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Reconfigurable WLAN Notch for UWB Filters

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Abstract—**This paper presents the design and results of an ultra-wideband (3.1–10.6 GHz) filter with a reconfigurable WLAN notch at 5.8 GHz. Reconfigurability has been achieved by the implementation of Graphene based switching elements. The switches are in OFF state when Graphene is unbiased at a chemical potential of μ_c = 0.0eV and are in ON state when Graphene is biased at a chemical potential of μ_c = 1.0eV. The simulation and measurement results of the filter when the Graphene switches are OFF show an entire bandpass response from 3.1 GHz to 10.6 GHz and with low insertion loss. When the Graphene switches are ON, the simulation result shows that a sharp rejection of the WLAN band at 5.8 GHz is achieved, with a very low passband insertion loss. The obtained results of both states, i.e. switches OFF and switches ON, are as desired. An additional filter, implemented with PIN diodes as the switching elements, is also designed and measured. Upon comparison, the obtained results of PIN diodes in OFF and ON states match those of the Graphene switches in OFF and ON states.**

Keywords—graphene; uwb; reconfigurable filter; bias, pin diode; notch; wlan.

I. INTRODUCTION

Graphene has captured the attention of the research community all over the world. The reasons are the unique properties that it possesses, i.e. its chemical, thermal, mechanical, electronic and optical properties [1]. Graphene is a monolayer of graphite laid out in a honeycomb lattice structure, with a thickness of only 0.34 nm, and is the first 2D material. Graphene presents a very promising future for replacement of conventional materials and future electronics [2].

Because of its distinctive properties as compared to conventional materials, Graphene has been implemented in a wide range of applications over the last few years. The published work [3]-[5] reports a plethora of applications. For example, from Graphene based filters reported in [3] and [4] and to antennas in [5]. However, there has been no reported work on using Graphene as reconfigurable elements, such as switches for use in reconfigurable filters.

Since the Federal Communications Commission of the United States released the unlicensed frequency band 3.1–10.6 GHz for ultra-wideband (UWB) commercial communications in February 2002 [6], the development race for commercialising UWB technology has been heating up in Europe and all over the world. UWB covers a very wide frequency range and is overlapped with a variety of other wireless services; e.g. WLAN band. These services potentially interfere with UWB signals, causing signal distortion as well as loss of sensitivity. In order to best use that frequency band, filtering is essential. One of the possible and effective solutions for this problem is to realise reconfigurable narrow rejection bands (notches) within the passband of UWB bandpass filters. For this purpose various techniques can be employed; such as applying a slot resonator [7] or a terminated cross-shaped resonator [8] or by using pin diodes [9] and [10]. However, in this paper, the concept, method and modelling of Graphene based switches for reconfiguring/controlling a WLAN notch in an UWB filter is presented. Comparatively, using Graphene as switching elements is easier to implement than the other techniques. The designed filter utilises microstrip technology. In Section II, modelling of Graphene for use as switching elements is detailed. Section III presents the design of the structure, with the results in Section IV. The conclusions of the work follow in Section V.

II. MODELLING OF GRAPHENE AS SWITCHING ELEMENT

As Graphene is a 2D material, its surface conductivity is expressed as a tensor in the most general form [11]. The chemical potential of Graphene is defined by variables such as gate voltage and substrate thickness and controlled by doping and/or applying an electrostatic bias field. When the chemical potential is varied, a frequency shift of the real and the imaginary parts of conductivity is observed. In operational frequencies below THz range, when there is no magnetic bias field present and no doping, the surface conductivity of Graphene is a scalar. It is expressed by the formula [11] given in (1). Change in surface conductivity causes the surface resistance and reactance to change as well. These relationships are given in (2) and (3) respectively.

In this paper, the switches are implemented by modelling the complex surface impedance of Graphene. Complex surface impedance modelling takes in to account the surface resistance and surface reactance of Graphene. As compared to traditional bulk modelling, surface impedance modelling is much faster and takes up considerably less computing resources and memory. Hence these parameters can be easily manipulated in order to obtain the required reconfigurable characteristics of Graphene switches.

