Varactor-loaded SIW cavity backed antennas for modern wireless communication systems

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Abstract—**A novel compact, low profile frequency reconfigurable antennas, loaded by varactors and based on substrate integrated waveguide (SIW) structure, are proposed. Due to the loaded varactors, the operating frequency of the antenna can be tuned in a wide frequency range by changing electric bias. Two samples of frequency reconfigurable SIW cavity backed antennas are presented. They are designed, fabricated and measured. The antenna radiating from a circular slot is designed for low frequency band (2.28 GHz). The antenna radiating from a rectangular slot is designed to radiate at higher frequencies (11 GHz). The experimental results demonstrate the frequency tunability of the antennas. The radiation pattern and gain characterize the antennas good radiation performance, which is suitable for modern wireless communication systems.**

Keywords—component, formatting, style, styling, insert *(key words)*

I. Introduction

Wireless communications have evolved rapidly in recent years to become an indispensable part of our daily life. At the same time, the rapid growth of the market has led to an increase in the number of standards allocated to systems and terminals operating in different frequency bands. In particular, the use of reconfigurable antennas operating in several frequency standards can drastically reduce the size, the power consumption and the cost of novel communication systems [1]. Frequency agility can be achieved by integrating into the antenna structure one or more agile device such as PIN diodes, varactor diodes, RF MEMS devices [2-4] or agile materials such as ferromagnetic, liquid crystal and ferroelectric, etc. [5-7].These elements can directly modify the topology, the structure, the environment of the radiating element, and thus induce a specific operation of the antenna for each given state of the agile device. Recently, substrate integrated waveguide (SIW) cavity backed slot antennas with frequency tunability have been widely inmvestigated since they feature low loss, high quality factor, good power handling capability, and can be easily integrated with planar circuits [7].

In this letter, two compact, tunable SIW cavity backed slot antennas are presented. Both designs have been carried by the CST simulator, then, two prototypes have been fabricated and experimentally tested. The agility of the operating frequency has been obtained by properly applying a DC bias voltage on the varactor diodes loaded on the radiating slot of the cavity. Measurement and simulation of the frequency shifts were carried out and good agreement has been obtained.

II. Antennas configuration

Fig. 1 show the two proposed broadband frequency tunable antenna structures. Both antennas consist of a rectangular SIW cavity formed by metal via arrays. The cavity operates in the transverse electric fundamental mode TE101. The relation between the operating frequency and the length and width of the cavity are revealed by relations (1), (2) and (3) given in [8].

$$f_{mnp} = \frac{1}{2\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m}{L_{eff}}\right)^2 + \left(\frac{n}{W_{eff}}\right)^2 + \left(\frac{p}{h}\right)^2}, \quad (1)$$

$$L_{eff} = L_c - \frac{1.08 s^2}{d} + \frac{0.1 s^2}{L_c}, \quad (2)$$

$$W_{eff} = W_c - \frac{1.08 s^2}{d} + \frac{0.1 s^2}{W_c}. \quad (3)$$

Besides, the dimensions of the SIW via walls defined by the diameters d of the vias and the spacing between each consecutive vias s are optimized from the relations (4) and (5)

$$d < \lambda_g / 5 \quad (4)$$

$$s \le 2d \quad (5)$$

The first antenna operating at low frequency consists of an SIW cavity radiating through a narrow circular radiating slot graved on the ground plane of the structure. The circular aperture is loaded by two SMV1430-040LF varactors. To isolate the DC voltage from the RF signal, a current limiting 20 kΩ resistor and a RF inductance of type CC45T47K240G5 with a value of 0.84 μH are used. The second proposed structure operating at higher frequency is also composed by a SIW cavity radiating from a rectangular slot placed on the ground plane as shown in [9]. In this structure, three varactors of the same type as employed in the first structure are used. The DC voltage is connected via CC110T47K240G5 inductor and a 20 kΩ resistor.

The equivalent model of the diode is shown in Fig. 4. The final geometric parameters of the fabricated antennas are summarized in Table 1 and Table 2.

