Progress In Electromagnetics Research Letters, Vol. 39, 9–16, 2013

A COMPACT FREQUENCY RECONFIGURABLE UNEQUAL U-SLOT ANTENNA WITH A WIDE TUNABILITY RANGE

Zhen Ren*, Wentao Li, Le Xu, and Xiaowei Shi

School of Electronic Engineering, Xidian University, Xi'an 710071, China

Abstract—A new frequency reconfigurable unequal U-slot antenna is presented in this paper. The U-slot antenna loaded with two lumped variable varactors is capable of 6 different frequencies switching between 2.3 GHz and 3.6 GHz. The small slots in the ground plane are employed for the biasing circuit to minimize the parasitic effects towards the performance of the antenna. It is found that the unequal U-slot fed by an L-shaped feed line can reduce 30% of the size of the conventional U-slot antenna. Moreover, the proposed antenna offers stable radiation characteristics for each operating frequency in the tunable range. The antenna offers a gain of 4.5 dB in average. The designs are verified through both numerical simulations and measurements of an experimental prototype. Details of the antenna designs and measured results are presented and discussed.

1. INTRODUCTION

With the rapid development of electronics and wireless communication, reconfigurable antennas have attracted a lot of attention. Antenna reconfiguration is defined as the capability of modifying one or more antenna parameters without perturbing the other properties of the radiator. Superior characteristics such as reconfigurable capability, low cost, multipurpose functions, and size miniaturization have given reconfigurable antennas advantage to be integrated into the wireless systems [1].

Generally, antenna properties such as frequency, radiation pattern, and polarization are reconfigured. During the last two decades, clever

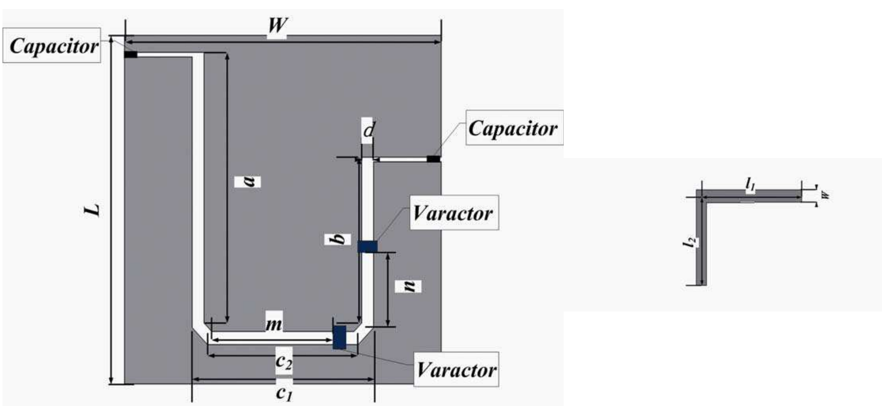
Received 25 February 2013, Accepted 29 March 2013, Scheduled 30 March 2013
* Corresponding author: Zhen Ren (13488472021@163.com).

solutions have been developed for one-parameter reconfiguration. Frequency agility is typically provided by scaling the antenna dimensions physically or electrically. In order to design a frequency reconfigurable device, five main methods can be used: mechanical change of the physical dimensions, integration of microwave diodes, integration of micro-electro-mechanical systems (MEMS) switches, change of the substrate permittivity and integration of voltage controlled membranes [2]. In [3–5], new techniques for designing frequency reconfigurable slot antennas are presented. In [6], MEMS switch is used for its low power dissipation and insertion loss. In [7], two PIN diode switches are placed on the connecting lines of a simple feed network to the patch elements. However, these methods require the complex biasing circuits which are not an easy task in practice. Majid et al. use five PIN diodes to switch frequency at six different bands [8]. In [9], it presents a reconfigurable antenna by using five PIN diodes whose biasing network is software-controlled via a PIC microcontroller connected to a laptop. Nevertheless, most current widely tunable antennas require many diodes, leading to an increased complexity of the structure and low switching efficiency. A U-slot is used on the patch with a dimension ($W \times L$) of 77 mm × 57 mm and the antenna attains a tunable frequency range from 2.6 GHz to 3.35 GHz [10]. In [11–14], it is proved that loading varactor diodes to resonant antennas to demonstrate frequency agility has been widely employed. A 3 GHz folded slot antenna with varactors is reported in [11] with a miniaturization of 30% and a tunability of 5%. In [12], a varactor diode is used in a PIFA antenna for tuning the operating frequency. It is proposed that a dual-band slot antenna uses a single varactor to achieve tunability in only its second band of operation and has a fixed first band [13]. In [14], the resonant frequency of a coplanar patch antenna is tuned using a varactor component, which is placed over the radiating slot.

