Reconfigurable UWB Filtennas with Sharp WLAN Dual Bandnotch

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Abstract*—This paper presents the design and results of a reconfigurable ultra-wideband (UWB) 3.1–10.6 GHz filtenna with sharp dual bandnotch for WLAN 5.25 GHz and 5.8 GHz bands. A design for a bandstop filter is first proposed. Reconfigurability of the filter is achieved by the implementation of Graphene based switches and PIN diodes within the proposed filter. The filter was simulated, fabricated and measured for switch OFF and ON states. The simulated and measurement results are in good agreement with each other. The results for a switch OFF case show no bandnotch in the passband of the filter. While for a switch ON case, dual bandnotch have been obtained at a measured insertion loss rejection of 30 dB. The filter is then integrated with an UWB antenna. The resulting filtenna is simulated, fabricated and measured. Obtained simulation and measurements results of both switches in OFF and ON states have been presented to validate the accuracy of the proposed structures. On comparison, the obtained results of PIN diodes match those of the Graphene based switches. The results of the filtenna with both switches in OFF state show an entire bandpass response from 3.1–10.9 GHz with no bandnotch present. In ON state, the results show that sharp rejections at 5.3 GHz and 5.8 GHz are achieved at a measured return loss of 2.5 dB.

Keywords*— *uwb filtennas; bandstop filters; reconfigurable elements; bandnotch; graphene based switches; pin diodes.

I. INTRODUCTION

Since the release of unlicensed frequency band 3.1–10.6 GHz for UWB commercial communications [1], the race for commercializing UWB technology is heating up. The UWB covers a wide frequency range and is overlapped with a number of other wireless services, such as lower and upper WLAN bands of 5.15–5.35 GHz and 5.725–5.825 GHz. Since the power level of these bands is about 70 dB higher than that of UWB, these services interfere with UWB signals, causing signal distortion and loss of sensitivity. Hence, filtering is essential for the best usage of the UWB. A possible and effective solution is to realize notches at the unwanted frequencies. In order to achieve this, a number of methods can be employed, such as applying capacitively-loaded loop resonators [2], slots [3] or by using stubs [4] and [5]. However, in all the aforementioned work, the bandnotch are permanent, with no possibility of reverting back the resulting responses to a full UWB. Also in [3] and [4], the bandnotch is a single band from 5–6 GHz, thereby rejecting 5.35–5.725 GHz which is not a part of WLAN. These issues can be countered by introducing extremely sharp dual bandnotch at the two bands and by using switches to control the response respectively. Recently, the attention of researchers has been caught by Graphene. Although Graphene has been realized in a wide range of applications, there has been no reported work on using Graphene as reconfigurable elements, such as switches for use in reconfigurable filtennas. In this paper, the design and results of a reconfigurable UWB filtenna; formed by the integration of an UWB antenna with a bandstop filter - incorporated with Graphene based switches and PIN diodes for controlling WLAN bandnotch - is presented. Measured results of PIN diodes will be used to compare with the Graphene based switches simulated results. Sections II, III and IV present the designs of the proposed structures, results and conclusions of the work respectively.

II. PROPOSED DESIGN OF FILTERS AND FILTENNAS

The dual bandnotch are inserted in the filtenna's passband by the coupling of a bandstop filter based on stepped impedance resonators (SIRs). The proposed filter structure and an equivalent lumped elements circuit model are shown in Fig. 1. The structure consists of two identical pairs of $\lambda_g/2$ SIRs; where λ_g is the guided wavelength at the mid-frequency between the dual bandnotch. The two resonators within each pair are set in a complementary shape in order to occupy a smaller area and be compact. Each pair is placed on each side of the feedline. As the first spurious modes of the SIRs are at frequencies greater than $2.2f_0$, the spurious harmonics are out of the UWB range. The bandwidths of the dual bandnotch are determined by the gap between the SIRs and the feedline, whereas the middle gaps in both pairs of the resonators determine the insertion loss. There is a gap of 0.3 mm in each of the four interconnecting lines which join the fingers of the resonators; wherein would lie the switches. In OFF state, the switches behave like insulators and cut the current flow in the resonators; thereby the structure acting only as parallel transmission lines with no effect on the filtenna's passband. In ON state, they act like conductors and current flows in the interconnecting lines to make the structure act as a complete coupled bandstop filter; thus introducing the dual bandnotch.