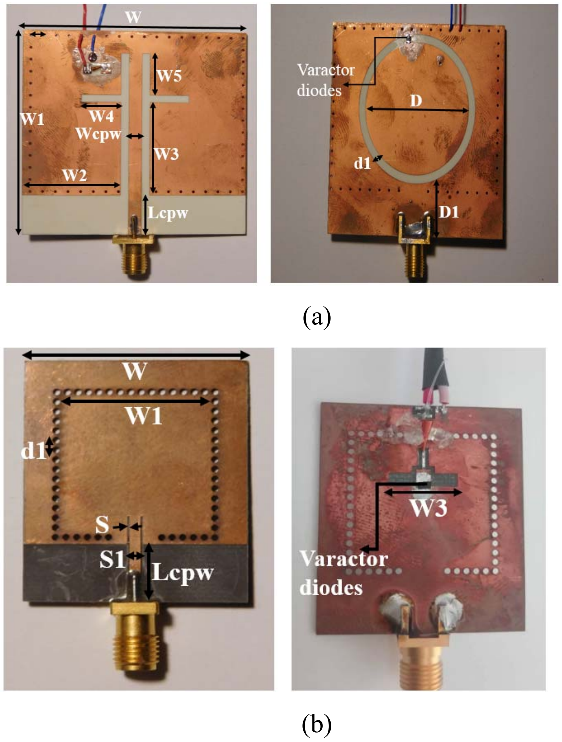


Fig. 1. Photographs of the fabricated SIW cavity antennas, (a) Top and bottom layout of first fabricated SIW cavity antenna backed by circular slot. (b) Top and bottom layout of second fabricated SIW cavity antenna backed by rectangular slot presented in [9].

Table I: Dimensions parameters of the designed antenna shown in Fig. 1*a*

Parameters	*W*	*W*$_1$	*W*$_2$	*W*$_3$	*W*$_4$	W$_5$
Value (mm)	53.9	41.4	23.5	23.4	9.4	10.5
Parameters	*W*cpw	*d*	*L*cpw	*D*	*d*$_1$	*D*$_1$
Value (mm)	3.1	2.4	10	16	2	13.2

Table II: Dimensions parameters of the designed antenna shown in Fig. 1*b*

Parameters	*W*	*W*$_1$	*W*$_3$	*W*$_4$	*W*$_5$
Value (mm)	29.6	21.6	6	3	5
Parameters	*S*	*S*$_1$	*L*cpw	*D*	*d*$_1$
Value (mm)	0.2	1.56	8.2	1	1.4

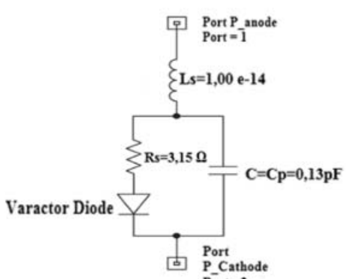


Fig. 2 Equivalent model of the SMV1430-040LF varactor diode

III. Experimental Validation

The photographs of the fabricated antenna prototypes are shown in Fig. 1. The performance of the two SIW cavity backed antennas obtained for different DC control voltage obtained by CST software are compared to measured results. The first antenna achieves a tuning range of 1.8 - 2.18 GHz within the DC bias voltage 0 - 26 V (0.31 - 1.29 pF) as presented in Fig. 3a. The resonant frequency of the second antenna varies from 8.95 to 9.85 GHz when the capacitance C of the diodes is changed by adjusting the DC bias voltage from 0 to 30 as shown in Fig. 3b. It can be noted that a wider tuning range is observed when the antenna is operating at a higher frequency. Measured and simulated results of the first antenna operating at low frequency have shown a good agreement. However, the second antenna shows that the level of the measured matching is higher than the simulation and a discrepancy is observed. Numerous factors can explain this, such as the manufacturing errors, the dielectric constant and the tolerances on the substrate thickness, the errors in the connector and the localized component soldering and the losses of the SMA port that are not considered in the simulation and finally the high power consumption of the diodes working in the millimetre band. Measured radiation patterns of the two fabricated antennas at different bias voltages are presented in Fig. 4. It is noted that the behavior of both antennas radiation patterns in E-plane is quasi unidirectional in all discussed cases.

The measured maximum gain versus the bias voltage of the two fabricated antennas are plotted in Fig. 5. It can be seen from the results of the first antenna operating at low frequency shown in Fig. 5a that, the radiation gain is lowered with the decreased bias voltage when the varactor capacitance is increased. From the result of the second structure presented in Fig. 5b, it can be noted that stable gain across the operating frequencies with a variation less than 1 dB is obtained.

