Switchable Filtennas with Sharp Dual Bandnotch using Looped Resonators

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Switchable Filtennas with Sharp Dual Bandnotch using Looped Resonators

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***Abstract*—This paper proposes a reconfigurable/switchable UWB filtenna with sharp dual bandnotch at WiMAX 3.5 GHz and WLAN 5.8 GHz bands. The filtenna is formed by placing three looped resonators in an UWB antenna. The resonators are fitted with Graphene based switches and PIN diodes which introduce reconfigurability. The filtenna was simulated and measured in switch OFF and ON states. Results show a measured passband from 2.8–11.97 GHz in OFF state and ON state results in sharp dual bandnotch within the passband at 3.49 GHz and 6.15 GHz at a return loss of 2.2–2.5 dB. The gain and efficiency in both states has also been given and is reduced in ON state at the dual bandnotch. Surface currents at the dual bandnotch and the radiation patterns in E- and H-planes have also been presented.**

Keywords—reconfigurable; filtennas; graphene; pin diodes; bandnotch; uwb; loop resonators.

I. INTRODUCTION

After the unlicensed 3.1–10.6 GHz frequency band was released for UWB commercial communications [1], it became necessary to cull the overlying, interfering and unwanted wireless services whose power level was higher than the UWB; for instance the 3.4–3.6 GHz WiMAX and 5.725–5.825 GHz WLAN bands. So, notches are introduced at these frequencies as an effective solution. To achieve this, numerous approaches are used; such as using stubs [2] and [3], slits/slots [4], capacitively-loaded resonators [4] or by SRRs [5]. Yet, in these works, the bandnotch are either not at a good measured rejection value or are not sharp enough for their band [4]–[5] or the filters are cascaded with the antenna [2]–[3], rather than being integrated within; so increasing size, cost and complexity of circuits. This work presents an UWB filtenna, formed by integrating three looped resonators within an UWB antenna. In this manner, the size does not increase and the bandnotch are acquired at good rejection values and are sharp. The filtenna has reconfigurable characteristics using two different types of switches: Graphene based switches and PIN diodes. Hence, the dual bandnotch can be switched off or on at will.

Because of its unique chemical, thermal, mechanical, electronic and optical properties [6], Graphene has captured the attention of the entire research community. A major factor in this is that Graphene presents a very promising future for the replacement of conventional materials and future electronics [6]. Hence, it has been implemented in a wide range of applications. For example, from Graphene based filters reported in [7] and to antennas in [8]. However, there has been almost no reported work on using Graphene as reconfigurable elements, such as switches for use in achieving reconfigurability in filters integrated in antennas, i.e. reconfigurable filtennas. This work also shows how to introduce reconfigurability using Graphene based switches.

II. RECONFIGURABILITY AND DESIGN OF PROPOSED FILTENNA

A. Modelling of Graphene based Switches and PIN Diodes

Graphene based switches are implemented by modelling the complex surface impedance of Graphene using (1)–(3). Complex surface impedance modelling takes into account the surface resistance and surface reactance of Graphene. Such modelling is faster and uses far less computing and memory resources than customary bulk modelling. OFF state of the Graphene based switches (GbS) is when Graphene is unbiased to a chemical potential of μ_c = 0.0eV and ON state occurs when Graphene is biased at a chemical potential of μ_c = 1.0eV. Therefore, the two reconfigurable states of the switches can be easily obtained. To calculate and model the varying surface resistance and reactance in both states, MATLAB was used and the resultant data was exported to the electromagnetic simulation software.

$$\sigma = -j\frac{q_e^{\,2}K_bT}{\pi\hbar^2(\omega - j2\Gamma)}\left(\frac{\mu_c}{K_bT} + 2\ln(e^{\frac{\mu_c}{K_bT}}+1)\right) \quad (1)$$

$$\text{resistance} = \text{Re}(1/\sigma) \quad (2)$$

$$\text{reactance} = \text{Im}(1/\sigma) \quad (3)$$

In (1)–(3), σ is the surface intraband conductivity, j is the imaginary constant, q_e is the electron charge, K_b is Boltzmann's constant, T is temperature, $\hbar$ is reduced Planck's constant, ω is the radian frequency, Γ is scattering rate and μ_c is the chemical potential. Scattering rate is defined as $\Gamma = (2\tau)^{-1}$; where τ is the average relaxation time. Here, the parameters' values used are T = 300 K and τ = 9.4 ps [9]; resulting in a resistance of 25.22 Ω in the OFF state and a resistance of 0.9 Ω in the ON state.

