A Tunable Monopole Antenna Using Double U-Shaped Defected Ground Structure with Islands

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Abstract — In this paper, a novel tunable microstrip monopole antenna using defected ground structure has been presented. The configurability of the antenna is implemented by a tunable matching network comprising double U-shaped defected ground structure with islands. The frequency agility is thus easily realized by capacitive loading onto the islands. Simulation and measurement results of a prototype monopole antenna verify the frequency tuning from 2.7 GHz to 2.1 GHz at voltage variation of 29 V to 5 V. Instantaneous bandwidth of this prototype is measured from 65 MHz to 15 MHz. Good matching of more than 21 dB as well as monopole like antenna pattern has been achieved over tunable frequency range of 623 MHz.

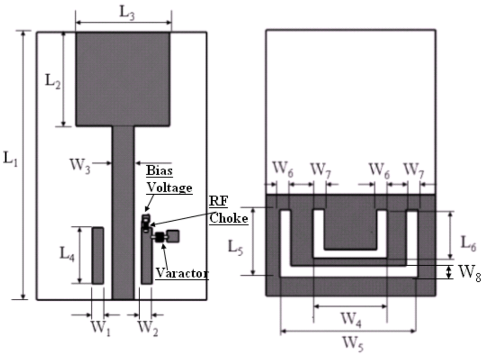
I. INTRODUCTION

The design of reconfigurable antennas is important for mobile communication and its frequency tuning not only allows multi-band communication reconfiguration but also offers immunity of interference jamming, multi-path fading for example [1]. The instantaneous bandwidth of tunable antennas is limited as they become small. Such narrow bandwidth is advantageous for frequency selectivity component like RF front-end filters. The reconfigurable antenna is commonly implemented by techniques of capacitive loading, matching networking and so forth [2-4]. Latest tunable antennas include either capacitive loading or reconfigurable matching networks. For example, capacitive loading was easily shrunk into annular slot antenna yielding frequency tuning from 2 GHz to 1.76 GHz [5]. In [6], a tunable antenna comprising two antennas with narrow bandwidth was used for 1.9 GHz PCS transceiver. Using PIN diodes, each antenna can be selected for either reception or transmission. Application of Electromagnetic Band Gap (EBG) to antenna research has attracted immense research interest in the past few years [7-10]. A notable class of EBG structures named Defected Ground Structure (DGS) is recently introduced and it has a controllable finite transmission zero characteristic [11]. It was reported that an H-shaped DGS was used to suppress higher order harmonics of a microstrip patch antenna by more than 20 dB and; a circular DGS reduced the cross-polarized (XP) radiation of a microstrip patch antenna by 8 dB [12,13]. As to the best of our knowledge, the usage of DGS in antenna tuning has not yet been addressed. To this end, we propose yet another technique that a matching feedline etched with double U-shaped DGS with islands is employed to implement the frequency agility of a microstrip-fed monopole antenna. A prototype microstrip monopole antenna tunable from 2.7 GHz to 2.1 GHz is presented and experimentally characterized.

II. MONOPOLE ANTENNA WITH DGSI

The proposed antenna is the microstrip feedline monopole antenna printed on a grounded substrate with a Defect Ground Structure with Island (DGSI). Its structure is shown in Fig. 1. The antenna uses a square patch, a basic monopole antenna is thus easily designed. Two islands are placed in parallel to the microstrip feedline. Under the microstrip feedline, a U-shaped DGS is etched on a finite ground plane. Like our previous works [14, 15], this U-shaped DGS is indeed similar to some slow-wave elements [16, 17]. The above monopole has been fabricated on a Rogers RO4003 substrate with dielectric constant of 3.38 and a thickness of 1.524 mm. As shown in Fig. 1, each U-shaped pattern consists of three etched lines with different widths (W_6, W_7 and W_8). Using different lengths of these U-shaped patterns (L_5 and L_6, where $L_5 > L_6$), these two DGS patterns can be embedded with the open-end alignment. To offer the later tunable ability to the antenna, the varactor loading is used to terminate at the end of one island. For a basic microstrip monopole operated at 3.3 GHz, the optimized dimensions are listed in Table 1.

