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Novel Design of Printed Antenna Integrated with Bandpass Filter for C-band Applications

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Abstract

A novel configuration of filtering antenna for C-band applications is presented in this paper. An elliptical radiator based UWB monopole antenna is first investigated and then integrated to a wideband bandpass filter to achieve high frequency selectivity as well as compactness. The bandpass filter is constituted by stepped impedance stub loaded resonator for C-band applications. Aperture backed inter-digital coupled lines are used to feed the multiple-mode resonator of proposed bandpass filter. The proposed filtenna leaves out the necessity of cascading any additional 50 Ω microstrip elements in between the developed antenna and filter, thus making the system smaller. The incorporation of planar antenna and the filter is carried out using FR4 substrate board with permittivity 4.4 and thickness 1.6 mm. The overall dimension of the wideband filtenna is obtained as 59×42 mm^2. Performance analysis of the UWB antenna, bandpass filter and their integrated structure has been carried out systematically in this paper. An in-depth agreement between simulated and measured results is discovered for the proposed configurations.

1. Introduction

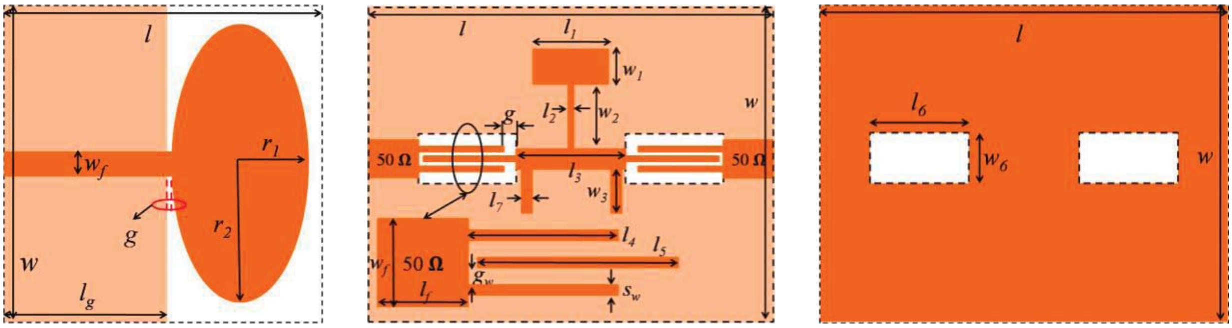
Scaling down the overall dimension in addition to low cost implementation are the two most essential demands for any RF front-end systems. One of the approaches for miniaturizing a RF front-end, is to place and interconnect its passive circuitries into a package, called as system-in package (SIP) [1-2]. In another approach, referred to as co-design, multiple functional circuitries are coordinated into a single device without the 50-Ω constraints [3]. The co-design technique has the ability to enhance the performance of the circuits, and simplify the associations between different components [4]. Antennas are considered a necessary part of the RF front-end in wireless communication systems. However, it is necessary to control the radiation characteristics of antennas outside the specified frequency band as this may cause interference to other communication systems [5]. So they need to be accompanied by a band pass filter (BPF) which can discard any undesired signal and provide high roll off factor.

Conventionally, the designed antennas are connected independently to the bandpass filters through a matching network. Such an approach contributes design complexity, requires large area and increases losses [6]. In recent years, use of integrated filter antenna or the filtenna has been emerged out as a promising solution to this drawback. In this approach, antennas are smoothly integrated with a bandpass filter into a single subsystem to achieve compactness as well as high performance [7]. Filtenna posses both radiations as well as filtering characteristics and also dispenses with the interconnections and matching networks. Several investigations have been carried out to incorporate radiating or filtering function into a filter or an antenna [8-9]. One of the common techniques used for designing filtenna is the synthesis process of bandpass filters [10-14]. The antenna radiator, in these approaches, is considered as the last-stage resonator and the load impedance of the bandpass filter. However, the limitation with such kind of approach is that coupling of multiple resonators and then cascading those resonators lead towards occupying larger area.