For reconfigurability using PIN diodes, the PIN diode NXP BAP65–02 is used and has a resistance of 0.9 Ω, an inductance of 0.6 nH and a capacitance of 0.8 pF [10]. 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. A reverse bias connection gives the OFF state and forward bias results in the ON state.

B. Layout of Filtenna

The proposed filtenna is illustrated in Fig. 1. The filtenna is designed with a mid-band frequency of 6.85 GHz. It is excited via port 1 and is inductively coupled to the source via a 50 Ω feedline. The design uses a defected ground with a partial ground plane of a length of 13.1 mm. The structure is symmetrical in its longitudinal direction. A spade shape is chosen for the top metallization. Owing to the steady change in the shape of such design, a wideband impedance bandwidth is easily achieved. It also provides a smooth change from one resonant mode to another. Between the semi-circular patch at the top and the feedline at the bottom, two rectangular patches of different sizes are put. They provide good characteristics at the higher frequencies and also improve impedance matching. The 3.5 GHz bandnotch is formed by a circular loop resonator laid within the top radiating patch. The 5.8 GHz bandnotch is produced by two rectangular loop resonators; each laid on either side of the feedline. These resonators are capacitively coupled with the main structure and, thus, two have been used so as to improve the coupling and achieve better rejection results. A splitting gap - 0.8 mm in the circular loop and 0.5 mm in the rectangular loops - is present in the resonators. All resonators are 0.5λ_g long; where λ_g is the guided wavelength at their respective bandnotch frequency. The switch thickness is 50 µm for the GbS and 0.3 mm for the PIN diodes. As marked in Fig. 1, the switch for the circular loop is placed within its splitting gap. However, the switches for the rectangular loops are put at the midpoint of their longest transmission line; thus separating each loop in two mirrored parts. This way, all three switches can stop or allow the flow of current in all resonators.

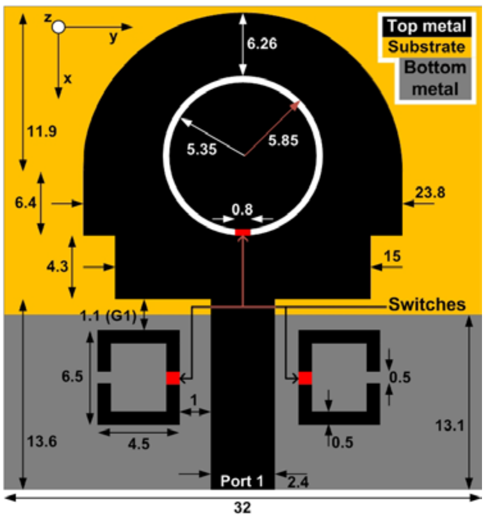


Fig. 1. Geometry of the filtenna (dimensions in mm).

III. Results

The structure is designed on 0.8 mm thick Rogers RT5880 substrate, of a dielectric permittivity ε_r = 2.2 and a loss tangent tanδ = 0.0009. The commercial electromagnetic software *CST Microwave Studio* is used for simulation and the fabricated filtenna is measured by an Agilent E8361A Network Analyzer.

