Simulation and Fabrication of Compact four band hybrid filtering antenna using step impedance resonators and tuning stub transition structure

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Abstract— **A novel compact four band hybrid filtering antenna composed of a hybrid radiator and a four band bandpass filter is presented. The hybrid radiator is constructed using the micro-strip line fed, the square-ring and the T-stub near the ground plane. The proposed four band bandpass filter is composed of two parts, one is two-step impedance resonators (SIRs) and the other is the tuning stub transition structure. With tuning stub transition structure, two SIRs effectively match to 50 Ω hybrid radiator. Furthermore, the geometry of the proposed filter is U-shaped with the micro-strip fed around the hybrid radiator. The evolution of the hybrid radiator and the construction of the four band bandpass filter using the two SIRs and the transitions are discussed in detail. The proposed filtering antenna not only possesses numerous operation band with good band edge gain selectivity but also reduces the occupied size in the modern communication device. The overall size of the proposed filtering antenna is 33 mm × 36.4 mm × 0.508 mm, and the operation frequencies are 1.8/2.45/4.2/5.2 GHz band for GSM1800/WLAN/ WiMAX applications. The measured results agree with simulated outcomes.**

I. INTRODUCTION

As developing of wireless communication systems in the last few decades, the capability of operating in multiband and the conditions of compact, low cost and low profile antennas are required. In traditional design, both of the filters and antennas are designed individually and connected to each other with the matching networks or the transition circuits. However, the section of matching networks may not only degrade the performance of system but also occupy the large circuit area. Therefore, the filtering antenna that integrates both of the band pass filter and the antenna minimizes the traditional radio-frequency (RF) size intensively in recent years.

The approaches of integrating the last stage of the band pass filter network into an antenna structure had been proposed for size reduction by saving the matching network. In these approaches, the antenna not only regarded as a traditional radiator but also a part of RF filter. Unfortunately, the design method requires a precise equivalent circuit model with complex mathematical analysis and faces challenges. Therefore, the methods of the dual-band cases using the multi-layer structure had been proposed . In this approach, a patch antenna is integrated using the dual-band resonators through electromagnetic coupling to produce a dual-band filtering phenomenon. However, the implementation of the patch antenna and the resonators are located in the different layer with the common defect ground that is complex and time consuming. Moreover, in , the gain is only −4 dBi at lower band and the size is large. In , although the size had been reduced by using the aperture coupled feed techniques, its gains were only −1.8 and 1.1 dBi at the two band. Another approach to building up the filtering antenna for the multiband operation had been utilised. In these approaches, an antenna and a filter are developed separately. Then the filter is utilised instead of a feeding line of the antenna to simplify the integration process. Meanwhile, the antenna is able to design in accordance with different requirements, so the multiband operation becomes easy. However, the method does not achieve a full synthesis process and just connects the filter and the antenna without matching networks. Hence the area utilisation is relatively inefficiency.

In this paper, a novel compact four band hybrid filtering antenna using the step impedance resonators and the tuning stub transitions is presented. The proposed structure is composed of the hybrid radiator and the four band bandpass filter. In our design processes, these elements are designed individually and then modified their outline to share the limited space. Finally, the detailed structure is adjusted to meet the RF performance requirement. The proposed filtering antenna shows good RF performance in the notched band, especially the radiated gain, the band-edge selectivity and the gain suppression.

Differing from other literature, the tuning stub transition structure of the proposed antenna provides an effective method of impedance matching between antenna and microstrip line. The tuning stub transition, which compactly combines wideband antenna and RF front-end components, is quite useful for implementation in other similar impedance matching design, especially for band-pass or band-stop filters with narrow bandwidth. With above mentioned components and transition methods, the proposed four band filtering antenna operates at 1.8/2.45/4.2/5.2 GHz band for GSM1800/WLAN/WiMAX applications with good antenna performance and sharp frequency selectivity.