In this article, a compact wideband filter combined with ultra wideband (UWB) antenna is designed for C-band operations. Firstly, an elliptical monopole antenna operating in the UWB region is designed and then a wideband bandpass filter based on stepped impedance stub loaded resonator is developed. Finally, the individual antenna and filter elements are developed together in a single subsystem following co-design approach of filtenna. The proposed filtenna can now easily reject unwanted out-of-band signal and can be easily integrated to any planar circuit due to its compact size and light weight. Organization of this article is done as below: Section 2 describes the layout of the UWB antenna, bandpass filter (BPF) and the filtenna, respectively. Their respective performances are analyzed in Section 3. Section 4 includes the comparison of simulated results with experimentally obtained results and the fabricated prototype. The concluding remarks are presented in Section 5 followed by references.

2. Layout of Proposed Designs

In this section, description of the proposed UWB antenna and the bandpass filter has been carried out. The development of the proposed filtenna configuration is described in three different steps; Step-A, Step-B, and Step-C, respectively.



(a) (b) (c)

Figure 1. Schematic layout of the (a) proposed UWB antenna, (b) proposed bandpass filter (top-view), (c) proposed bandpas filter (bottom-view).

Step-A: Design of UWB Monopole Antenna

The proposed antenna consists of an elliptical monopole radiator with partial ground plane as illustrated in Fig. 1(a). It is implemented using low cost FR4 epoxy substrate (dielectric constant $\varepsilon_r = 4.4$, tan $\delta = 0.02$) having an overall dimension $39 \times 42 \times 1.6$ mm^3. The top-layer of the substrate is associated with an elliptical shaped radiator whereas bottom-layer occupies partial ground plane. Elliptical-shaped radiators are capable of having wide bandwidth and hence, they are considered for the proposed antenna design. A 50 Ω microstrip line connecting to the center of the patch is used for feeding purpose. A partial ground plane is used on the bottom-side of the substrate for improved impedance matching. The optimized dimensions for the proposed antenna are as follows: $l = 39$, $w = 42$, $w_f = 2$, $l_g = 18$, $r_1 = 9.7$, $r_2 = 20.37$ and g = 0.2. Here all dimensions are taken in mm.

Step-B: Design of Wideband Filter

This section discusses about the development of a wideband bandpass filter (BPF) for C-band application. Fig. 1(b) and Fig. 1(c) displays the schematic representation of the proposed multiple-mode resonator (MMR) based filter. MMR structures are widely used in designing UWB filters as they have simple structures as well as easy design procedure. Here, the suggested filter consists of a stepped impedance resonator (SIR) loaded with a rectangular stepped impedance stub (SIS) at the center. Two uniform impedance resonators are loaded from the central microstrip line and are placed at symmetrical locations with respect to the centrally loaded stepped impedance stub. The MMR is fed through inter-digital coupled lines on both sides of the filter. The aperture in the ground plane helps in achieving higher degree of coupling. The overall size of the proposed filter is $39 \times 42 \times 1.6$ mm^3. The optimized values of the dimensions are obtained as: $l = 39$, $w = 42$, $l_f = 6$, $w_f = 2.2$, $l_1 = 7.5$, $w_1 = 3.1$, $l_2 = 0.6$, $w_2 = 5.6$, $w_3 = 5.4$, $l_3 = 10.8$, $l_4 = 7$, $l_5 = 7.3$, $l_6 = 8.1$, $w_6 = 3.6$, $l_7 = 0.7$, $g_w = 0.2$, $s_w = 0.2$, g = 1.1. Here, all the dimensions are taken in mm.

Step-C: Integration of UWB antenna with BPF

This section introduces filtering antenna for C-band satellite operations. The proposed antenna is integrated with the filter (Fig. 1(a) and Fig. 1(b)) in order to design a filtering antenna with improved performance and filtering characteristics. The overall layout of the proposed filtenna is shown in Fig. 2. Optimized dimensions for the filtenna configuration are listed below: $l = 59$, $w = 42$, $l_f = 6$, $w_f = 2.2$, $l_1 = 7.5$, $w_1 = 3.1$, $l_2 = 0.6$, $w_2 = 5.6$, $l_3 = 8.1$, $w_3 = 3.6$, $l_4 = 0.7$, $w_4 = 5.4$, $r_1 = 9.7$, $r_2 = 20.37$, g = 1.1. Here all dimensions are in mm.