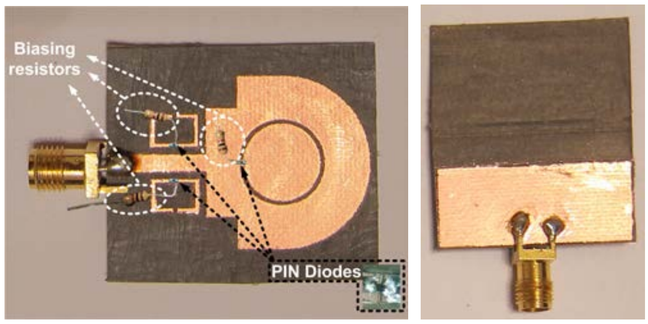


Fig. 2. Photographs of the top and bottom sides of the fabricated filtenna.

A. Return Loss

Perfect electromagnetic simulations with the switches in OFF state are done by laying gaps where the actual switches will be placed and in ON state by replacing the gaps with perfect electric conducting (PEC) metal patches. Simulations in the two states using GbS are done by using the data from MATLAB. The fabricated filtenna with the aforementioned PIN diodes was measured.

The OFF state results are presented in Fig. 3. The resulting return loss shows a good agreement between the PEC, Graphene based switches and measurements using PIN diodes. PEC simulation gives a full passband from 2.82–11.45 GHz. Graphene based switches show a full passband in the 2.81–11.95 GHz range. With the PIN diodes in OFF state, the measured passband is 2.8–11.97 GHz. In this state, using any type of switch, no bandnotch exists in the filtenna's passband. This allows the filtenna to cover the 3.5 GHz and 5.8 GHz bands.

The ON state return loss results given in Fig. 4 show a reasonable agreement between the three switching elements. Using PEC, the passband is 2.81–11.91 GHz. Sharp dual bandnotch are present at 3.45 GHz and 6.04 GHz at a return loss of 0.8 dB and 1.3 dB respectively. Graphene based switches present similar results. The passband is from 2.81–11.93 GHz and sharp dual bandnotch are observed at 3.45 GHz and 6.03 GHz with a return loss of 2 dB and 1.8 dB respectively. These results are echoed when the PIN diodes are switched on. The filtenna has a passband of 2.75–11.7 GHz. Also, dual bandnotch are seen at 3.49 GHz and 6.04 GHz having a return loss of 2.2 dB and 2.5 dB respectively. Even though the measured bands have shifted to 3.49 GHz and 6.15 GHz, these shifts are minor and can be linked to initial optimization and fabrication discrepancies. In this ON state, all switches introduce sharp dual bandnotch, showing the desired rejection.

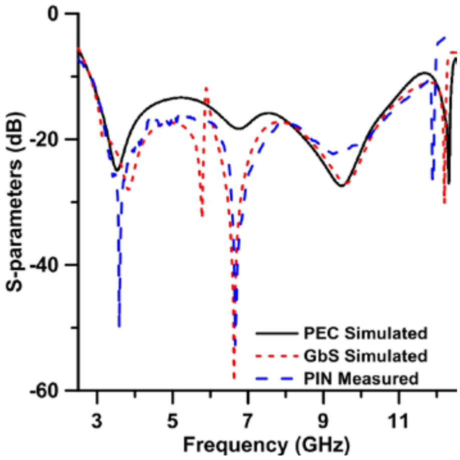


Fig. 3. Return loss of filtenna in switch OFF state.

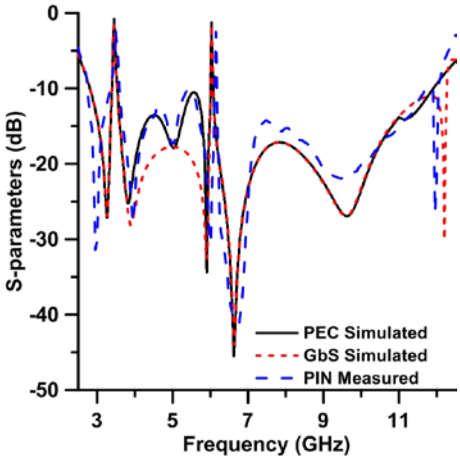


Fig. 4. Return loss of filtenna in switch ON state.