II. STRUCTURE OF ANTENNA

The structure dimensions of the filtering antenna are given as the following (in millimetres): W1 = 33, W2 = 20, W3 = 18, W4 = 1.88, W5 = 2.7, L1 = 36.4, L2 = 19.1, L3 = 11, L4 = 7, L5 = 14.35, L6 = 3.4, L7 = 12.7, L8 = 11.7, L9 = 11.2, L10 = 12.6, L11 = 15.1, L12 = 4.8, L13 = 11.7, L14 = 3.4

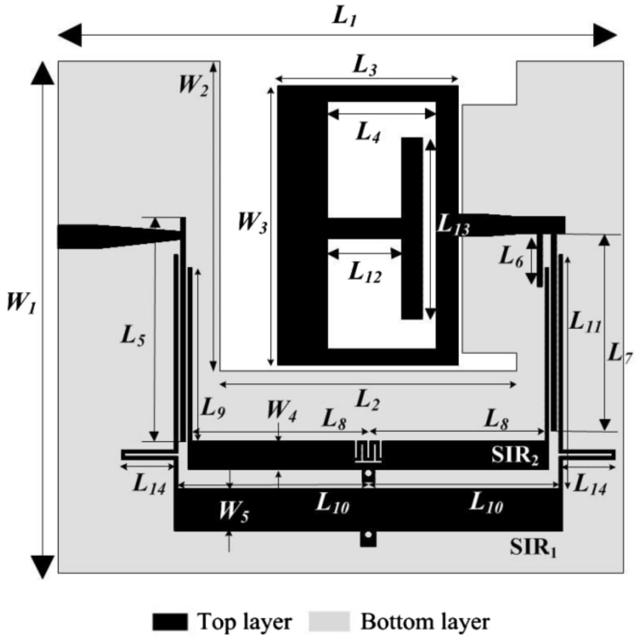


Fig. 1: Structure of Antenna

The proposed antenna composed of the hybrid radiator which is placed near the ground plane and the four band bandpass filter with the U-shaped is around the hybrid radiator. The filtering antenna is printed on a 0.508 mm thick Rogers RO4003 substrate with the permittivity 4.25 and loss tangent 0.0027, and its overall size is 33 × 36.4 mm2. The structure parameters are simulated by Ansoft's HFSS version 15.0 are shown in Figure 1.

III. DESIGN OF THE FILTERING ANTENNA

The geometry of the proposed filtering antenna is shown in Fig. 1. The hybrid radiator is constructed using the micro-strip line fed, square-ring as the radiator near the ground plane and an extended T-stub to enhance the operation bandwidths. Consequently, the four band bandpass filter composed of two-SIR with the different resonant frequencies, which are simply named SIR1 and SIR2 in Fig.1. SIR1 has the 1.8 and 4.2 GHz resonant frequencies by a viahole and the necessary section of high and low impedance metals. SIR2 has 2.45 and 5.2 GHz resonant frequencies and the external perturbing element is a section of the high impedance meander line between two low impedance sections. The perturbing element produces the proper capacitive and inductive coupling to adjust the resonant frequencies of SIR2. In order to connect the antenna, the SIR1 and SIR2, the tuning-stub transition structures are developed to replace the traditional 50 Ω matching network. To achieve a compact size, the tuning-stub transition of output side is rotated in the opposite direction so that the proposed antenna can be constructed on the not used space between two tuning-stub transitions. For optimising, the impedance matching, the length of tuning-stubs transitions, L5 and L6 are coordinated with the property of the proposed antenna. On the other hand, the asymmetry effect caused by rotation of tuning stub transition can be eliminated by fine tuning lengths L5 and L6.

1) Design of Hybrid Radiator

The evolution of the proposed hybrid radiator is depicted in the fundamental radiator is a monopole antenna near the groundplane as shown in Fig.3. Consequently, according to the electronic current simulation, both of the central metal of the patch and two slits of ground plate are etched as shown in Fig. 3. The etched plate of radiator not only provides lots of freedom in design but also not degrades the antenna bandwidth. Because the electronic current travels along the edges of the patch. Meanwhile, two slits of ground plate are used, simply named slit1 and slit2. One is used for improving the antenna impedance and the other is used for increasing the length of the travelling current path and bring the inductive effect. Furthermore, to meet the requirements of the multi-band operation, the T-stub is added to the central of the square-ring structure as shown in Fig. 3. The design concept of the T-stub is creating the notched property in the unwanted band which usually leads the impedance enhancement in the both of upper and lower sides of the unwanted band.