In the circuit model, each SIR is represented by an inductor L and a capacitor C; where *L* and *C* are the sum of individual inductances and capacitances of a single SIR. The two J inverters, each next to the feedline with capacitance C_{J1}, represent the gap between the SIRs and the feedline on both sides. Since the couplings in the outer fingers of the SIRs are opposite and cancel out each other, the gap within each pair of SIR is denoted by one J inverter, of capacitance C_{J2}, on each side of the feedline. The values of the lumped elements and the J inverters were calculated and then fine-tuned using the software Agilent ADS. The final optimized values were: L = 1.64 nH, C = 0.5 pF, C_{J1} = 1.43 pF and C_{J2} = 6.37 pF.

The proposed filtenna is illustrated in Fig. 2. The designed structure utilizes defected ground structure with a partial ground plane of length 12 mm. The filtenna is symmetrical with respect to in the longitudinal direction and is fed with a 50 Ω feedline. A spade shape is chosen for the design. Due to the gradual change in structure of the radiating patch of this shape, a broadband impedance bandwidth is easily achieved and also provides a smooth shift from one resonant mode to another. Between the spade patch and the feedline, lie two rectangular patches of different sizes. These improve impedance matching and also provide good characteristic at the higher frequencies.

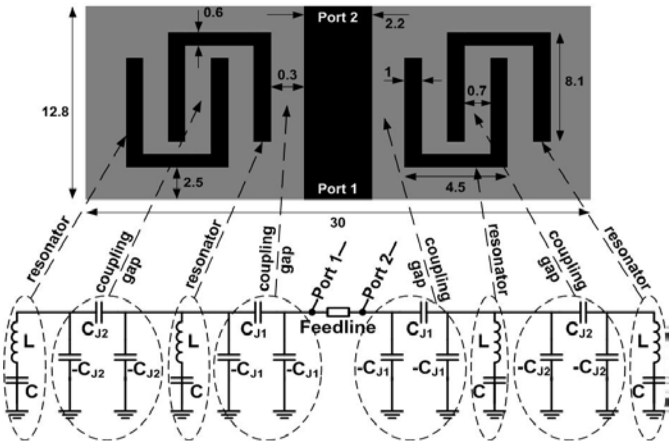


Fig. 1. Geometry (in mm) and equivalent circuit model of filter.

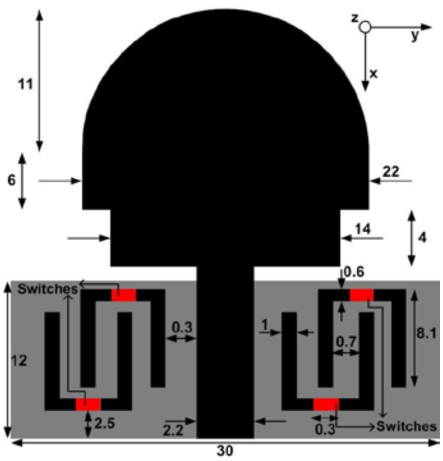
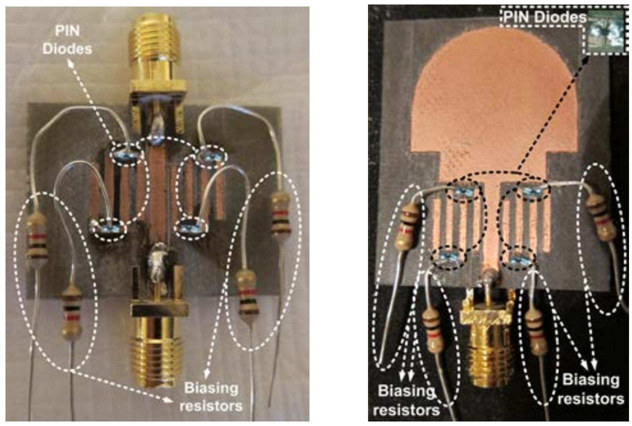


Fig. 2. Geometry (in mm) of filtenna (black: top layer, grey: ground layer).

III. RESULTS

The proposed structures are designed on a Taconic TLX-8 substrate 0.8 mm thick, permittivity ε_r = 2.55 and loss tangent tanδ = 0.0018. They are simulated using CST Microwave Studio and measured by Agilent E8361A Network Analyzer.



(a) (b)

Fig. 3. Photograph of the fabricated (a) filter and the (b) filtenna.

The filter is simulated and is fabricated with PIN diodes as the reconfigurable element. The PIN diode NXP BAP65–02 is used and has values of 0.9 Ω resistance, 0.6 nH inductance and 0.8 pF capacitance [6]. The diodes are switched on by supplying a DC voltage of 3 V and current of 1 mA. The DC blocking capacitance is 33 pF and a resistor of 1 kΩ is used for biasing. The simulated and measured results of the OFF (reverse bias) and ON (forward bias) states are shown in Fig. 4 and Fig. 5 respectively. The result for the OFF state shows no notch bandnotch in the entire frequency range and is considered as exhibiting an all-pass response and thus no band rejection. Comparatively, the resulting response for the ON state shows that sharp dual bandnotch are present at 5.25 GHz and 5.8 GHz. Both bands have been measured at an insertion loss of almost 30 dB.

