bandwidth is presented in [21]. In which, the design process of the proposed filter antenna in this research starts from the prototype of the second-order Chebyshev low-pass filter (LPF).

Characteristic mode analysis to study the dual polarization behaviour of simple monopole antenna is presented in [22]. where the antenna consists of a monopole feed with symmetrical arms, resonant at 2.45 GHz and connected to the right stub (RHS) for resonance at 5.8 GHz.

A small stacked patch antenna with circular polarization in GPS L1 band and dual linear polarization in WiMAX band is proposed for internet of things applications in [23], where the upper patch acts as an independent receiver in the WiMAX band using the improved second mode of the lower patch.

In [24] the main objective is to provide a significant improvement in the gain of the micro-strip patch antenna by adding L-shaped and I-shaped slots to a rectangular patch, which is a very common structure used in 5G antennas. Also, the focus of this study is on 5G high-band millimetre waves, especially 26 and 28 GHz as widely used frequency bands.

In this paper, the structure of a filtering antenna consisting of a pass filter and a ring micro-strip antenna is considered. This structure operates in three main bands with resonant frequencies of 3.4, 5.28, and 5.8 GHz, each of which has a relative bandwidth of 2.94%, 3.22%, and 5%, respectively. The obtained radiation pattern has a shape similar to a monopole antenna, which radiates vertically. The fabrication and measurement results of the prototype are in good agreement with the simulated and optimized sample. It should be noted that the proposed structure is designed for use in Wi-Max networks as well as mobile network services and the fifth-generation mobile communication network.

2. Proposed antenna design

Antennas are commonly used to transmit and receive electromagnetic radiation in the frequency range from 3 kHz≲f≲3 THz. Gain, bandwidth, radiation pattern, beam width, polarization and impedance are typical parameters of antennas.

In order to better justify and provide more accurate results of the lower band of the frequency band of the structure, the diagonal stubs are introduced. By sweeping the angel of the stubs the desired band is crated. The antenna used in the proposed structure is a dual array superimposed antenna of internal rings and diagonal branches. The dual arrays are staggered, corner-fed. The reason for using diagonal branches is better impedance matching.

The final structure of the antenna is shown in Fig. 1 whose dimensions are M, N, D1, D2, D3, D4 and S equal to 18, 16, 1, 1, 1.25, 1 and 7.9 mm, respectively. And the angle θ1 is equal to 15 degrees. In order to determine the initial value of the dimensions of the antenna to create three separate amplification frequencies for the rectangular loop micro-strip antenna, the best choice for the ratio of the sides of the rectangle (gamma coefficient) to obtain the best radiation pattern is equal to 0.5. For example, for the amplification frequency of 3.4 GHz, it is equal to:

$$\gamma = \frac{\frac{M}{2}}{N} = \frac{9}{16} \approx 0.5 \tag{1}$$

For three different resonant frequencies, the dimensions of the ring are summarized in table 1, where, the parameter L is the length of the antenna.

Fig. 2 shows the radiation patterns of the rectangular ring micro-strip antenna based on different frequencies.

Table.1.
Calculations of rectangular ring micro-strip antenna for three resonance frequencies

Parameter ***Resonance frequency (GHz)***	***λg (mm)***	***L***	***l/λ_g***
3.4	46.8	48	1.02
5.28	30.15	48	1.59
5.8	27.4	48	1.75

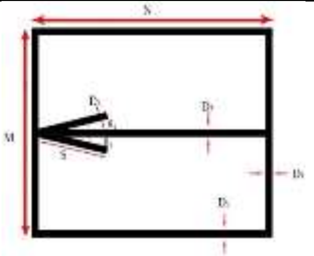


Fig. 1. Micro-strip rectangular loop antenna

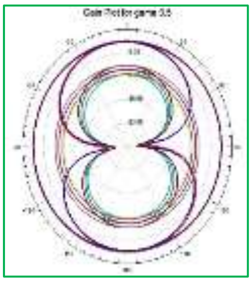
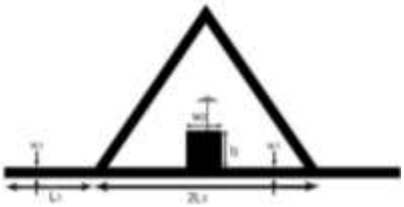


