An Analysis of Reconfigurable SIW Filter Reconfigurable Antenna using Varactor Diodes

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***Abstract*—This paper introduces a novel reconfigurable SIW filter and reconfigurable antenna for 4G applications by using varactor diodes. This SIW filter consists of two floating islands with two via holes that connected with two varactor diodes while the antenna has a slot on the patch itself. This method allows designing SIW filter and patch antenna with the tunable centre frequency with a constant absolute bandwidth. The filter and antenna is designed through the simulation on a standard printed circuit board technology. The SIW filter at 2.097 GHz shows an insertion loss of 1.87 dB and 3 dB bandwidth of 163.39 MHz while at 2.012 GHz gives return loss of 32.17 dB and 10 dB bandwidth of 40.28 MHz. This reconfigurable SIW filter and reconfigurable antenna are used to obtain a good performance that suitable for integration with any reconfigurable planar structure. This analysis provides an alternative solution for reconfigurable SIW filter and antenna, particularly in 4G communication systems.**

***Index Terms*— Bandpass Filter; Bandwidth; Reconfigurable Antenna; Reconfigurable Filter; Varactor Diode;**

I. Introduction

Presently, the rapid growth in the field of electronics and wireless communication systems, the demand for respective mobile devices functioning at different standards or for different applications is extending. Currently, the wireless communication systems are evolving in the direction of multi-functionality with different operating frequencies. A reconfigurable filter that has tunable fundamental characteristics, including attenuation, operating frequency, isolation, and bandwidth, is a better alternative for providing multi-functionality [1]-[6].

Significant research activities have been proposed to discover various types of reconfigurable filter and antenna for front end wireless communication systems [7]-[11]. A compact tunable bandpass filter is capable to tune a frequency response from 2.1 GHz to 2.9 GHz by using stepped-impedance resonator. The overall size of the filter is 13 x 15 mm. However, the tunable insertion loss is quite poor in the range of 9.2 – 4.2 dB [7].

A very frequency tuning range of 16 % was demonstrated with interdigital coupling structure from the tuning range of 784 Mhz to 918 MHz [8], but the return loss was very poor which is around 10 dB. The insertion loss gives the overall good performance at 9 V of 0.69 dB with compact structure of 27.8 x 16 mm.

Tunable SIW filter using RF MEMS with a return loss better than 20 dB is proposed by [9]. The overall size is just around 70 x 40 mm. However, the tunable insertion loss response is quite poor, which is in the range from 4 dB to 6 dB.

A selective frequency-tunable antenna is capable of varying between a wide-band of 2.63 GHz - 3.7 GHz with four different sub-bands, which allows adjusting the bandwidth range to select a suitable sub-band. However, the measured bandwidth for the second sub-band has been observed to be 50% larger than the actual simulated results [10].

A tunable antenna by using two PIN diodes with a return loss greater than 10 dB is proposed by [11]. The antenna is able to operate in six different bands that suitable use for GSM, UMTS and LTE bands. The overall size of the antenna is just around 36.5 x 10 mm. However, the response of the return loss of the first operating mode of the antenna is quite poor were around 10 dB with low impedance matching.

In this paper, a novel structure is proposed to design a reconfigurable SIW filter and reconfigurable antenna with the tunable capability of varactor diode that operates from 1.9 GHz to 2.1 GHz through electromagnetic (EM) simulation. The reconfigurable filter, which uses two floating patch diode-loaded SIW cavity, has a simple structure to locate the varactor diode on the SIW filter while the reconfigurable antenna, which uses a slotted structure for the tunable element, has a simple structure to locate the varactor diodes on the antenna design. The tuning of the center frequency is obtained by varying the varactor diode with DC input source. The analysis focuses on EM simulation, frequency response based on return loss, insertion loss, and bandwidth.

II. Resonant circuit theory of filter

In this section, a low pass equivalent circuit is used to produce a filter equivalent circuit as shown in Figure 1 (a). The impedance inverter represents as K_{01} and K_{02} are used for the input and output coupling of the filter with varactor diode. The element value of the capacitance, C'_n and inductance, L'_n can be determined from the equation in [12] for the equivalent circuit of n^{th} order of the filter as follows:

$$L'_n = \frac{1}{\alpha C_n \omega_0} \quad (1)$$

$$C'_n = \frac{\alpha C_n}{\omega_0} \quad (2)$$

where ω_0 is the angular resonant frequency and α is bandwidth scaling factor respectively.

The equivalent circuit of filter with varactor diode was designed at operate frequency of 2.1 GHz to obtain the coupling values of impedance inverter, $K_{01} = K_{12} = 50$ with LC resonators of capacitance, C'_1 = 60.63 pF and inductance, L'_1 = 89.00 pH. The varactor diode tunable range is from 0.1V – 6.0V based on input DC power supply. Figure 1 (b) and Figure 1 (c) shows the simulated result for lumped elements of antenna by increasing the reverse DC bias voltages from 0.1V – 6.0V, the frequency of the first response is increased from 1.485 GHz to 2.102 GHz. However, the return loss value is exhibits a saturation level of reverse voltage beyond 5.5 V.