The resulting S-parameters of the equivalent circuit model are presented in Fig. 6. Although the response is quite similar to that of the filter in ON state, the magnitude is much better. This is because these are simulated results of lumped elements and also the software does not take into account any losses, such as metal or substrate loss, fabrication tolerances, etc.

The EM simulation and Graphene based switches simulation S-parameters results in OFF and ON states are shown in Fig. 7 and Fig. 8 respectively. EM simulation results in both states show the filtenna's passband to be about 3.06–10.67 GHz at a return loss of more than 10 dB. In OFF state, no bandnotch are present in the filtenna’s passband. This allows the filtenna to cover the 5.25 GHz and 5.8 GHz bands. In ON state, sharp dual bandnotch are present at 5.25 GHz and 5.8 GHz. The Graphene based switches are a material type with varying surface conductivity. The modelling of these switches has been obtained from the method outlined in [7]. Reconfigurability is achieved by using unbiased Graphene with a chemical potential of μ_c = 0.0eV to obtain OFF state and by biasing Graphene to a chemical potential of μ_c = 1.0eV to obtain ON state. The Graphene based switches simulation results are in agreement with the EM results. The passband is slightly increased to about 3.07–10.9 GHz. No bandnotch are present in OFF state. In ON state, the dual bandnotch have been achieved at a return loss of about 1.7 dB.

A filtenna is fabricated with the aforementioned PIN diodes as the switching element and biased in the same way as the filter. The results are presented in Fig. 7 and Fig. 8 for OFF state and ON state respectively. The passband is 3.09–10.88 GHz with no bandnotch present in the OFF state. In the ON state, sharp dual bandnotch are introduced in the filtenna's passband. Compared to the Graphene based switches, the achieved return loss rejection at the dual bandnotch frequencies is less by 0.8 dB, i.e. it is at 2.5 dB. Additionally, the bands have shifted forwards to frequencies of 5.3 GHz and 5.81 GHz. These minor shifts can be attributed to fabrication discrepancies.

The gain and efficiency of the filtenna in OFF state is presented in Fig. 9. In OFF state, the measured gain and efficiency at the dual bandnotch frequencies is about 5.8 dBi and 79 %. In ON state, shown in Fig. 10, when the dual bandnotch are present, these values are reduced to -5 dBi and 32 % respectively. As seen in Fig. 11, the filtenna has bidirectional radiation patterns in the E-plane and omnidirectional radiation patterns in the H-plane.

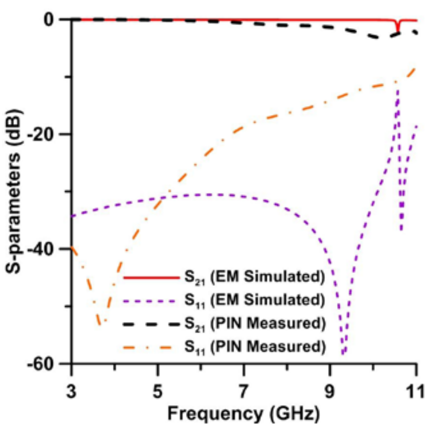


Fig. 4. S-parameters of filter in OFF state.

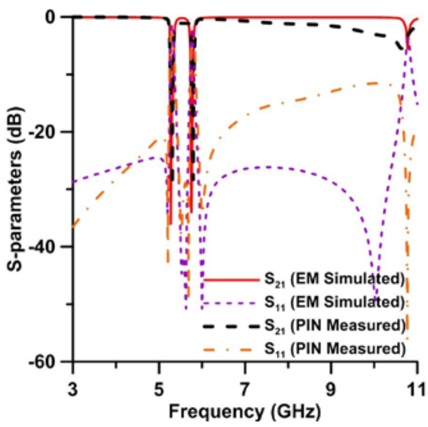


Fig. 5. S-parameters of filter in ON state.

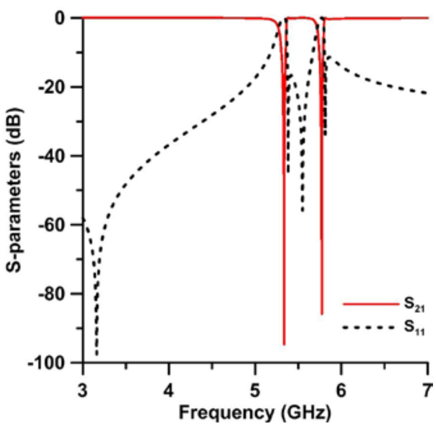


Fig. 6. S-parameters of equivalent circuit model of filter..