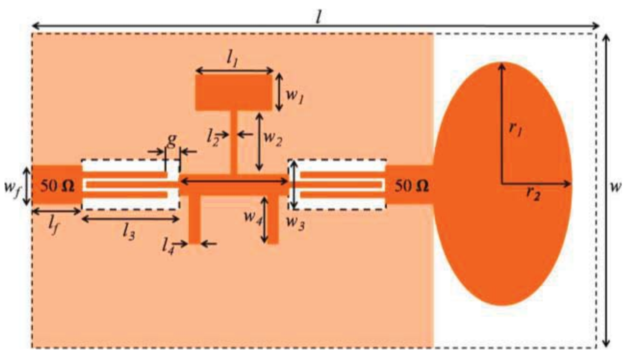
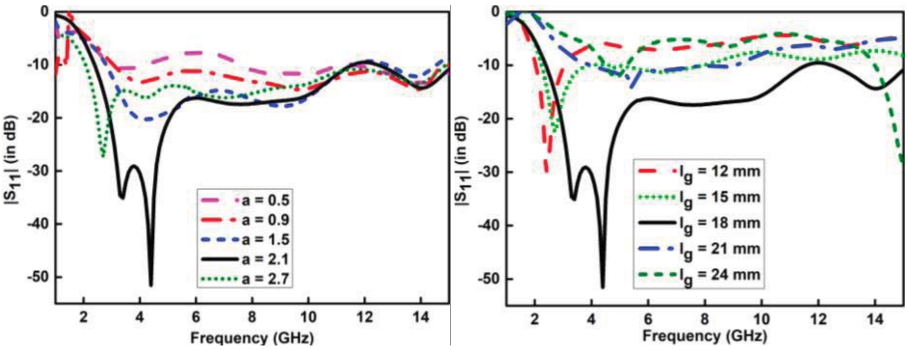


Figure 2. Optimized layout of the C-band filtenna.

3. Simulated Performance Analysis



(a) (b)

Figure 3. $|S_{11}|$-parameter variations of proposed antenna for different values of (a) axial ratio *'a'*, (b) ground plane length *'l_g'*.

In this section, parametric analysis of different variables associated with the suggested geometries of UWB antenna and bandpass filter has been carried out. At first, the effect of radiator dimensions has been examined. Fig. 3(a) plots the $|S_{11}|$ variation against frequency for different values of axial ratio *'a'* (r_1/r_2) keeping the minor axis length constant at r_1 = 9.7 mm. It can be observed that an increase in the axial ratio value improves the impedance matching of the antenna and also decreases the lower cut off frequency. However, the cut off frequency at higher side remain almost unaffected. Similarly, dimensions of the partial ground plane are also responsible for achieving improved impedance matching, as displayed in Fig. 3(b). Fig. 4 shows the simulated reflection coefficient variation for the initially proposed elliptical UWB antenna with optimized dimensions. The bandwidth of the proposed design is noticed to be varying from 2.45-11.53 GHz.

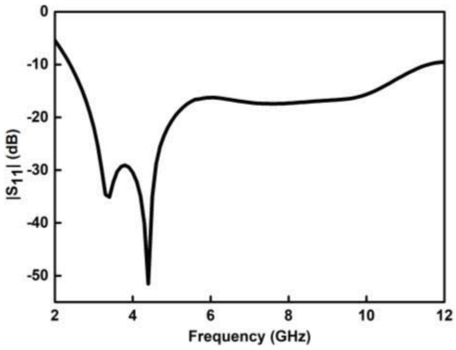
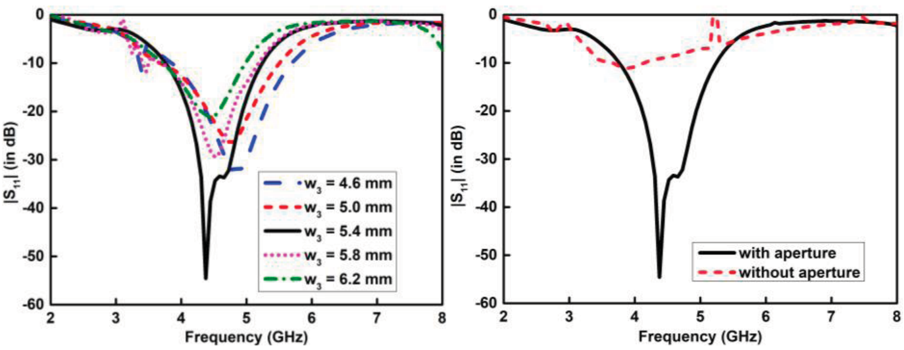


Figure 4. Simulated $|S_{11}|$ variations for UWB antenna.



