A Novel Slot Antenna with Reconfigurable Meander-Slot DGS for Cognitive Radio Applications

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Abstract **─** A new planar reconfigurable wideband slot antenna is proposed for cognitive radio (CR) applications in this paper. The wideband function is obtained by inserting a meander ε-shaped slot in the rectangular radiation patch. The reconfigurable characteristics with frequency diversity are achieved using four ideal switches integrated on the meander-slot defected ground structure (DGS) band stop filter embedded in the ground plane. The design procedures, impedance bandwidth, and radiation patterns are presented for explanation and examination of this antenna. The proposed reconfigurable slot CR antenna can work at three modes by controlling the switches at ON and OFF states. It operates over the frequency band between 1.52 GHz and 2.75 GHz (bandwidth of 57.6%), with two independent bands from 1.54 GHz to 2.28 GHz (38.7%) and 2.28 GHz to 2.85 GHz (22.2%). The measured results show that it has wide impedance bandwidth, multimode characteristics, and omnidirectional radiation patterns.

Index Terms **─** Cognitive radio (CR), defected ground structure (DGS), reconfigurable, reconfigurable meander-slot (RMS), slot antenna (SA).

I. INTRODUCTION

Recently, an increasing demand for antennas with multimode and cognitive radio (CR) operation in modern wireless applications with high-data-rate has drawn the very attention of researchers. The CR or software defined radio is directed to improve the spectral utilization by dynamically interacting with the RF surroundings. Sensing the surroundings may involve the measurement of the interference and communications traffic across a large part of the electromagnetic spectrum [1].

Dynamic control based on CR is usually achieved by incorporating switches in the antenna for reconfigurability. In other words, reconfigurable antennas with frequency diversity, which can scan the spectrum in a wideband mode and choose an available narrowband mode, provide the best solution for CRs. To this end, several CR antennas with complex single- and dual-port structure have been studied and investigated [2-7]. These references gave various methods for achieving frequency diversity using changing the structure of the antenna radiator or ground plane, defected microstrip structure bandpass filter, etc.

In recent years, a great trend towards the design and implementation of a reconfigurable defected ground structure (DGS) where the location of the transmission zeros can be controlled and tuned may be seen from a number of authors [8-9]. DGS is realized by etching a certain defected pattern or slot in the ground plane. The reconfigurable DGS can been used in many applications like antennas due to their interesting properties in terms of size miniaturization, arbitrary stopbands and suppression of surface waves [8, 10-12]. However, still not a large amount of work has been presented in this domain.

Several DGS have been proposed so far, such as dumbbell-shaped DGS, semicircle-shaped DGS, circle-shaped DGS, cross-shaped DGS, spiral DGS, arrow-head DGS, U-slot DGS, V-slot DGS, concentric ring DGS, MS-DGS and so on [10]. These DGSs are different from the quality factors (Q factors) and the band rejection characteristics [13]. Some of DGSs are already utilized in the letters as a switchable structure [8, 14]. In [8], a novel reconfigurable DGS unit cell on coplanar waveguide technology is presented. The presented DGS contains a number of PIN diodes on each side of the coplanar waveguide ground planes to give complete control of the number of transmission zeros obtained and their resonant frequencies. An UWB antenna with DGS and varactor for tuning the notch band has been studied in [14]. The varactor is loaded on the DGS to control the resonance frequency.

In this article, a new slot antenna with reconfigurable meander-slot (RMS) DGS, which was previously introduced in [13], and multimode performances for CRs is presented. In the proposed structure, wideband function is provided by etching a slot on the rectangular radiating stub, and a multi-resonance characteristic is obtained by using ideal

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switches inside the MS-DGS. The reconfigurable characteristics by implementing ideal switches are already achieved in some articles [4, 15-16]. The MS-DGS using ideal switches in this paper is designed to achieve reconfigurability of several stop bands. This reconfigurable DGS, when integrated with a wideband antenna, results in a frequency-agile system with a wideband operation when the DGS is disconnected by placing switches in the ON/OFF states. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for wireless applications.

II. ANTENNA CONFIGURATION AND DESIGN

In this section, the proposed slot antenna integrated with MS-DGS for CR applications is illustrated in detail. Design procedures are separated into three sections. Firstly, we will introduce the MS-DGS and its reconfigurability which will be integrated into the new slot antenna. Secondly, the slot antenna with and without a new slot on the radiation patch will be studied. Finally, we will study the proposed antenna integrated with reconfigurable DGS. In this study, the ideal switches for reconfigurability are metal bridges. The presence of the metal bridge represents that the switch status is ON; in contrast, the absence of the metal bridge represents that the switch status is OFF. The simulated results are obtained by using Ansoft HFSS [17] based on finite element method.