B. *Parametric Study of Position of 5.8 GHz Loops*

A parametric study was done to check the rejection when the location of the 5.8 GHz resonators was changed. It is expected that when they are located near the top radiating patch, the return loss rejection would increase, i.e. an increase in VSWR. The filtenna was simulated with the location of the 5.8 GHz loops changed by using various values for *G1*. These results are given in Fig. 5; where, the VSWR in a limited frequency range is given for clarity purposes. The loops were first moved 2.5 mm downwards in the x-axis (i.e. towards the bottom) and then a further of 5.5 mm; while maintaining constant distance from the feedline. As the loops move downward, away from the top radiating patch, the rejection can be seen to decreasing. In the final design, the VSWR at 5.93 GHz is 52.73 (S_{11} = 0.33 dB). When they are moved 2.5 mm, the VSWR decreases to 41.92 (S_{11} = 0.41 dB) and after a movement of 5.5 mm, the VSWR drops further to 23.51 (S_{11} = 0.74 dB). In these results, the frequency shift is minor, averaging at ±40 MHz (±0.68 %).

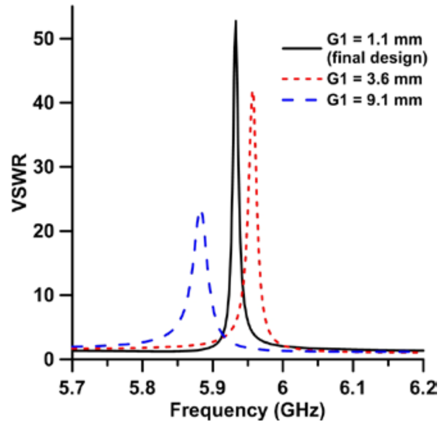
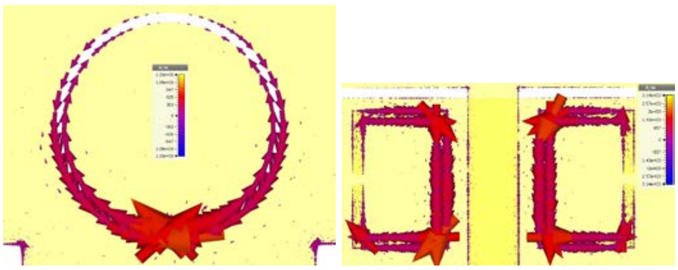


Fig. 5. VSWR of filtenna with varied positions of 5.8 GHz loop resonators.

C. *Distribution of Surface Current*

To deeper explain the effects of the looped resonators on the passband and how the bandnotch are achieved, the simulated current distribution at the two bandnotch frequency are shown in Fig. 6. A zoomed-in view is presented to be able to see clearly. At these two frequencies, much stronger current distribution is concentrated along the edges of the resonators. As can be seen, the directions of the current flow along the inner and outer edges of the resonators are opposite to one another. Thus, the currents are cancelled by each other and, the filtenna does not radiate and bandnotch are achieved.



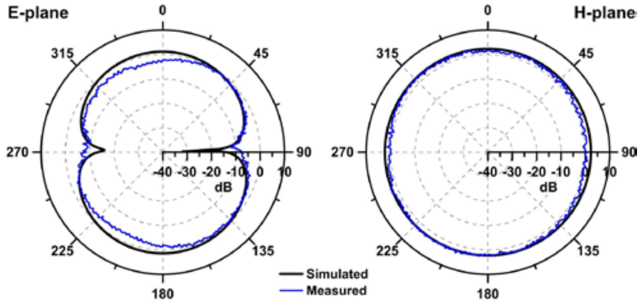
(a) (b)

Fig. 6. Surface current distribution at (a) 3.5 GHz and (b) 5.8 GHz.