Fig. 2. Antenna radiation pattern

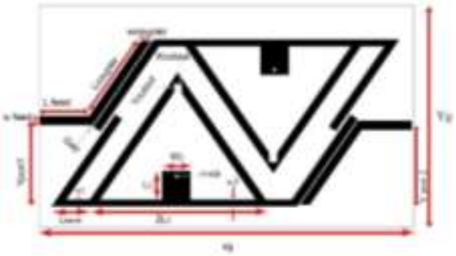
A) Structure of the proposed filter

In order to create the filtering property, a stub-loaded triangular ring resonator (SLTRR) is designed for use at the required frequency. The prototype of the filter is shown in fig. (3-a). The filter is placed on Rogers RO-4003 substrate with tgδ=0.0027, ε_r=3.55 and thickness mil=32h. This structure consists of two feeding arms with a length of L1 and a thickness of W1, which is connected to the base of the triangle, the dimensions of the base are 2L3 in length and W3 in thickness, and inside the structure is a short connection stub with dimensions of L2 and W2, which is in the middle of the base. It is located. The structure is in the form of an equilateral and symmetrical triangle.

An antenna and a band-pass filter are essential components employed at the front-ends. Proper design can improve filter response by adjusting the radiation resistance of the resonant antenna to match the load resistance of the filter circuits at the resonant frequency. Filters provide the ability to attenuate lower-energy X-ray photons, thus allowing only high-energy photons to pass through and ultimately reach the imager to produce more diagnostic images with fewer target artefacts. For better embedding of the structure, 2 filter arms are bent in the structure, and the arms are parallel to each other and to the resonance side. By adding another similar filter to the structure, the filtering property will be intensified. Also, the combination with the semi-digital structure improves the frequency band. A rectangular cut is placed in the upper corner of the triangle, which causes the last impedance matching and improves the final dispersion parameter. This matching of impedance in the high band has caused the overall increase of the band so that it includes all the frequencies considered in the design. The final structure of the filter is shown in fig. (3-b). The frequency response of the filter is shown in fig. 4. The filter has intensified in two bands at the frequencies of 3.4 GHz and 5.8 GHz, the bandwidth of which is 5.91% and 11.15%, respectively. When the current passes through the structure of the micro-strip filter, weak radiations are created, which are not visible at long distances and do not have much effect on the final radiation pattern, but on the other hand, these radiations are created in the near field distance of the antenna and as a result. The current coupling in the antenna affects the impedance matching and creates the final return coefficient of the filtering antenna. The final design of the proposed multi-band filtering antenna is shown in fig. 5. Dimensions in millimeters after optimization by HFSS software are given in table 2. The angle θ1 is equal to 15 degrees. The dimensions of the proposed filtering antenna circuit are 64 mm x 34 mm.



(a) Filter prototype with SLTRR structure



(b) The final design of the proposed filter structure

Fig. 3. Suggested filter structure

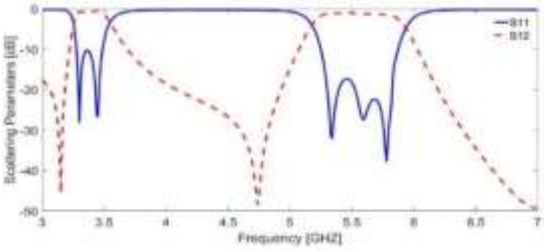


Fig. 4. Dispersion parameter of the final design of the filter with a rectangular cut

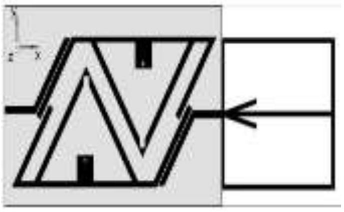
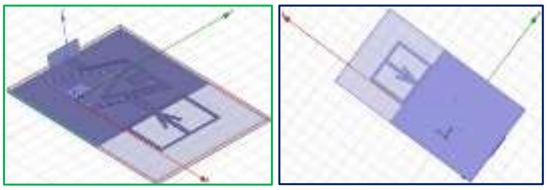