A. Design and characteristic of RMS-DGS

In microwave and electromagnetic engineering, hairpin filters are widely used than parallel-coupled microstrip filters because of its good filterable property and compact structure. To this end, in [13], a novel DGS which the authors name as MS-DGS is presented. It is conceptually obtained by folding the multi long arm-slots outwards to the U-slot DGS. The typical MS-DGS is sketched in Fig. 1. Its defected pattern consisted of a U-shaped body and multi folding arms. In order to design a switchable DGS, four ideal switches are incorporated into the meander slot. The four switches are described as switch 1 (SW1), switch 2 (SW2), switch 3 (SW3) and switch 4 (SW4), as shown in Fig. 1. In general, horizontal slots of the MS provide inductance effects, while vertical slots exhibit capacitive characteristics [13]. Thus, the resonant frequency can be adjusted by controlling lengths of the meander slot. The dimension parameters of MS-DGS, including slot width c, w, central joint-slot length d, arm-slot length f, and side joint-slot length e are shown in Fig. 1. This MS-DGS is built on a FR4 substrate whose relative permittivity (ε_r) is 4.4 and thickness (h) is 0.8 mm. The microstrip line on the top layer is designed to be 50-Ω transmission line (its width is 1.16 mm under resonant frequency).

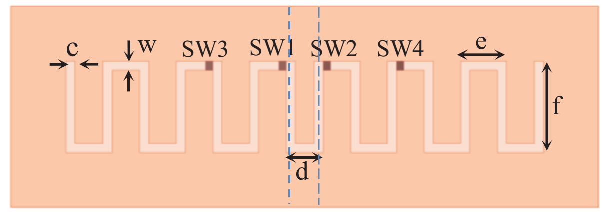


Fig. 1. Sketch view of MS-DGS with defected pattern dimensions.

The simulated reflection coefficient (S_{11}) and transmission coefficient (S_{21}) of the switching characteristics from DGS are illustrated in Fig. 2. In this simulation, the ideal switches are replaced with four metal strips with length 0.5 mm and width 0.4 mm. It is obvious that MS-DGS has four narrow stop bands with all switches OFF. The center frequency and number of these stop bands can be controlled by adjusting the MS lengths. When SW1, SW2 are ON and SW3, SW4 are OFF, the DGS has only one stop band which is near 8.6 GHz. For SW3, SW4 ON and SW1, SW2 OFF, the DGS has two stop bands with different center frequency compared to the previous situation. The DGS with longer length has narrower stop band than the DGS with shorter length at first center frequency. So, the switchable MS-DGS has tunable functions which can work in a stop band mode and multi stop band mode with different center frequency.

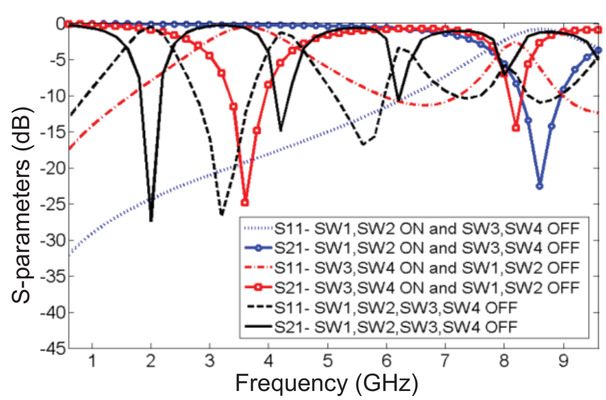


Fig. 2. Simulated S-parameters of the RMS-DGS.

B. Design of a novel slot antenna

The configuration of the rectangular slot antenna fed by a 50-Ω microstrip line is shown in Fig. 3 (a), which is etched on an FR4 substrate of permittivity 4.4 and thickness 0.8 mm. The basic antenna structure consists of a rectangular radiating stub with a 50-Ω microstrip feed line and a ground plane. The radiation patch and the feed line are printed on top of the substrate, while the ground plane is printed on the bottom of the substrate.

In this study, to design a novel antenna, a meander ε-shaped slot has been added to the antenna structure. As illustrated in Fig. 3 (b), this slot is placed in the center of the radiating patch and is also symmetrical with respect to the longitudinal direction. The slot excites the resonant response and also acts as a half-wave resonant structure [18]. The meander ε-shaped slot creates an additional path for the surface current, which leads to an additional resonance, and consequently wider bandwidth can be produced [7].