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

$$\text{resistance} = \text{Re}\left(\frac{1}{\sigma}\right) \qquad (2)$$

$$\text{reactance} = \text{Im}\left(\frac{1}{\sigma}\right) \qquad (3)$$

where σ is surface intraband conductivity, j is imaginary constant, q_e is electron charge, K_b is Boltzmann's constant, T is temperature, $\hbar$ is reduced Planck's constant, ω is radian frequency, Γ is scattering rate and μ_c is chemical potential. Scattering rate is defined as $\Gamma = (2\tau)^{-1}$, where τ is average relaxation time.

Here, the parameters' values used are T = 300K, τ = 3 ps and Γ = 1.67 x 10^{11} [11], [12]. MATLAB was used to model the varying surface resistance and reactance of Graphene for μ_c = 0.0eV (switches OFF) and μ_c = 1.0eV (switches ON). The obtained modelling results for the two values of μ_c are shown in Fig. 1.
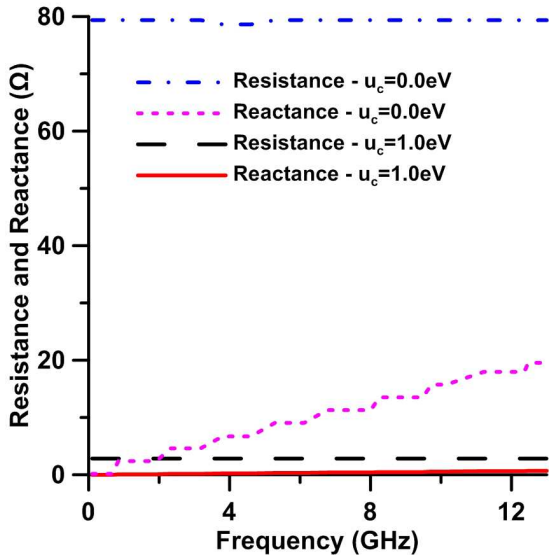

Fig. 1. Modelled surface impedenace of Graphene.

III. DESIGN OF FILTER

The proposed third order bandpass filter is illustrated in Fig. 2. The filter is designed with a mid-band frequency of 6.85 GHz. It is inductively coupled to the source and load and is excited via ports 1 and 2, where Z_0 = 50 Ω. The proposed structure consists of a $\lambda_g/2$ resonator placed between a pair of $\lambda_g/4$ short circuited resonators; where λ_g is the guided wavelength. The short circuited resonators are folded so as to utilise a common ground via and also the structure to be compact. The notch is inserted in the filter's passband by coupling of an identical, but inverted, pair of three-sections resonators. They consist of stepped impedance resonators (SIR) and rectangular open circuited stubs in the SIRs' symmetry plane. The stubs build sharp rejections in the desired band. The notch bandwidth is determined by the width of the transmission lines joining the SIRs and the stubs. As shown, the Graphene switches are placed in the two centers of the pair of coupled three-sections resonators, i.e. the points where the SIRs connect to the stubs. In the ON state (μ_c = 1.0eV), the Graphene switches behave like conductors and a notch is introduced in the filter's passband. When the Graphene switches are in the OFF state (μ_c = 0.0eV), they act like insulators and cut the current flow to the coupled resonators; thus removing the notch.