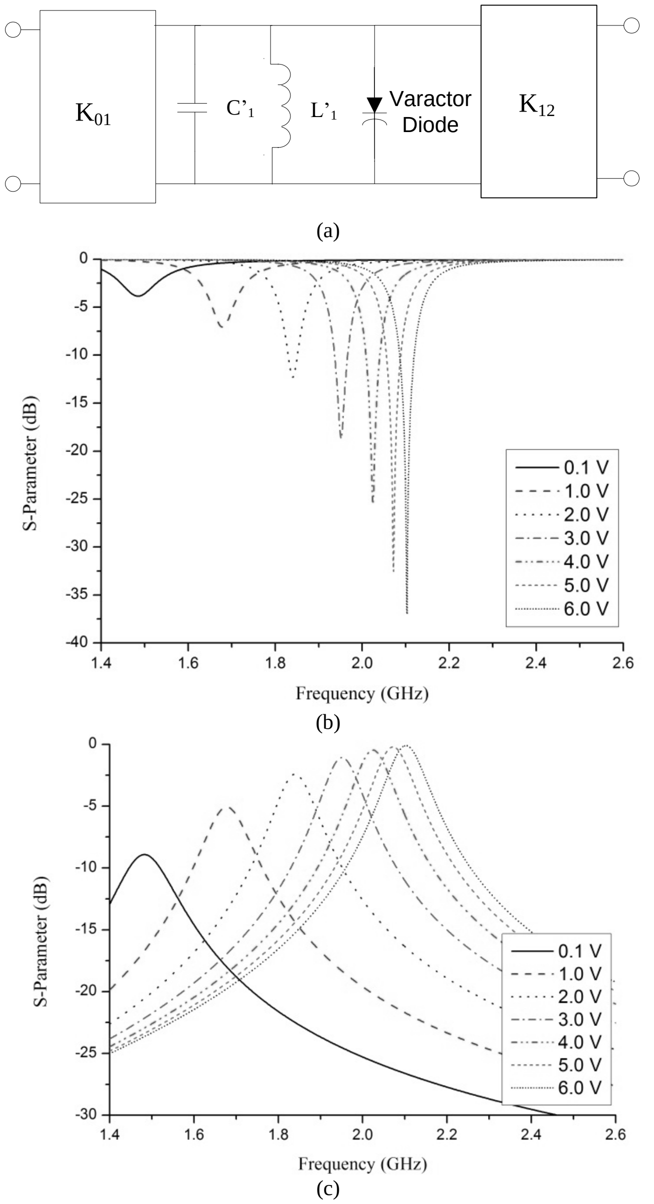

Figure 1: (a) Equivalent circuit of filter with varactor diode (b) Simulated response of reconfigurable bandpass filter for return loss (c) Simulated response of reconfigurable bandpass filter for insertion loss

III. SIW FILTER DESIGN

The physical structure of the SIW filter is designed and simulated using CST Microwave Studio software. The SIW filter is designed to operate on a 1.6-mm-thick FR-4 substrate with dielectric constant of 4.6 and the loss tangent of 0.019. The geometry of the SIW filter was determined using equations in [12]-[13]. Figure 2 shows the physical layout of the reconfigurable SIW filter.

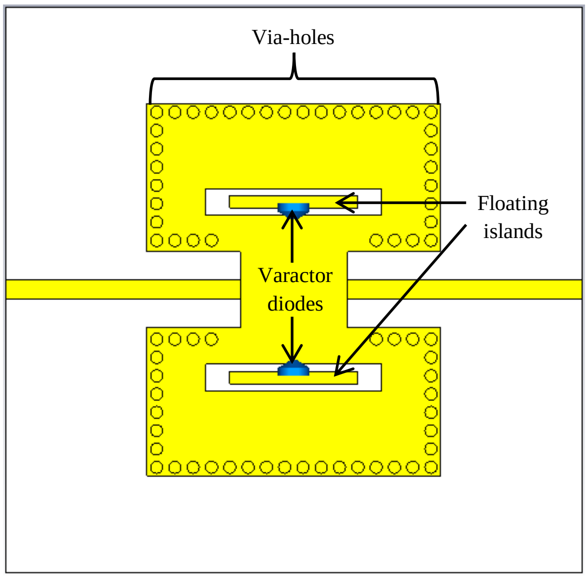

Figure 2: Physical layout of reconfigurable SIW filter

The bias line is important elements in any active component of the microstrip circuit to supply specific input voltage and current. In this design, this filter uses two varactor diodes (NXP BB202) as the tuning elements are implemented to tune the filter. The varactor diode is placed connected with the floating patch island and via hole.