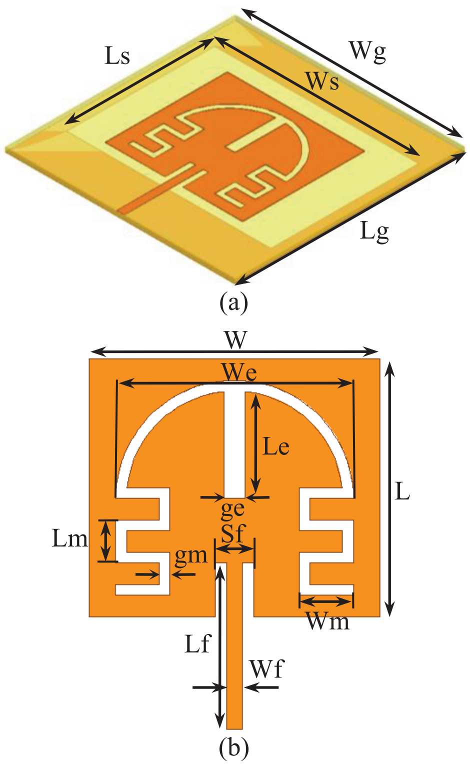


Fig. 3. Structure of the proposed slot microstrip antenna: (a) side view, and (b) modified radiating patch.

In this article, we start by choosing the aperture length Ls. We have a lot of pliability in choosing this parameter. The aperture length mostly affects the antenna bandwidth. As reduces, so does the antenna bandwidth, and vice versa. At the next step, we have to determine the aperture width Ws. The aperture width is approximately λs, where λs is the slot wavelength. λs depends on a number of parameters such as the slot width as well as the thickness and dielectric constant of the substrate on which the slot is designed. The last and final step in the design is to choose the length and width of the radiating patch L and W. A good starting point is to choose it to be equal to W=λm, where λm is the guided wavelength in the microstrip line.

Figure 4 shows the structure of the various antennas used for simulation studies. Return loss characteristics for an ordinary rectangular antenna [Fig. 4 (a)], with a slot in the ground plane [Fig. 4 (b)], and the antenna with meander ε-shaped slot in the radiating stub [Fig. 4 (c)] are compared in Fig. 5. It is found that by inserting slot in the ground plane, the antenna can create a wider bandwidth. Also as shown in Fig. 5, in this structure, the meander ε-shaped slot is used for the new resonance excitation function.

As shown in Fig. 5, the impedance bandwidth is effectively improved by the use of slot in the ground plane. In addition, by inserting the meander ε-shaped slot on the radiating patch, the lower-frequency bandwidth is significantly affected and the antenna can create the new resonant frequency at 1.57 GHz.

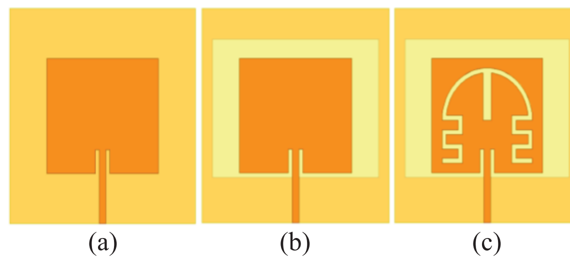


Fig. 4. (a) Ordinary antenna, (b) slot antenna, and (c) slot antenna with a new slot on radiating stub.

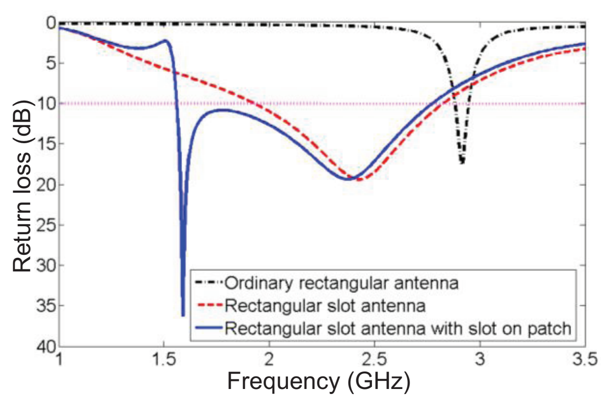


Fig. 5. Simulated antennas return loss shown in Fig. 4.

To design a novel wideband slot antenna, three modified slots are inserted in the radiating stub of the proposed slot antenna, as displayed in Fig. 6. Three such slots with different sizes are specified in as cases 1–3. Figure 6 also shows the effects of these slots with different values on the impedance matching. It is found that by cutting the multi MS of suitable dimensions at the follow of ε-shaped slot, additional resonances are excited and hence, wider impedance bandwidth with multi-resonance characteristics can be produced, especially at the lower band.