Fig. 5. The final design of the proposed filtering antenna from the top view



(a) Top view (b) Bottom view

Fig. 6. The proposed filtering antenna in three dimensions

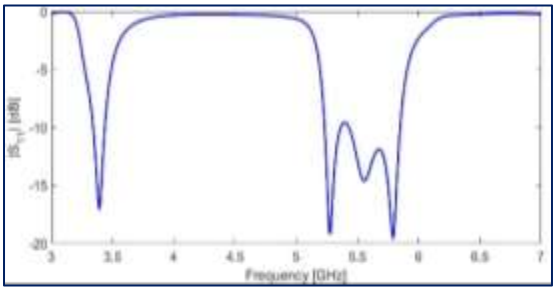


Fig. 7. The proposed filtering antenna in three dimensions

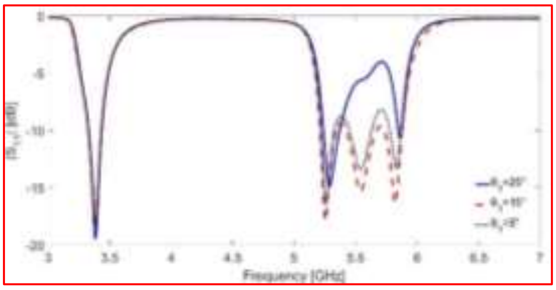


Fig. 8. Parameter S11 of the filtering antenna with the change of θ1 from 5 to 25 degrees

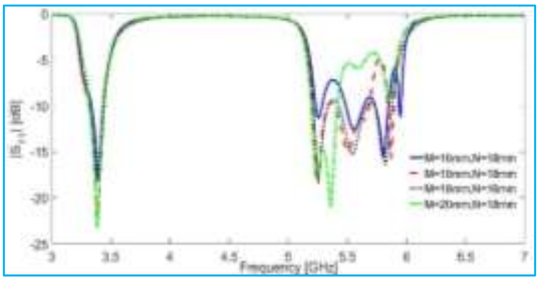


Fig. 9. Parameter S11 of the filtering antenna with the change of N and M

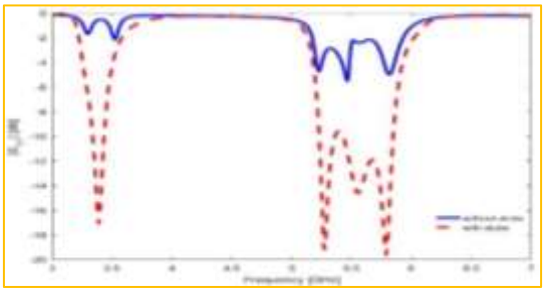
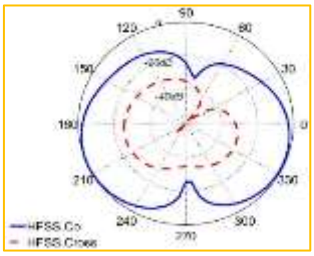


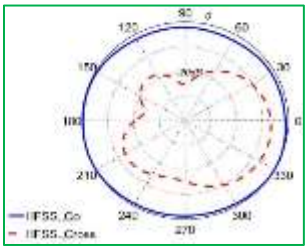
Fig. 10. Parameter S11 of the filtering antenna in the presence of diagonal stubs and their absence in the antenna structure

B) *Parametric analysis*

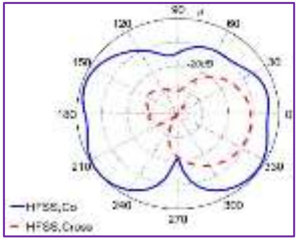
Changing the dimensions of the proposed structures can be effective in the final response, which are among the most influential parameters in the antenna structure, θ1, M, and N, as well as the presence of diagonal stubs inside the antenna structure. The angle sweep of diagonal stubs and the main dimensions of antenna M and N are shown in figs. 8 and 9 respectively, and in fig. 10 the presence of stubs is examined, which fully confirms their key role in the field. It is impedance matching. The radiation pattern obtained in these three resonant frequencies is presented in figs. 11 and 12. The radiations similar to the monopole antenna are seen at the desired frequencies. The surface current distribution density at three resonant frequencies is investigated and plotted in fig. 13. As expected from the design of the filter, the current propagation in the first resonance is in odd mode and in other resonances in even mode, which is checked by checking the current density around the shorted connection point inside the filter stub.