(a) (b)

Figure 5. $|S_{11}|$-parameter variations of bandpass filter for different values of (a) stub-height *'w_3'*, (b) with and without aperture.

Next the performance of the bandpass filter has been analyzed. The wideband response is mainly contributed by the two vertically loaded stubs in the MMR structure of the proposed filter and the corresponding effect is displayed in Fig. 5(a). Further, the two apertures drawn in the ground plane at the back-side of the inter-digital coupled lines contributes in achieving enhanced coupling between the arms of the inter-digital coupled lines and also improving impedance matching of the filter geometry. The effect of aperture on the performance of filter is plotted in Fig. 5(b). Based on the results of parametric analysis of the UWB antenna and filter structure, the optimum dimension for the antenna, filter and the filtenna has been selected which is listed in section 2.

4. Experimental Validation

In order to demonstrate the feasibility of the proposed filtering antenna, the wideband bandpass filter and integrated filtering antenna has been fabricated and measured. Fig. 6 and Fig. 7 show the images of the fabricated filter, and the filtenna, respectively. The prototype is fabricated on FR4 epoxy dielectric having relative permittivity of 4.4, loss tangent of 0.02. The substrate height and the metal thickness are taken as 1.6 mm and 0.035 mm, respectively.

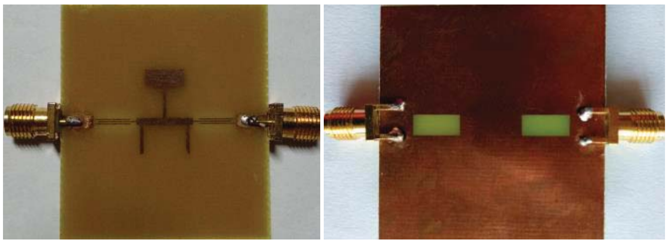

(a) (b)

Figure 6. Fabricated prototype of bandpass filter: (a) top view, and (b) bottom view.

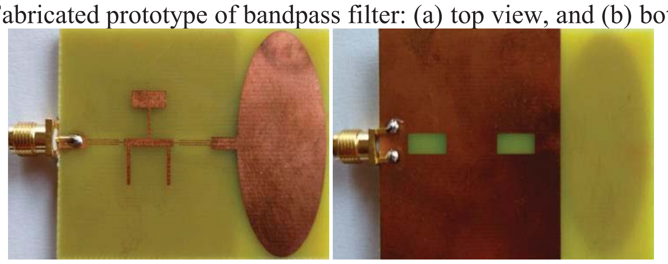
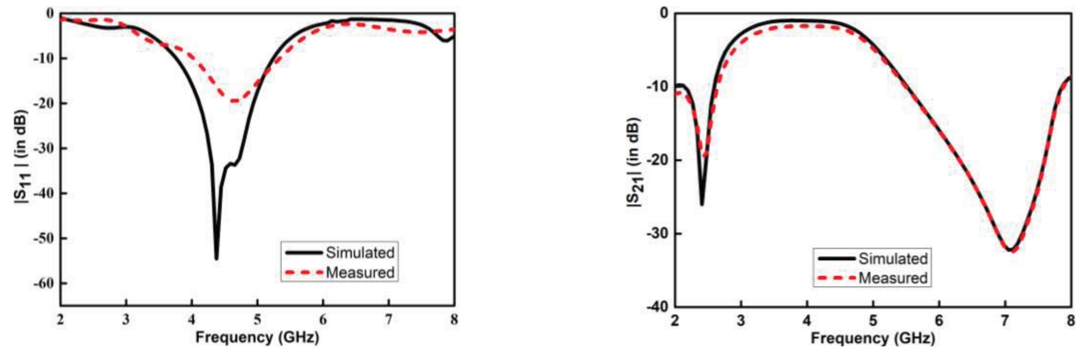

(a) (b)

Figure 7. Fabricated prototype of filtenna: (a) top view, and (b) bottom view.