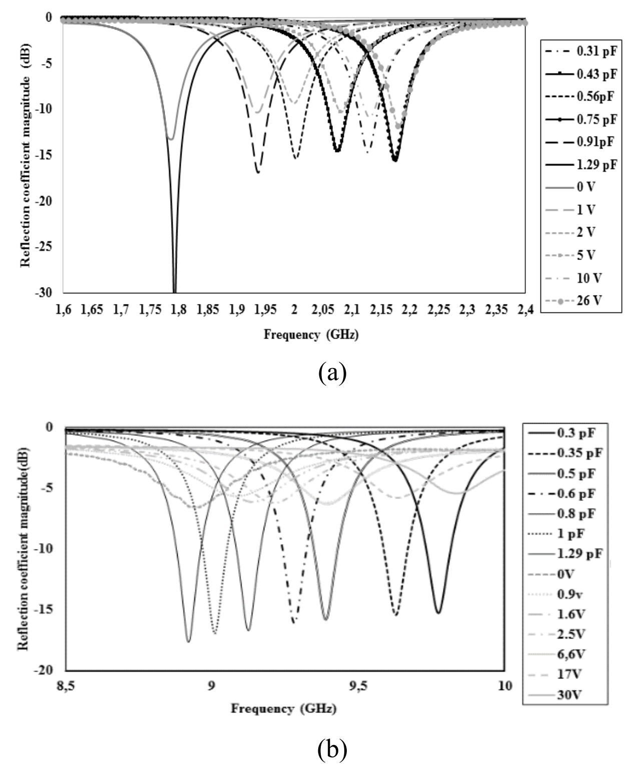
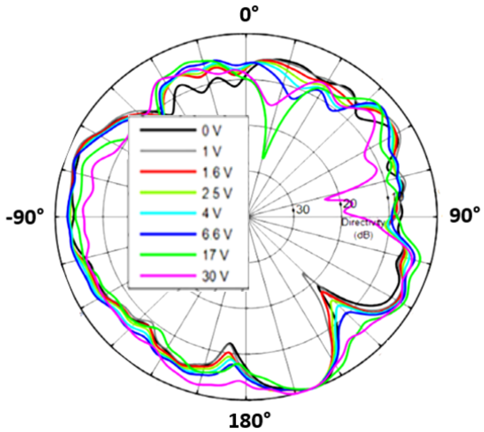
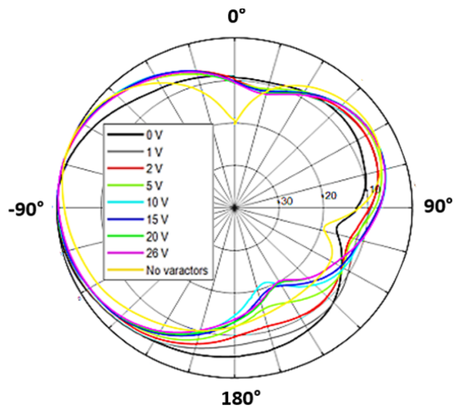


Fig. 3 Measured and simulated return loss (a) Results of the fabricated SIW cavity antenna backed by circular slot, (b) Results of the fabricated SIW cavity antenna backed by rectangular slot

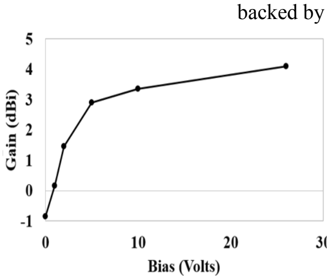


(a)

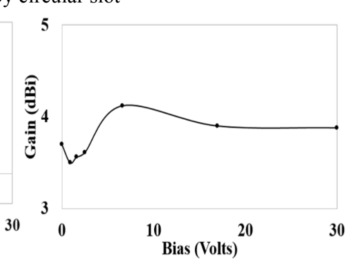


(b)

Fig. 4 Measured E- plan radiation patterns of the proposed antenna with varying the bias voltage. (a) Results of the fabricated SIW cavity antenna backed by rectangular slot, (b) Results of the fabricated SIW cavity antenna backed by circular slot



a



b

Fig. 5 Measured gain over bias voltages, (a) Results of the fabricated SIW cavity antenna backed by circular slot, (b) Results of the fabricated SIW cavity antenna backed by rectangular slot.

IV. Conclusion

Two low-profile reconfigurable SIW cavity backed antennas with frequency diversity are presented. From experimental results, a wide range of frequency diversity is obtained when a DC voltage is applied to the varactors. Stable quasi omnidirectional radiation patterns across the band of interest are attained, which shows that the proposed antenna design is suitable for application in current wireless communication systems.

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