In this paper, a compact frequency reconfigurable unequal U-slot antenna is achieved by changing the bias voltages of the two varactors. The two varactors are located across the unequal U-slot, which can switch six different frequencies between 2.3 GHz and 3.6 GHz. The biasing circuits are integrated into the ground plane. With this approach, it is easier to fabricate as there no vias are required. Furthermore, the unequal U-slot and the L-shaped feed line can reduce 30% of the size of the original antenna. To maximize the tunability range of the antenna's frequency ratio, the unequal U-slot is used on the patch. Besides, the modified corners of the U-slot are used to reduce the loss and increase the gain of the proposed antenna.

2. ANTENNA GEOMETRY AND DESIGN

The geometry of the proposed U-slot frequency reconfigurable antenna is shown in Figure 1. The antenna consists of a rectangular patch with a U-slot, two varactors across the slot and an L-shaped fed line. The antenna is fabricated on a Taconic TLT substrate with a thickness of 1 mm and a relative permittivity of 2.55. The patch has a dimension $(W \times L)$ of 40 mm × 40 mm. The L-shaped coupling feed line strip has a width of $w = 2$ mm and the total length $l = 33$ mm where the length of $l_1 = 19$ mm and $l_2 = 14$ mm. The length of one side of the unequal U-slot is $a = 31$ mm, and the length of the other side is $b = 19$ mm. The length of the bottom U-slot is $c_1 = 23$ mm and $c_2 = 19$ mm. The width of the U-slot is $d = 1.5$ mm. The longer side of the slot is perpendicular to the L-shaped fed line. Small slots with a width of 0.5 mm are introduced for the biasing circuit. The two varactors are equal to two lumped variable capacitors across the U-slot. With the aid of the Ansoft HFSS simulation software, the optimum locations of the varactor diodes are inserted on the shorter side of the slot and the bottom of the slot, where the length are $m = 15$ mm and $n = 8.5$ mm. The type of the varactors we use is SMV 1232-79FL from SKYWORKS. The fabricated antenna is shown in Figure 2.



(a) (b)

Figure 1. Geometry of the proposed antenna. (a) Front view, (b) back view.

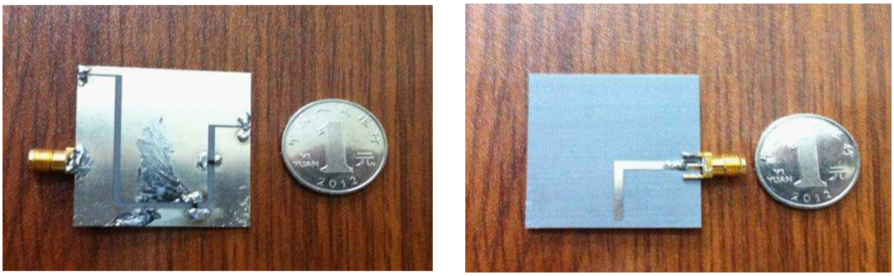


Figure 2. Prototypes of the fabricated antenna.

3. RESULT AND DISCUSSION

The unequal U-slot antenna is considered as a transmission line in this paper. And the varactor diodes across the slot are used as variable capacitors. In order to change the effective electrical length of the transmission line, the two capacitors vary from 0.73 pF to 4.15 pF with the variation of the voltage in the range of 0 V $\sim$ 14 V. Thus, the resonant frequency reconfiguration of the proposed antenna can switch between 2.3 GHz and 3.6 GHz.

The frequency response of the proposed antenna has been evaluated by using Ansoft HFSS simulation software for all the six configurations. Next, in order to verify the reliability of our design, a prototype of the proposed antenna has been fabricated. The simulated and the measured reflection coefficients (S_{11}) at all the frequencies are shown in Figure 3. The simulated and measured S_{11} are less than

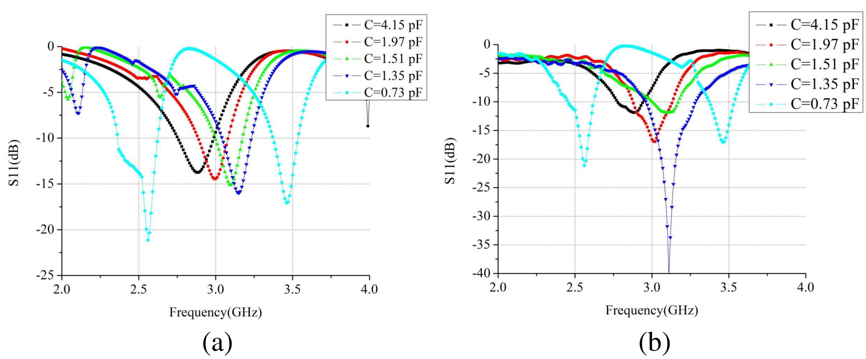


Figure 3. Reflection coefficients (S_{11}) of the proposed antenna for different capacitance value of varactors. (a) Simulated results, (b) measured results.