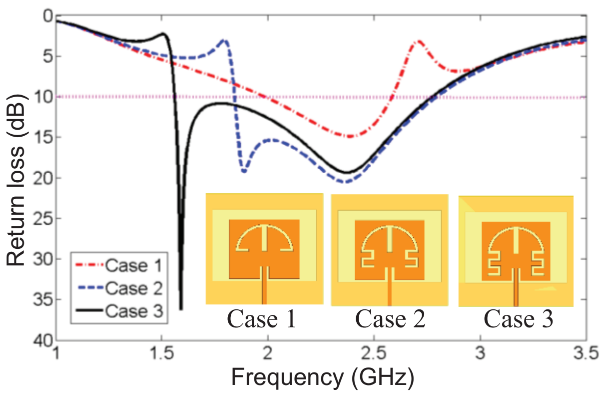


Fig. 6. Simulated return loss for the slot antenna at three cases with various slots on radiating patch.

C. Design of CR antenna with RMS-DGS

Based on the studies of RMS-DGS (Section A) and novel slot antenna (Section B), a CR antenna has been proposed numerically and experimentally.

The proposed antenna connected to a 50-Ω SMA connector is shown in Fig. 7. Firstly, a wideband slot antenna is designed. Secondly, a slot is etched in the radiation patch of the wideband slot antenna to produce wider band for covering UMTS 2100, PCS 1900, DCS 1800, 2.4 GHz WLAN 802/11 (b & g), 2.6 GHz WiMAX 802/16e, GPS, DMB, and DECT systems. Thirdly, a switchable MS-DGS is embedded in the proposed antenna ground plane to generate multiple frequency bands and controlling bandwidth for reducing or avoiding of systems.

Fig. 7. Geometry of the proposed antenna.

The final dimensions of the proposed antenna are improved using an extensive parametric study and listed as follows: *L*g=45 mm, Wg=45 mm, Ls=29 mm, Ws=40 mm, L=24 mm, W=27 mm, Lf=15.5 mm, Wf=1.5 mm, Sf=3.5 mm, Le=9.9 mm, We=22 mm, ge=2 mm, Lm=4 mm, Wm=5 mm, and gm=1 mm. The dimensions of improved DGS of the antenna are f=5 mm, e=2.5 mm, d=2 mm, w=0.5 mm, and c=0.5 mm.

III. RESULTS AND DISCUSSIONS

To verify the above designs, the modified antenna is fabricated and measured. The four ideal switches, are also metal bridges which are replaced by a microstrip line in fabrication. In simulation and fabrication, the metal bridges with dimensions of 0.5×0.4 mm are used to approximate switches.

The improved antennas, as shown in Fig. 8, are measured using Agilent Network Analyzer. Measured and simulated results of return losses are compared in Fig. 9. The measured results almost agree with the simulated ones, which help to verify the accuracy of the simulation. The difference between the measured and simulated results may be due to a number of parameters such as the manufactured antenna dimensions as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated.

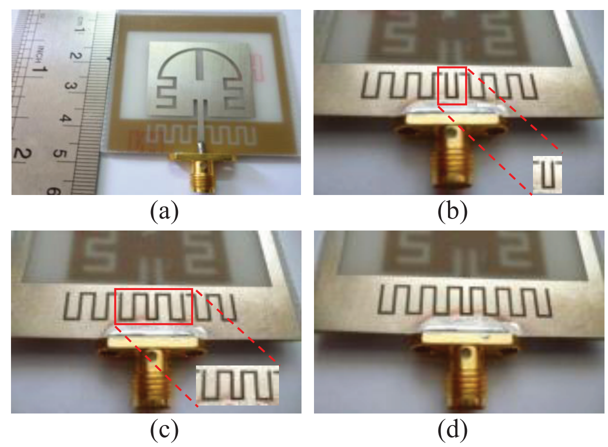


Fig. 8. Prototypes of improved antennas: (a) top view, (b) bottom view of proposed slot antenna with SW1, SW2 are ON, and SW3, SW4 are OFF (state 1), (c) with SW3, SW4 are ON, and SW1, SW2 are OFF (state 2), and (d) with all switches OFF (state 3).