(a) 3.4 GHz

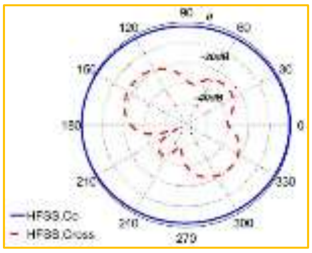


(b) 5.2 GHz

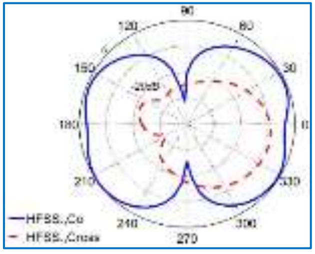


(c) 5.8 GHz

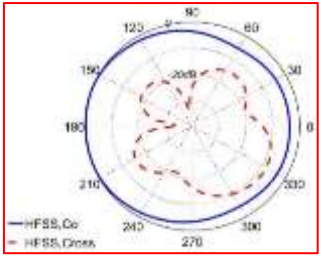
Fig. 11. Radiation pattern for parallel polarization and cross polarization in x-z and y-z planes (H-plane)



(a) 3.4 GHz



(b) 5.2 GHz

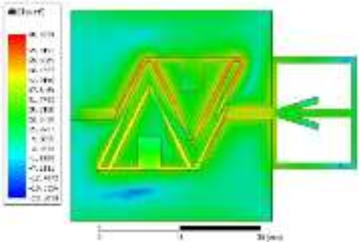


(c) 5.8 GHz

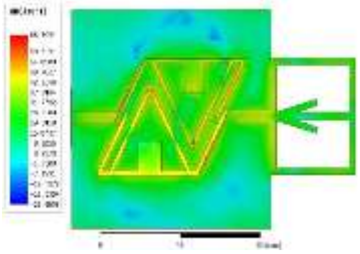
Fig. 12. Radiation pattern for parallel polarization and cross polarization in x-z and y-z planes (S-plane)

Table.2.
The final dimensions of the filtering antenna

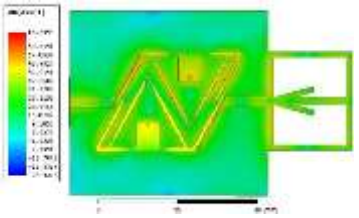
Parameter	***Value***	***Parameter***	***Value***	***Parameter***	***Value***
L_1	12.9	W_1	0.70	Gap	0.15
L_2	5.40	W_2	4.40	W_{feed}	1.80
L_3	7.82	W_3	0.70	L_{feed}	8.00
r_via	0.25	X_g	38.00	$W_{coupler}$	0.30
L_{bend}	2.15	Y_g	34.00	$L_{coupler}$	10.98
Y_{Port1}	17.10	X_{cutout}	0.60	M	18.00
Y_{Port2}	17.40	Y_{cutout}	0.97	N	16.00
D_1	1.00	D_2	1.00	S	7.90
D_3	1.25	D_4	1.00	$\Theta_1=15^{O}$	



(a) 3.4 GHz



(b) 5.2 GHz



(c) 5.8 GHz

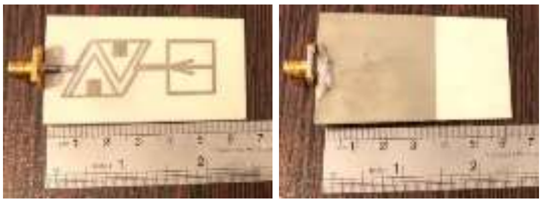
Fig. 13. Surface current distribution density in the structure for three different frequencies

3. Laboratory results

To check the optimal structure of the antenna, a laboratory prototype is made according to fig. 14. The structure of H and E antenna is shown in fig. 15. The radiation pattern obtained from the results of antenna construction at three resonance frequencies is shown in figs. 16 and 17 for three frequencies. The dispersion parameter has been measured, and the experimental result is shown in fig. 18, which shows the good agreement of the two construction and simulation cases, indicating the confirmation of the structure.