−10 dB at all the frequencies of interest. From Figure 3, it can be clearly seen that the resonant frequency can be tuned continuously and that 6 different operating frequencies between 2.3 GHz and 3.6 GHz can be switched by changing the voltage across the two varactors. The simulated bandwidths are 220 MHz, 190 MHz, 170 MHz and 180 MHz, as the capacitance values of the two lumped capacitors are 4.15 pF, 1.97 pF, 1.51 pF and 1.35 pF, respectively. Besides, a dual-band is obtained with the respective bandwidths of 250 MHz and 150 MHz when the capacitance values of the two lumped capacitors are both 0.73 pF. For comparison, the measured bandwidths are shown in Figure 3(b). It is proved that, with the varactors reducing, the effective electrical length of the transmission line can be changed, so the resonant frequency can be increased. Even though the parasitic effects

Table 1. The variation of the varactors and the voltage for different frequencies.

Voltage (V)	Capacitance (pF)	Simulated Frequency (GHz)	Measured Frequency (GHz)
0	4.15	$2.76 \sim 2.98$	$2.78 \sim 2.93$
4	1.97	$2.89 \sim 3.08$	$2.88 \sim 3.13$
6	1.51	$3.00 \sim 3.17$	$3.00 \sim 3.17$
9	1.35	$3.05 \sim 3.23$	$2.97 \sim 3.28$
14	0.73	$2.37 \sim 2.62$	$2.46 \sim 2.62$
		$3.38 \sim 3.53$	$3.38 \sim 3.53$

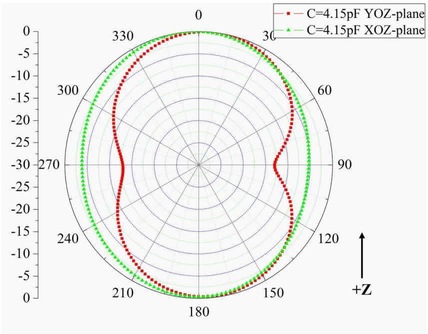


Figure 4. The *E*- and *H*-plane radiation pattern at 2.88 GHz.

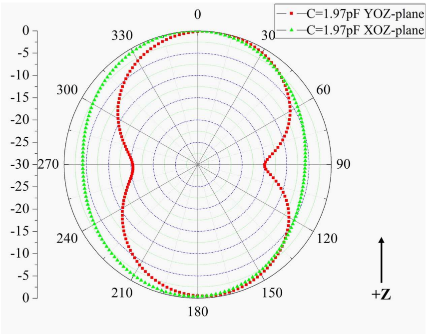


Figure 5. The *E*- and *H*-plane radiation pattern at 3 GHz.

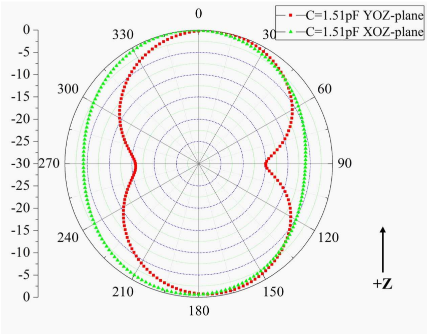


Figure 6. The *E*- and *H*-plane radiation pattern at 3.1 GHz.

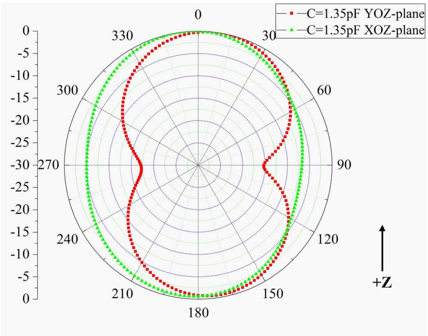


Figure 7. The *E*- and *H*-plane radiation pattern at 3.15 GHz.

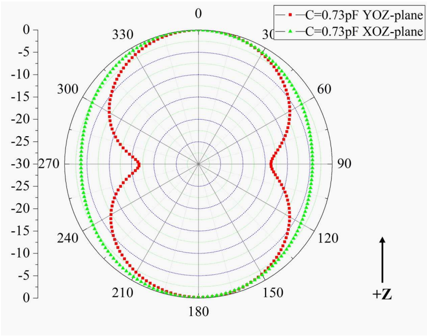


Figure 8. The *E*- and *H*-plane radiation pattern at 2.56 GHz.