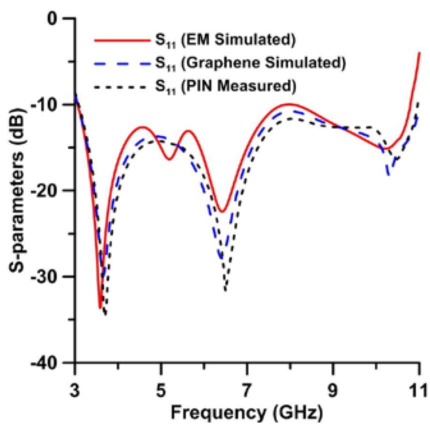


Fig. 7. S-parameters of filtenna in OFF state.

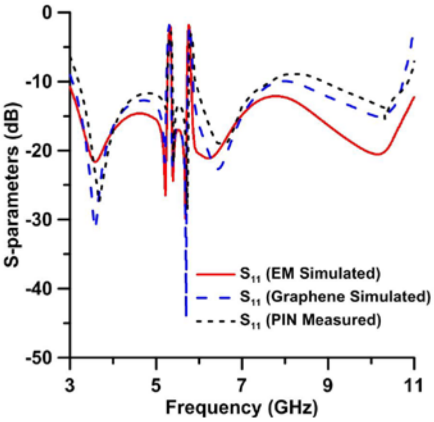


Fig. 8. S-parameters of filtenna in ON state.

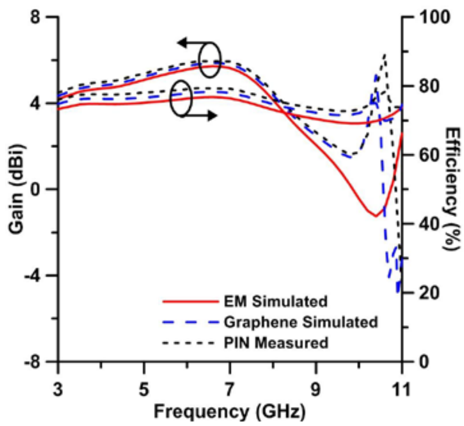


Fig. 9. Gain and efficiency of filtenna in OFF state.

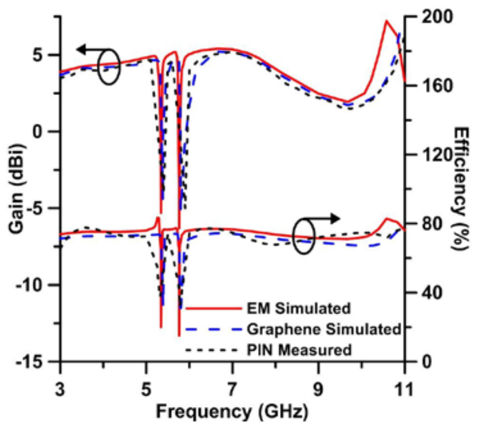


Fig. 10. Gain and efficiency of filtenna in ON state.

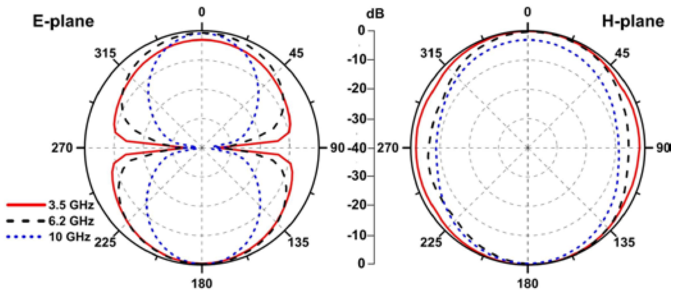


Fig. 11. Radiation patterns of filtenna in E-plane and H-plane.

IV. Conclusion

An UWB filtenna consisting of an UWB antenna coupled with SIRs - which are integrated with Graphene based switches and PIN diodes - has been designed and presented. The two switching elements are a means of reconfiguring the filtenna to shift to and fro between a full UWB and an UWB with dual bandnotch, with each band at the WLAN bands of 5.15–5.35 GHz and 5.725–5.825 GHz. The simulation and measurement results of both switches in OFF and ON states have been shown. A full UWB has been attained when the switches are in OFF state. Whereas in ON state, sharp dual bandnotch at the WLAN frequency bands are present. Even though some differences between the results of PIN diodes and Graphene based switches are present, these are negligible. Hence, it can be said that the two reconfigurable elements are in good agreement with each other. This filtenna configuration could be quite useful for indoor UWB applications with no interferences from WLAN signals.

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