The measured gain of the proposed filter antenna structure at resonance frequencies along with the simulated values are given in table 3. As can be seen, the biggest difference is in the frequency of 3.4 GHz, and the lowest error is in the frequency of 5.8 GHz. But in terms of percentage compared to the simulated value, the measured error is 18.83%, 19.47% and 16.15% respectively.

The comparison of the proposed filtering antenna with other filtering antennas in terms of resonance frequency, number of frequency bands, percentage of relative bandwidth, dimensions, gain, dielectric coefficient and structure is given in table 4. In fig. 6, the simulated structure of the filtering antenna can be seen in 3D in the HFSS simulation software, which is created by combining the proposed structures of the antenna and filter side by side. The graph of S11 parameter of the proposed structure is shown in fig. 7 whose bandwidth is less than -10 dB in the frequency ranges of 3.34-44, 5.23-5.4, and 5.56-56.85 GHz. Hertz and also the stopbands are close to zero decibels, which can indicate optimal filter performance. According to fig. 6, the filtering antenna has two main bands, the upper band of which is wide enough to include two operating frequencies of the structure, and the main resonances of the filtering antenna structure are 3.4, 5.28 and 8.0 GHz as the basic requirement of the proposed model. 5 GHz.



a) up view (b) bottom view

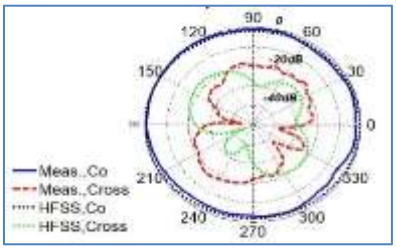
Fig. 14. Built prototype of the proposed structure

(a) Structure of H (b) Structure of E

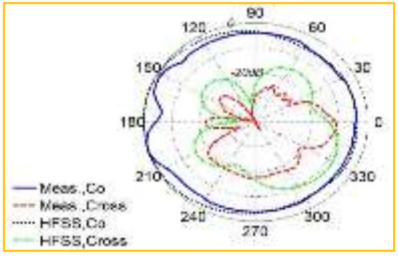
Fig. 15. Different antenna structures are made

Table.3.
Comparison of the proposed filtering antenna with a number of similar samples

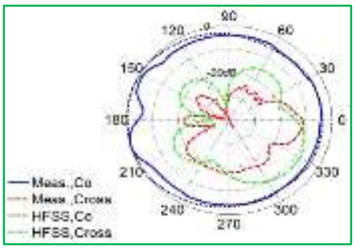
Structure	***Dielectric coefficient***	***Gain (dB)***	***Dimensions (in base wavelength)***	***Relative bandwidth percentage***	***Number of frequency bands***	***Resonance frequency***	***Reference***
Double layer printed circuit	2.65	2.41	0.41×0.60	16.3	Single band	2.26-2.66	[25]
Double layer printed circuit	2.55	2.1, 4.1, 4.6	0.38×0.77	9.6, 8.1, 3.1	Three bands	2.4, 5.2, 6.5	[26]
Double layer printed circuit	3.38	5	0.60×0.60	4	Single band	11.8	[27]
Double layer printed circuit	4.4	-	0.71×0.75	7.8, 11.8	Two bands	2.45, 5.2	[28]
Three-layer printed circuit	2.55	-1.8, 1.1	0.68×0.96	3.8, 4.5	Two bands	2.4, 5.8	[29]
Double layer printed circuit	3.55	3.08, 2.67,3.22	0.72×1.3	3.22, 2.94, 5	Three bands	3.4, 5.8, 5.28	suggested model