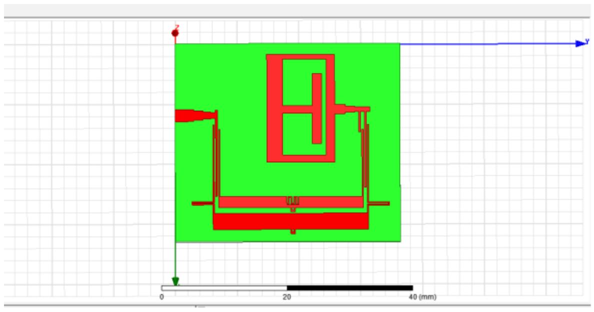


Fig. 2: Hybrid Radiator and SIR of Antenna

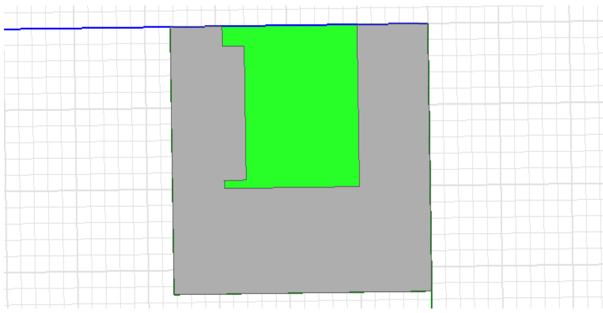


Fig. 3: Ground Plane of the Antenna

2) Design of Step Impedance Resonators(SIRs)

There are two different structures between SIR1 and SIR2, one is the bended high impendence line of SIR1 and the other is the perturbing element of SIR2. The perturbing element consists of the meander line and the via-hole in the middle of SIR2. These differences lead the different resonant frequencies, 1.8/4.2 GHz for SIR1 and 2.45/5.2 GHz for SIR2. Furthermore, the tuning stub transition structure is used to provide the properly impedance transferred from SIRs to 50 Ω . The via-hole and the meander line are considered as the inductor and the high impedance transmission section, respectively . The equivalent circuit model approach is applied to determine the resonant frequencies of SIR1 with 1.8 and 4.2 GHz to achieve the dual-band characteristic. With a *K* inverter, which is also known as impedance inverter, the proposed structure can transform series-connected elements to shunt connected elements and successfully match SIRs and 50 Ω hybrid radiator.

The reason for the pairs of *S*11 peaks pair may be the parasitic coupling between the tuning stub transition and the SIR filters, leading the two similar frequencies of resonances in the frequency band of concern.

IV. Results

1) <u>Simulation Results</u>

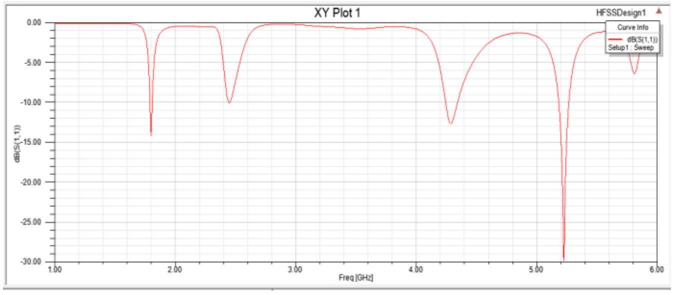


Fig. 4: Return Losses

The S11 of the Simulated antenna is shown in Fig. 4. It is seen that the antenna has four operation band. The bandwidths of four pass band are 1.8 GHz, 2.45 GHz , 4.2 GHz , 5.2 GHz at the condition of S11 below −6 dB, respectively. The proposed filtering antenna also shows sharp frequency selectivity in the operation band.