The main function of the floating patch islands on the SIW slot is to interrupt the current flow of the filter. The gap of the slot gives the major effects of the return loss across the resonant frequency. However, choosing a precise position of the floating patch islands with varactor diodes is a crucial decision to make in order to maintain the overall performance of the filter.

The simulated results of return loss and insertion loss at varying reverse DC voltage are shown in Figure 3 and Figure 4. As seen from Figure 3 and Figure 4, the simulated return loss and insertion loss value of the SIW filter is better than 14 dB and 1.9 dB respectively. The simulated resonant frequency can be varied from range of 1.947 GHz to 2.097 GHz which about 8.77 % from reverse DC voltages from 0.1V – 6.0V. The tuning range of bandwidth is from 183.60 MHz to 163.39 MHz which is about 11.04 %. The values of the return loss are increasing as the frequency increase to toward higher from 14.8 dB to 18.0 dB while for an insertion loss is decreasing from 1.55 dB to 1.87 dB respectively. The electromagnetic fields study show that the distribution of E-fields with single circular focuses on the middle of the SIW filter structure at 2.097 GHz is shown in Figure 5.

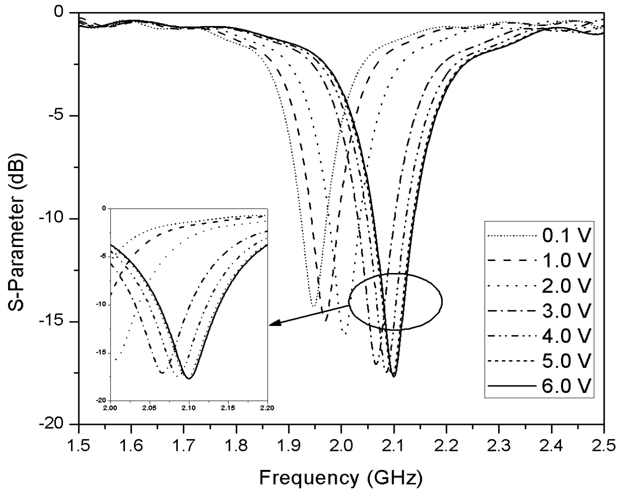

Figure 3: Simulated return loss of the reconfigurable SIW for different reverse voltage

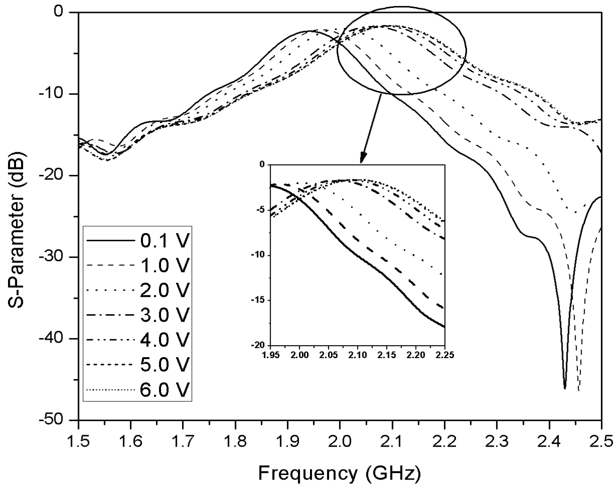

Figure 4: Simulated insertion loss of the reconfigurable SIW for different reverse voltage

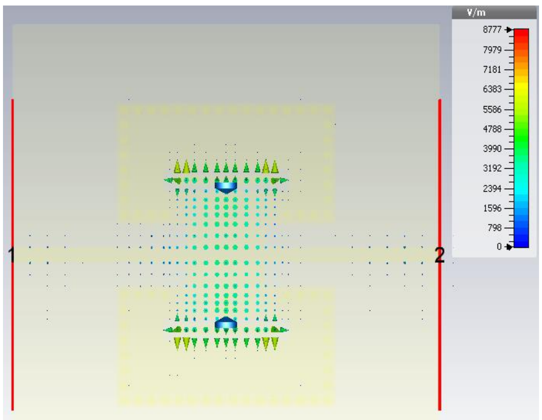

Figure 5: E-field distribution for reconfigurable SIW filter at 2.097 GHz

IV. MICROSTRIP PATCH ANTENNA

The bias line is important elements in any active microstrip circuit to supply specific input voltage shown in Figure 6 which can be designed by referring the equation from [14]. In this design, this antenna uses two varactor diodes that similar with SIW filter as the tuning element is implemented to tune the antenna operating frequency while the dc bias line is introduced into the design acts as RF choke to block RF signal to the via hole. Two varactor diodes are placed in line with the slot of the antenna and there is no any feeding cable is needed in this design. In actual measurement, Bias-Tee will be used to inject the dc source and RF signal to the microstrip patch antenna.