As a comparison, an additional structure is designed with Graphene replaced by PIN diodes as the switching elements. In forward bias (ON state), the SIRs are all connected and produce a notch. Whereas, in zero bias (OFF state), there is no connection and a full bandpass response is obtained.
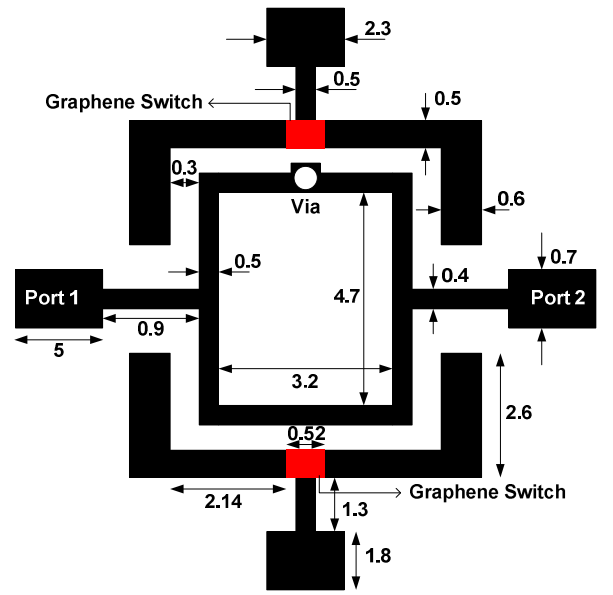

Fig. 2. Geometry of UWB bandpass filter with Graphene switches shown (dimensions in mm).

IV. RESULTS

The proposed structure is designed on a Rogers RO3010 substrate of thickness 0.635 mm, having a dielectric permittivity ε_r = 10.2 and dielectric loss tangent tanδ = 0.0023. It is modelled and simulated using the commercial software emSonnet and SonnetLab. The Graphene switches are implemented in emSonnet as "General" metal type with varying surface resistance and reactance, the values of which have been obtained from MATLAB earlier.
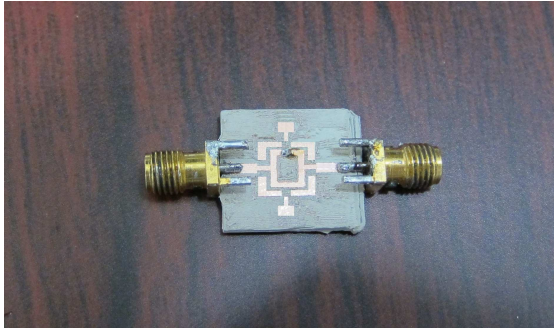
Fig. 3. Photograph of the fabricated UWB bandpass filter.

Simulation and measurement results of the filter with the Graphene switches in OFF state ($\mu_c = 0.0$ eV) and simulation result with the Graphene switches in ON state ($\mu_c = 1.0$ eV) are shown in Fig. 4 and Fig. 5 respectively. Both results show the filter's 3 dB passband to be about 3.1–10.6 GHz. This corresponds to the UWB frequency range as desired. In both the OFF and ON states, a good matching of the filter is present; as seen by the return loss being more than 14 dB.

The simulation result with the Graphene switches in OFF state shows that no notch is present in the filter's passband. This allows the passband to cover the WLAN 5.8 GHz band. The insertion loss of the filter in this case is about 0.58 dB. The fabricated filter was measured using the Agilent E8361A PNA Network Analyzer. The measured result is in good agreement with the simulation result. The passband in the measured result is about 3.2–10.8 GHz with no notch present. However, the insertion loss is about 2.1 dB. This can be attributed to the material quality and the fabrication tolerances involved. In the ON state, the result shows an insertion loss of about 0.32 dB. As also seen, a notch at WLAN frequency of 5.8 GHz is present. The achieved rejection for the notch is about 23 dB.