Fig. 8 reveals the S-parameter comparison of the proposed filter. Here, the passband of the filter, as plotted in Fig. 4(a), is found to be ranging from 3.80 to 5.20 GHz with entire passband having reflection coefficient values lower than -35 dB. Insertion loss ($|S_{21}|$) is observed uniform around -1 dB for this proposed filter, in Fig. 4(b). Further, it exhibits fractional bandwidth (FBW) of 30% centered at 4.5 GHz. Two transmission zeroes, at 2.70 GHz and 7.06 GHz, are obtained towards the lower- and upper-side of the frequency band which provides sharp selectivity. A good resemblance between the simulated and the measured performance has been observed for the proposed filter.



(a) (b)

Figure 8. Simulated and measured performance of C-band filter for (a) $|S_{11}|$ variations, and (b) $|S_{21}|$ variations.

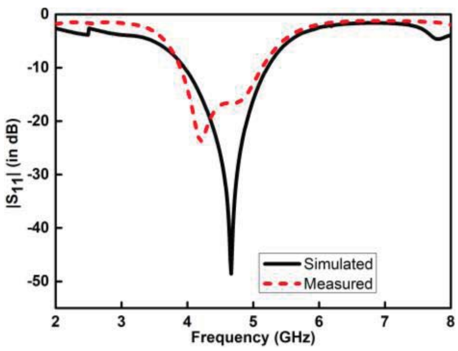
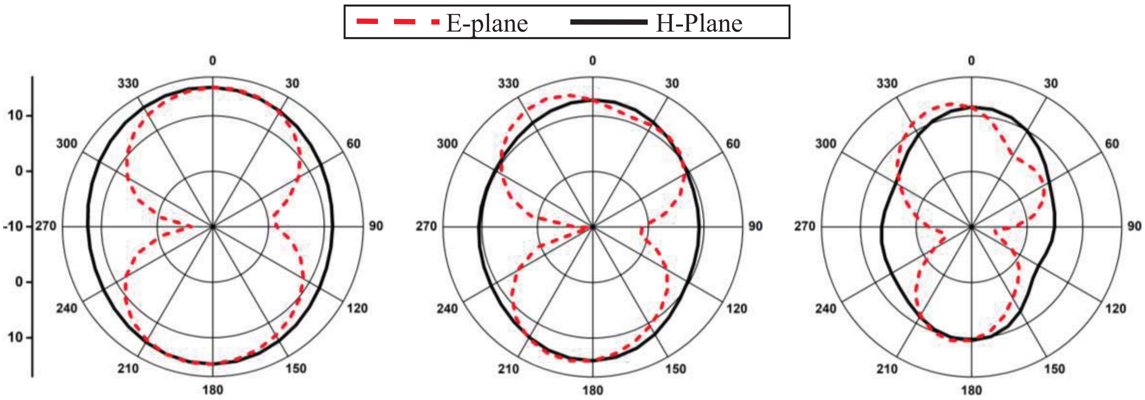


Figure 9. Representation of simulated and measured reflection coefficient ($|S_{11}|$) for filtenna.

Next, the performance of the integrated filtenna has been explored. Fig. 9 reveals the simulated and measured performance of the proposed filtenna in terms of reflection coefficient for its C-band state of operation. Here, the passband of the filter is found to be ranging from 3.96 to 5.21 GHz centered approximately at 4.60 GHz. The simulated normalized far-field radiation patterns of the filtenna are plotted in Fig. 10. An almost Omni-directional radiation pattern is observed both in H-plane whereas bi-directional radiation pattern is observed in E-plane for the proposed filtenna. However, little deviation is observed at higher frequency (5.20 GHz) for both E- and H- plane radiations.



(i) 4.00 GHz (ii) 4.60 GHz (iii) 5.20 GHz

Figure 10. Simulated far-field pattern for the proposed filtenna at (i) 4.00 GHz, (ii) 4.60 GHz, (iii) 5.20 GHz.

5. Conclusion

A new configuration of filtenna for C-band application is successfully demonstrated in this paper. An elliptical shaped radiator is first introduced followed by a wideband bandpass filter is designed for C-band applications. The antenna is then added to the bandpass filter for improving its performance and filtering characteristics. The simulated results for both the bandpass filter and filtenna structure are found to be in good agreement with the measured one. The proposed filtenna covers frequency band from 3.96–5.21 GHz which can be utilized for different C-band applications. As we have directly integrated the radiator of the proposed antenna to the filter, the system occupies a less space than the normal cascaded approach, in this way a compact design is accomplished.

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