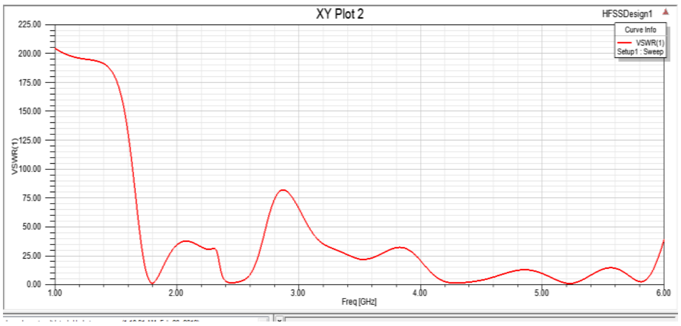
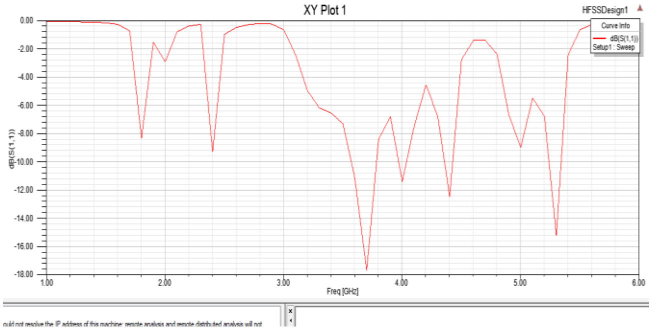


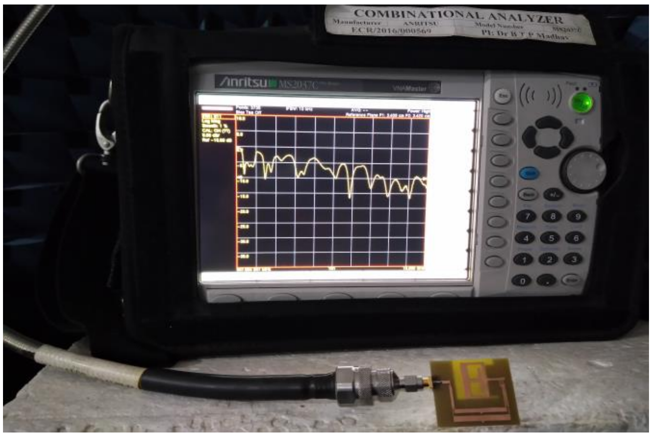
Fig. 5: VSWR

Fig.5 illustrates the VSWR versus operation frequency of the proposed antenna. In VSWR diagram, the smaller the reflection, the lower the voltage standing wave ratio. Compared with an S11 diagram of Fig. 4, it can be seen that the filtering antenna has the same result in frequency response with sharp frequency selectivity.

2) <u>Simulation Results without perturbing element (Fabricated)</u>



(a)



(b)

Fig. 6: (a) S11 of simulated antenna without perturbing element (b) S11 of Fabricated Antenna

When compared with the Simulated results of the antenna the Fabricated results of the antenna has multiple frequency selectivity at different frequencies in the S11 as shown in the Fig. 6

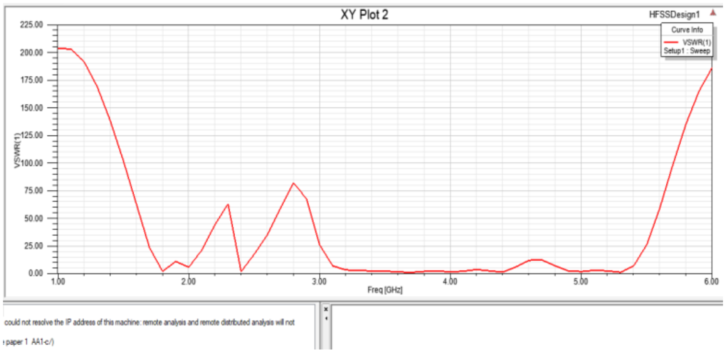


Fig. 7 : VSWR

The VSWR of the Fabricated antenna also shows the same frequency selectivity at multiple frequencies as shown in Fig. 7.

V . Conclusion

The Comparison between the Simulation and Fabricated antenna concludes that there is high S11 with sharp sweep which is greater than -10 db in each band and very low voltage standing wave ratio (VSWR) with respect to Return Losses (S11) .

Table 1. Comparison of Results of Return Losses

S.No	Frequency (GHz)	Return Losses (S11) of simulation	
		With perturbing element	Without perturbing element
1	1.8	-17.50 db	-6db
2	2.45	-11.0 db	-4 db
3	3.5 & 4.2	-10 db at (4.2GHz)	-20 db at (3.5 GHz)
4	5.2	-17.0 db	-10 db

The filtering antenna is composed of the hybrid radiator and the four band bandpass filter, both of which have been developed independently and discussed in detail.

VI. REFERENCES

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