Different from the previous work of DGSI [18], the effect of DGSI onto the proposed monopole antenna is studied by full-wave electromagnetic solver - *IE3D* [19]. A DGSI unit is applied to the feedline of the above monopole antenna. The return loss simulation result is plotted in Fig. 2. It clearly records the antenna has finite matching frequency at 3.3 GHz with 9.3% 10-dB bandwidth. In addition, the radiation patterns of the proposed antenna are simulated and the monopole like patterns is observed in Fig. 3.



(a) (b)

Fig. 1 Proposed monopole antenna with double U-shaped DGSI (a) Top view and (b) Bottom view.

Top		Bottom	
L_1	88	L_5	20
L_2	30	L_6	14
L_3	30	W_4	14
L_4	22	W_5	24
W_1	4	W_6	2
W_2	4	W_7	2
W_3	4	W_8	2
S	0.5		

Table 1 The dimensions of the proposed antenna (in mm).

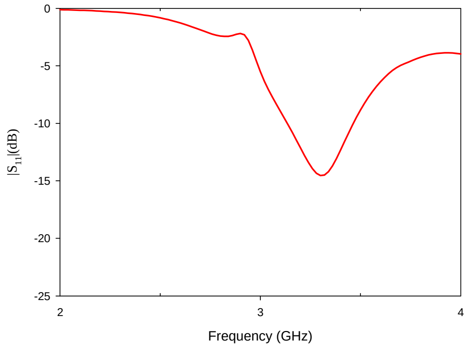
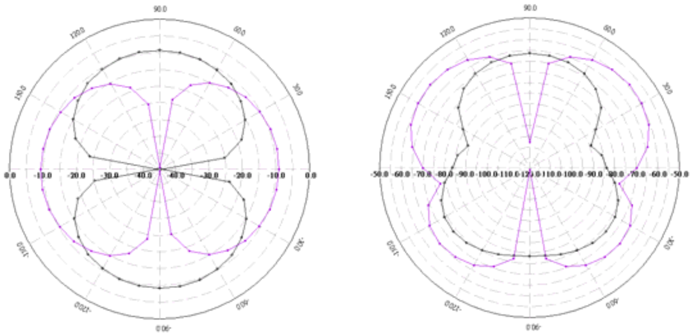


Fig. 2 Simulated return loss of proposed DGSI with double U-shaped defected ground pattern.



(a) E-Plane (b) H-Plane

Fig. 3 Simulated radiation patterns of the antenna at 3.3 GHz.

III. PARAMETRIC ANALYSIS OF MONOPOLE ANTENNA WITH DGSI

Similar to the study in [18], the matching frequency is varied by altering the etched dimensions of the DGSI geometry, i.e. length of the U-shaped pattern (L_5 and L_6) and its widths (W_6, W_7 and W_8) as well as; length and width of the island (L_4, W_1 and W_2).

A. Length and Width Variation of U-Shaped DGSI

The geometry of the U-shaped DGS is now studied against the characteristic of the antenna as in Fig. 4. It records the simulated return loss of the antenna when the widths of the etched slots are fixed but L_5 and L_6. In this figure, it is obvious that when L_5 changes from 20 mm to 19 mm and L_6 changes from 14 mm to 13 mm, the matching is kept at 3.3 GHz and its attenuation is varied to 13 dB and 15 dB respectively. Besides, the bandwidth of the antenna changes to 283 MHz, 312MHz and 342 MHz accordingly. Similar to the study of the U-shaped slot length, the widths of the DGS pattern are varied to investigate its effect on the antenna. In Fig. 5, by increasing 1 mm in W_8, the matching frequency elevates to 3.33 GHz and 233 MHz 10 dB-bandwidth is observed. If W_8 is kept as 2 mm, varying W_6 and W_7 to 3 mm, the antenna matching is further elevated to 3.4 GHz and 10-dB bandwidth becomes 307 MHz. The matching level is still kept better than 15 dB.