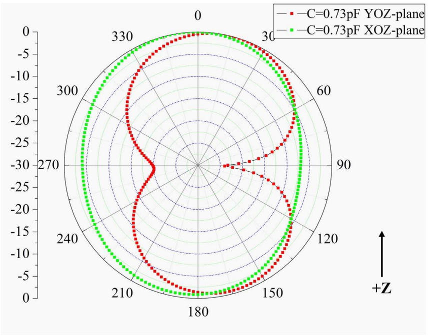


Figure 9. The *E*- and *H*-plane radiation pattern at 3.46 GHz.

of the varactor diodes slightly affect the performance of the antenna, the measured results are in good agreement with the simulated results at all of the frequencies of interest. The variation of the varactors and the voltage are listed in Table 1.

The *E*- and *H*-plane radiation patterns simulated at the center frequencies of the respective bands are shown in Figures 4–9. At all frequency bands of interest, the radiation patterns are bidirectional in pattern. The antenna exhibits similar radiation characteristics in the desired bands. The antenna offers a gain of 4.14 dB in band 1 (2.88 GHz), 4.55 dB in band 2 (3 GHz), 4.39 dB in band 3 (3.1 GHz), 5.00 dB in band 4 (3.15 GHz), 3.65 dB in band 5 (2.56 GHz) and 4.60 dB in band 6 (3.46 GHz). The results confirm the good performance of the proposed reconfigurable antenna designs.

4. CONCLUSION

A compact frequency reconfigurable unequal U-slot antenna with a wide tunability range is presented in this article. It has been proven that the frequency reconfigurable characteristic can be achieved by changing the bias voltages of the varactor. The design of the unequal U-slot antenna fed by the L-shaped strip can reduce 30% of the size of the original antenna. Moreover, it is achieved that the bias can be easily integrated with the fabrication. The good simulated and measured reflection coefficients for 6 different frequencies have been obtained. Besides, the radiation patterns show the antenna offers stable radiation characteristics for each operating frequency in the tunable range.

ACKNOWLEDGMENT

The authors would like to thank the financial support from the National Natural Science Foundation of China (No. 61101069) and the Fundamental Research Funds for the Central Universities (No. K5051302022).

REFERENCES

1. Yang, S., C. Zhang, H. Pan, et al., "Frequency-reconfigurable antennas for multiradio wireless platforms," *IEEE Microwave Magazine*, Vol. 10, No. 1, 66–83, 2009.
2. Petosa, A., "Frequency agile antennas for wireless communications — A survey," *2010 14th International Symposium on IEEE Antenna Technology and Applied Electromagnetics & the American Electromagnetics Conference (ANTEM-AMEREM)*, 1–4, 2010.
3. Alkanhal, M. A. and A. F. Sheta, "A novel dual-band reconfigurable square-ring microstrip antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 54, 409–416, 2006.
4. Li, H., J. Xiong, Y. Yu, et al., "A simple compact reconfigurable slot antenna with a very wide tuning range," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 11, 3725–3728, 2010.
5. Mak, A. C. K., C. R. Rowell, R. D. Murch, et al., "Reconfigurable multiband antenna designs for wireless communication devices," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 7, 1919–1928, 2007.
6. Daly, M. P. and J. T. Bernhard, "RF MEMS switch model for

reconfigurable antenna design," *IEEE Antennas and Propagation Society International Symposium, 2008, AP-S 2008*, 1–4, 2008.

7. Abutarboush, H. F., R. Nilavalan, S. W. Cheung, et al., "A reconfigurable wideband and multiband antenna using dual-patch elements for compact wireless devices," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 1, 36–43, 2012.
8. Majid, H. A., M. K. A. Rahim, M. R. Hamid, et al., "A compact frequency-reconfigurable narrowband microstrip slot antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 616–619, 2012.
9. Genovesi, S., A. Monorchio, M. B. Borgese, et al., "Frequency-reconfigurable microstrip antenna with biasing network driven by a PIC microcontroller," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 156–159, 2012.
10. Yang, S. L. S., A. A. Kishk, and K. F. Lee, "Frequency reconfigurable U-slot microstrip patch antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 127–129, 2008.
11. Scardelletti, M. C., G. E. Ponchak, J. L. Jordan, et al., "Tunable reduced size planar folded slot antenna utilizing varactor diodes," *IEEE Radio and Wireless Symposium (RWS)*, 547–550, 2010.
12. Oh, S., Y. Shin, and S. Park, "A novel PIFA type varactor tunable antenna with U-shaped slot," *7th International Symposium on IEEE Antennas, Propagation & EM Theory, 2006, ISAPE'06*, 1–3, 2006.
13. Behdad, N. and K. Sarabandi, "A varactor-tuned dual-band slot antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 54, No. 2, 401–408, 2006.
14. Holland, B. R., R. Ramadoss, S. Pandey, et al., "Tunable coplanar patch antenna using varactor," *Electronics Letters*, Vol. 42, No. 6, 319–321, 2006.