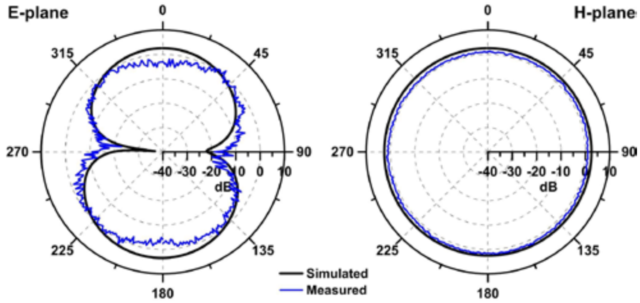
D. *Radiation Patterns, Gain and Efficiency*

The radiation patterns at various OFF state frequencies in the E-plane and H-plane are given in Fig. 7. Simulations show stable bidirectional patterns in the E-plane and omnidirectional patterns in the H-plane. A reasonable match has been obtained with the measured radiation patterns.

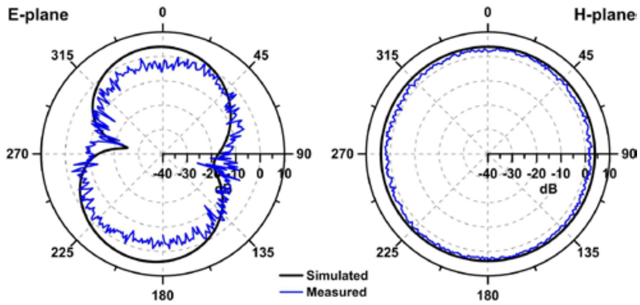
The gain and efficiency in OFF state is given in Fig. 8. When using Graphene based switched, the average gain and efficiency in OFF state is 4.33 dBi and 96 %. The gain and efficiency at the dual bandnotch are 3.15 dBi and 5.04 dBi, and 97.5 % and 96.9 %. When in ON state, in Fig. 9, these fall to 1.53 dBi and -0.85 dBi, and the efficiency falls to 42.5 % and 24.1 %.



(a)



(b)



(c)

Fig. 7. Radiation patterns at (a) 3.1 GHz, (b) 4 GHz and (c) 5.75 GHz.

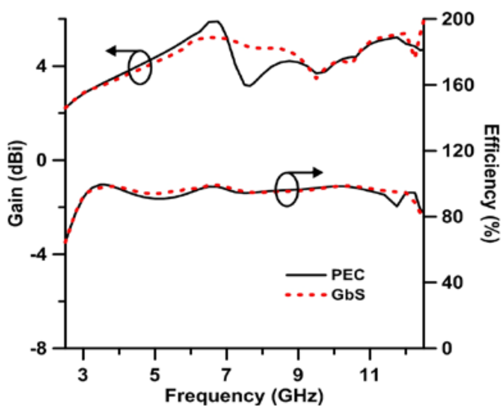


Fig. 8. Gain and efficiency of filtenna in switch OFF state.

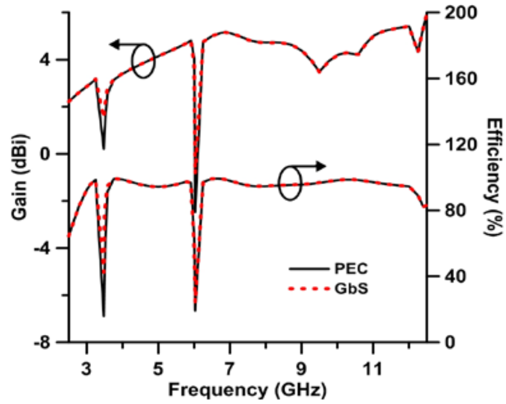


Fig. 9. Gain and efficiency of filtenna in switch ON state.

IV. Conclusion

A reconfigurable UWB filtenna is presented. Filtering is realized by integrating three looped resonators; with built-in Graphene based switches and PIN diodes to get reconfigurability. The processes of obtaining switchable characteristics of both Graphene based switches and PIN diodes are also given. In OFF state, a full bandpass response in the UWB is obtained. While ON state gives sharp dual bandnotch at the WiMAX 3.5 GHz and WLAN 5.8 GHz bands. These results are similarly echoed in the gains and efficiencies also. All these reductions signify the rejection capability of the filtenna and effective working of both switches in both states. This filtenna can be useful for UWB indoor applications with no interferences by WiMAX and WLAN services.

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