In the second structure, fabricated with PIN diodes as the switching elements, the PIN diode NXP BAP65–02 SOD523 has been used to correspond with the switching circuit parameters and has typical values of 0.9 Ω resistance, 0.6 nH inductance and 0.8 pF capacitance [13]. The diodes are switched on by supplying an external DC voltage of 3V and a current of 1mA. The DC blocking capacitance is 33 pF and a resistor of 1 kΩ has been used for biasing. The results are presented in Fig. 4 and Fig. 5 for zero-bias (OFF state) and forward-bias (ON state) respectively. The 3 dB passband appears to be from 3.3–10.65 GHz with no notch present in the OFF state. The insertion loss of the filter is about 2.3 dB. In the ON state, when the diodes are switched on, a notch is introduced in the filter's passband. As compared to the Graphene switches, the achieved rejection at the notch frequency by the PIN diodes is less by 5 dB, i.e. it is at 18 dB. Additionally the notch has shifted forwards to a frequency of 5.9 GHz. This shift can be attributed to the fabrication discrepancies. The insertion loss of the filter is about 2.42 dB. Even though some differences between PIN diodes and Graphene results are present, these are negligible. Hence it can be said that the measured results of the PIN diodes in both the OFF and ON states are in good agreement with the Graphene switches' simulated and measured results in the OFF and ON states.
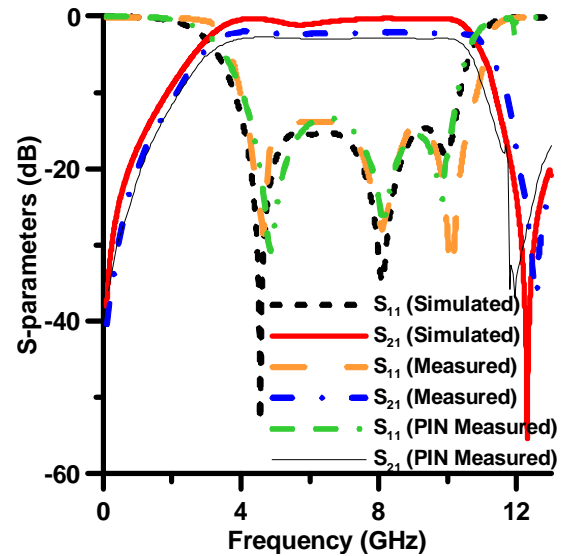

Fig. 4. S-parameters of UWB bandpass filter with the switches in OFF state.
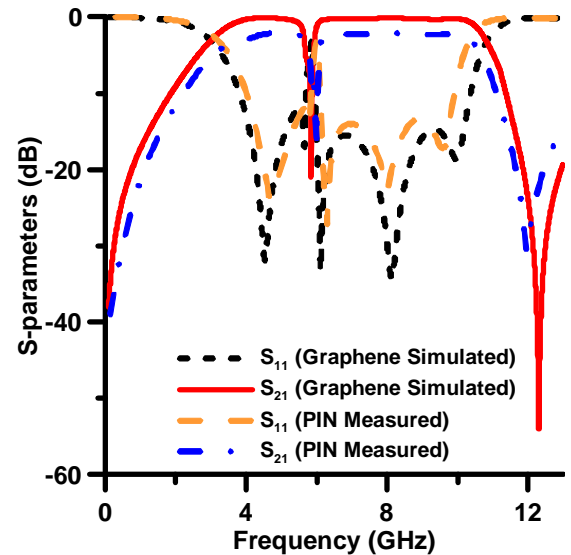

Fig. 5. S-parameters of UWB bandpass filter with the switches in ON state.

V. CONCLUSION

In this study, an UWB filter, coupled with external SIRs which are fitted with switches (Graphene based and PIN diode) and open circuited stubs, is designed and presented. The Graphene switches are a means of reconfiguring the filter to switch to and fro between a full bandpass response and a bandpass response with a notch at WLAN 5.8 GHz frequency band. The switching capability is achieved by using unbiased Graphene with a chemical potential of $\mu_c = 0.0$eV (switches OFF) and by biasing Graphene to a chemical potential of $\mu_c = 1.0$eV (switches ON). In the case of PIN diodes, the switching is obtained by supplying a voltage and current to turn on the diodes and using a resistor for biasing to make the diodes in a

forward-bias connection (switches ON) or zero-bias (switches OFF). The simulation and measurement results of Graphene and PIN diode switches in OFF and ON states have been shown and are as desired. Obtained results show no notch in the passband when both elements are in OFF state; while a notch is present at 5.8 GHz when the switching elements are in ON state. The proposed modelling and design could be implemented for future reconfigurable devices.

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