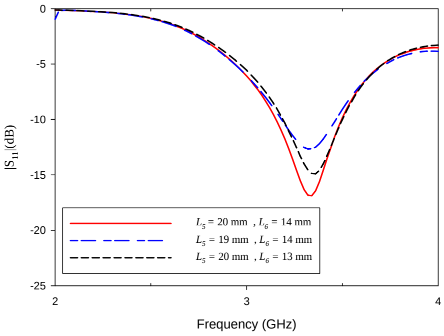


Fig. 4 Simulated $|S_{11}|$ of DGSI monopole antenna with W_6 = W_7 = 2 mm, W_8 = 2 mm and different lengths.

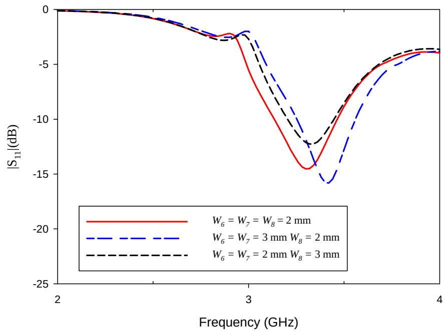


Fig. 5 Simulated $|S_{11}|$ of DGSI monopole antenna with L_5 = 12 mm, L_6 = 8 mm and different widths.

B. Length and Width Variation of Islands

In addition to the above ground's etched pattern geometrical variation, the length variation of microstrips island is studied whilst its width is fixed. When the length L_4 is increased from 22 mm to 23 mm, the matching frequency is lowered from 3.35 GHz to 3.2 GHz. Contrary to such variation, if L_4 is decreased to 21 mm, the matching frequency is relocated to higher frequency of 3.5 GHz. Moreover, the matching level of the antenna is changed along the variation of the length of island microstrip and this affects the antenna bandwidth as well. As shown in Fig. 6, when L_4 decreases by 1 mm, the matching level increases from 15.9 dB to 23 dB, but the bandwidth obtains 17 MHz shrink from 343 MHz to 326 MHz simultaneously. On the other hand, increasing the length L_4 from 22 mm to 23 mm, the bandwidth extends from 343 MHz to 353 MHz. Similar to the study of the length of the islands microstrips, matching frequency at 3.3 GHz is varied from 3.2GHz to 3.4 GHz when the width of the islands $W_1 = W_2$ is changed from 3 mm to 4 mm and length L_4 is fixed at 22 mm, as recorded in Fig. 7. In the premises, the coupling change on the antenna feedline due to the island line allows antenna frequency tuning in fact.

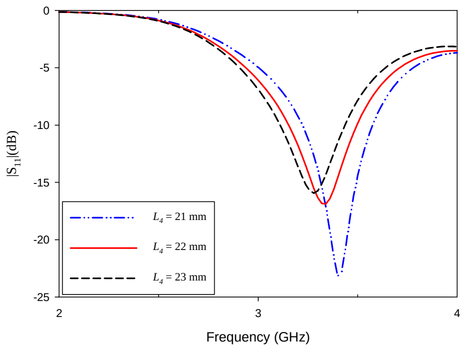


Fig. 6 Simulated $|S_{11}|$ of DGSI monopole antenna with W_1 = 4 mm and different lengths.

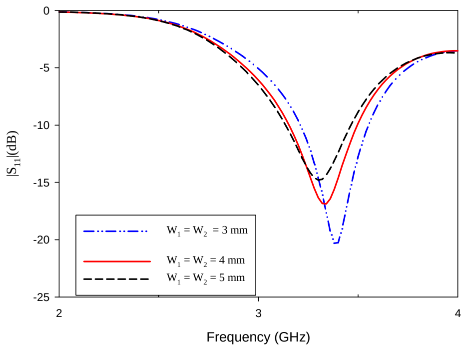


Fig. 7 Simulated $|S_{11}|$ of DGSI monopole antenna with L_4 = 20 mm and different widths.