(a) 3.4 GHz

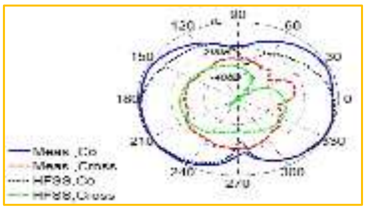


(b) 5.2 GHz

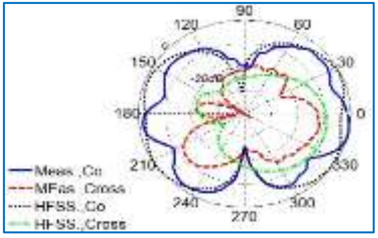


(c) 5.8 GHz

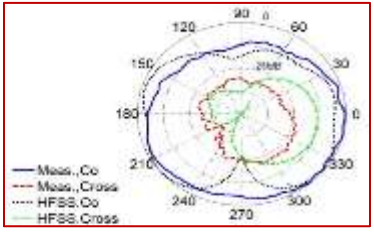
Fig. 16. Comparison of simulated and measured radiation patterns for parallel polarization and cross polarization in the x-z and y-z planes for three frequencies in the H structure



(a) 3.4 GHz



(b) 5.2 GHz



(c) 5.8 GHz

Fig. 17. Comparison of simulated and measured radiation pattern for parallel polarization and cross polarization in the x-z and y-z plane for three frequencies in structure E

Table.4.
Comparison of measured gain with simulated values at resonant frequencies

Measurement gain (dB)	*Simulation gain (dB)*	*Frequency (GHz)*
2/50	3.08	3.4
2.15	2.67	2.28
2.70	3.22	5.8

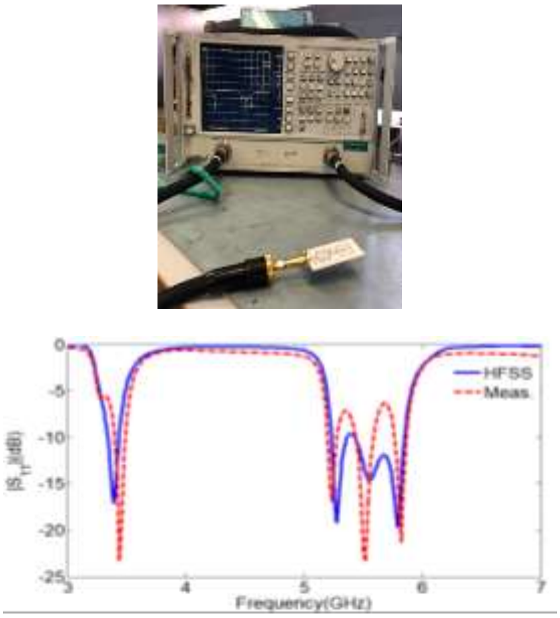


Fig. 18. E Comparison of simulated and measured scattering parameters

4. Conclusion

In this paper, a micro-strip filtering antenna has been designed, and the proposed structure consists of a combination of a rectangular micro-strip loop antenna and a resonant triangular filter. This antenna has good radiation and filtering properties.

The proposed structure in three main bands with resonance frequencies of 3.4, 5.28 and 5.8 GHz, with relative bandwidth of 2.94%, 3.22% and 5% respectively and gain of 3.08, 2.67 and 3.22 Works. The radiation pattern of the structure in all resonant frequencies is similar to the monopole antenna. The proposed filter antenna removes out-of-band frequency well, and has high selectivity. Its radiation pattern is suitable for the selected consumption cases, which are Wi-Max networks, mobile networks and 5G. The proposed resonator structure has the ability to increase the number and bandwidth by manipulating the dimensions and shape of the structure, and the radiation pattern can be changed and adjusted according to the antenna structure, which of course depends on the work requirement. We have used the filter to create the transmission zeros at desired band. While the antenna is responsible for the desired radiation which gives us a suitable radiation efficiency.

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