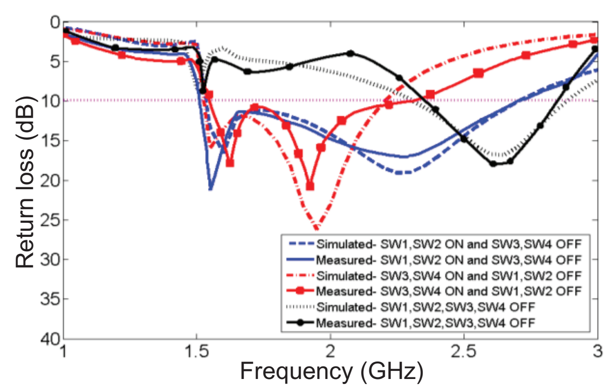


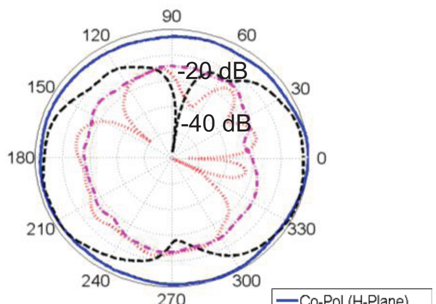
Fig. 9. Return losses of the antennas shown in Fig. 8.

It can be seen from Fig. 9, that CR antenna is a wideband antenna which has a wide bandwidth ranging from 1.52 GHz to 2.75 GHz with SW1, SW2 ON and SW3, SW4 OFF. In this state, antenna can be used in overlay mode for channel sensing. As for antenna with

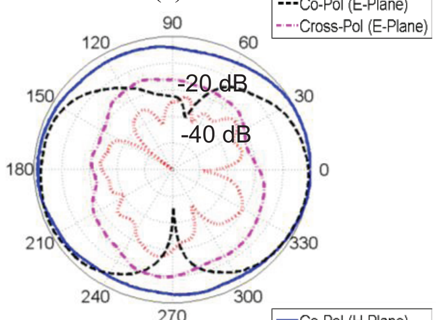
SW3, SW4 ON and SW1, SW2 OFF, it is a wideband antenna with narrower band from 1.54 GHz to 2.28 GHz than previous state which can prevent from WLAN, WiMAX, and DMB systems. In this state, CR antenna can be used for underlay mode.

For the state of all switches OFF, proposed antenna has a narrower bandwidth from 2.28 GHz to 2.85 GHz compared with the previous two states, to expunge from UMTS 2100, PCS 1900, DCS 1800, GPS, and DECT systems. Thereby, we can control the switches ON and OFF to allow the proposed slot antenna to work in underlay and overlay modes for CR system. Also, the antennas can be used for multimode wireless systems by controlling the switches at ON and OFF states.

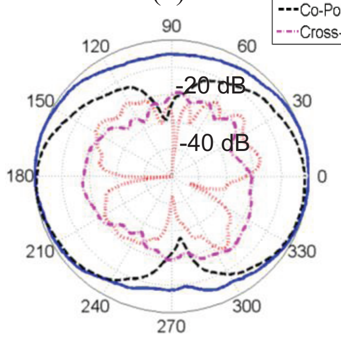
Figure 10 shows the measured radiation patterns including the co- and cross-polarization in the E- and H-planes at 1.57 GHz, 2.1 GHz, and 2.6 GHz for state 3 (with all switches OFF).



(a)



(b)



(c)

Fig. 10. Measured radiation patterns of antenna at: (a) 1.57 GHz, (b) 2.1 GHz, and (c) 2.6 GHz.

The radiation patterns are demonstrated that the antenna actually radiates over a wide frequency band. It can be seen that the radiation patterns in H-plane are nearly omnidirectional and dipole like in the E-plane for the three frequencies. It is found that the measured results of antenna using the RMS-DGS, the meander ε-shaped slot, and the ideal switches well satisfy the requirement of wideband CR applications.

IV. CONCLUSION

In this paper, a CR slot antenna integrated with RMS-DGS and the meander ε-shaped slot has been investigated. Reconfigurable DGS is analyzed and discussed before antenna design. The design procedures of CR antenna are illustrated in detail through analyzing antenna with and without slot and parametric studies. The reconfigurable functions are obtained using four ideal switches on MS-DGS. The switchable functions and bandwidth characteristics are investigated. By switching ON and OFF states of the four switches, CR slot antenna can work in three cases for underlay mode and overlay mode CR applications. The antenna with all switches ON and OFF is fabricated and measured. The impedance bandwidth and radiation patterns of the antenna are given and discussed. The proposed antenna can also be used as multimode antennas. As a result, they can well meet the wideband CR communication requirement and effectively change the modes.

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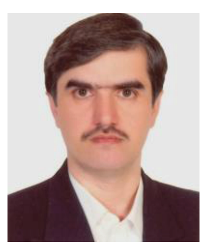

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