The main purpose of the slot is to interrupt the current flow of the radiating patch antenna. The gap of the slot gives major influences of the return loss across the operating frequency. However, choosing a precise position of the slot with varactor diodes is an important decision to make in order to maintain the peak performance of the reconfigurable microstrip patch antenna.

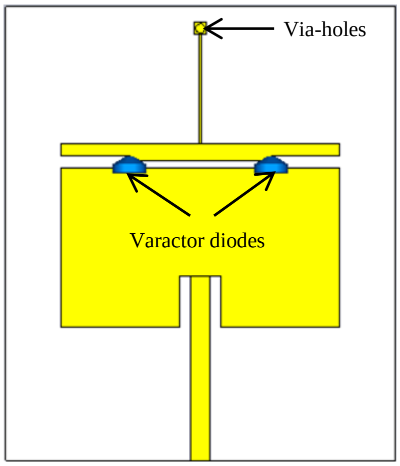

Figure 6: Physical layout of microstrip patch antenna

The simulated results of return loss at varying reverse DC voltage are shown in Figure 7. As seen from Figure 7, the simulated return loss value of the patch antenna is better than 20 dB. The simulated resonant frequency can be tuned from 1.915 GHz – 2.102 GHz (8.90 %) from reverse DC voltages from 0.1V – 6.0V and for the bandwidth is from 35.85 MHz to 40.28 MHz (11 %). For the simulated gain, the results show the increament of the gain from 2.033 dB to 3.697 dB for varying DC reverse voltage from 0.1 V to 6.0 V. Figure 8 shows the 3-D view of the radiation pattern through the simulation at voltage of 6.0 V.

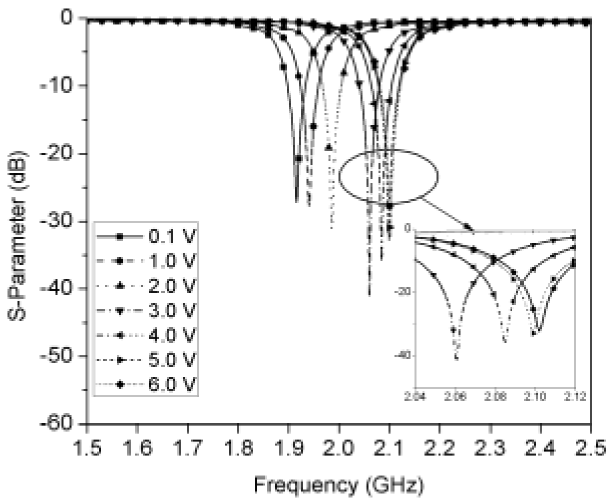

Figure 7: Simulated return loss of the reconfigurable microstrip patch antenna for different reverse voltage

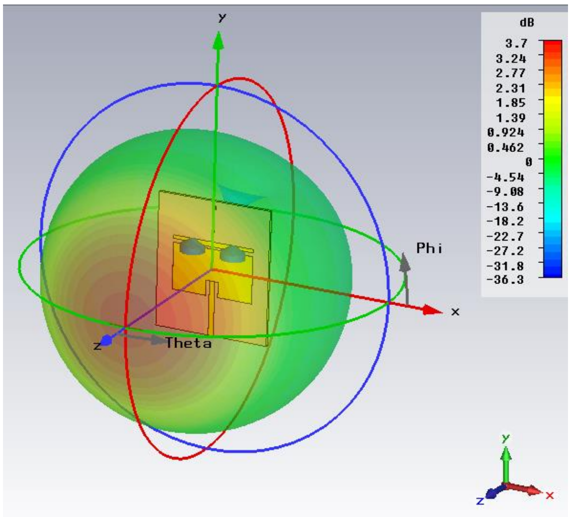

Figure 8: 3-D view of the radiation pattern through the simulation at 6.0 V

Further investigation will be carried out in future works in order to investigate the overall performance through the experimental works of the reconfigurable SIW filter and reconfigurable antenna. Furthermore, an integration technique will be introduced the reconfigurable SIW filter and reconfigurable antenna into single element through cascaded and multilayer approach. Therefore, this integration on both filter and antenna is expected to produce a good performance and as well as to provide an alternative solution for any wireless communication systems

V. CONCLUSION

The simulated of varactor diodes representation using CST Studio Suite software has been proposed. The varactor diodes on the reconfigurable SIW filter and antenna provide a good tuning frequency range over 200 MHz by maintaining the return loss value better than 10 dB for SIW filter and 20 dB for antenna respectively. This design is useful for RF/microwave front-end subsystems, especially in 4G technology.

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