IV. TUNABLE MICROSTRIP MONOPOLE ANTENNA USING DOUBLE U-SHAPED DEFECTED GROUND STRUCTURE WITH ISLANDS

Based on the above analysis, it shows that the proposed antenna operating frequency and bandwidth can be tuned by adjusting the dimensions of U-shaped DGSI. For *in-situ* frequency tuning, the varactor is proposed to terminate at the end of the island microstrip as described in the section II. With the terminated varactor, the electrical length of island microstrip can be varied and thus; the antenna's operating frequency and bandwidth are tuned indirectly according to the observation in section III-B. To verify such tuning ability of the proposed active antenna, Infineon BB833 varactor is used and the prototype antenna with dimensions listed in Table 1 is fabricated on the RO4003 substrate with dielectric height 1.524 mm. The photo of the prototype antenna is shown in inset of Fig. 10. The experimental return loss measurements of the prototype antenna with bias voltage in the range from 29 V to 5 V are recorded and plotted in Fig. 9. With the varactor termination, the matching frequency of the antenna is lowered to 2.78 GHz. It is due to the capacitive loading which is contributed by the varactor. As shown in Fig. 9, the operating frequency is located at 2.78 GHz when 29 V bias voltage is applied. Moreover, the 10-dB bandwidth of 64 MHz is obtained whilst 16 dB matching level is recorded. When bias voltage is decreased to 16 V and this increases the capacitance of the varactor indeed, the matching frequency is relocated to 2.628 GHz, matching level is now better than 21.2 dB but there is 62 MHz bandwidth shrink compared with that of condition using 29 V. When bias voltage is further decreased to 10 V and 5 V respectively, antenna's operating frequency is lowered to 2.46 GHz and 2.156 GHz. Also, 44 MHz and 15 MHz 10-dB bandwidth are recorded for the above bias voltages variation.

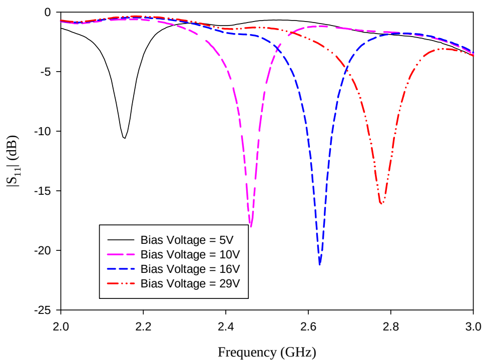


Fig. 9 Measured $|S_{11}|$ of the proposed tunable DGSI monopole antenna with different bias voltage.

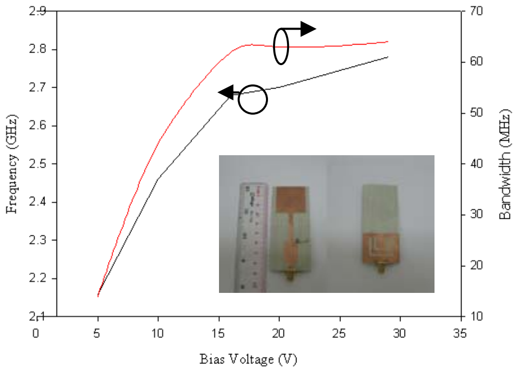


Fig. 10 Measured matching frequency and bandwidth of the proposed tunable DGSI monopole antenna with different bias voltage.

Based on the above experimental results, the operating frequency and bandwidth are plotted in Fig. 10 against the different bias voltage. It shows that by increasing the bias voltage, the operating frequency is elevated to the high frequency regime due to the decrease of capacitance monotonously. However, due to the parasites of the varactor, it affects the bandwidth of the antenna. Therefore, it is obvious that the change of the antenna bandwidth is not monotonous against the variation of the bias voltage. By increase the bias voltage from 5 V to 16 V, the bandwidth of the antenna increases from 15 MHz to 63 MHz dramatically as shown in Fig. 10. Moreover, increasing the bias voltage continuously to 29 V, the operating frequency is elevated to 2.78 GHz whilst the bandwidth is kept as that of condition with 16 V.

V. CONCLUSION

A novel tunable microstrip monopole antenna using defected ground structure with microstrip islands has been proposed. The operating frequency of the antenna can be varied *in-situ* by a tunable matching network which comprising double U-shaped defected ground structure with capacitively terminated islands. The frequency agility is thus easily realized by capacitive loading onto the islands. The measurements of the prototype monopole antenna record the frequency tuning of the antenna from 2.1 GHz to 2.7 GHz at voltage variation of 5 V to 29 V. Instantaneous bandwidth of this prototype is measured from 65 MHz to 15 MHz. Good return loss of more than 21 dB as well as monopole like antenna pattern has been achieved over tunable frequency range of 623 MHz.

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