Compact dual-band pattern reconfigurable antenna using switched parasitic array

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A compact dual-band pattern reconfigurable antenna using switched parasitic array is proposed for 2.4 and 5.8 GHz wireless MIMO applications. The proposed antenna is based on dual-band driven and parasitic radiators (PR) with RF switches. The PR performs as a reflector or a director by controlling RF switches. The antenna is designed to provide nine radiation patterns in three states at the frequencies of 2.4 and 5.8 GHz bands, respectively. Two states realise eight radiation patterns in the horizontal plane. The measured peak gain of all radiation patterns ranges from 6.1 to 9.7 dBi. Another state generates omnidirectional radiation patterns in the horizontal plane and measured gains of around 4.0 and 7.5 dBi for 2.4 and 5.8 GHz bands, respectively.

Introduction: With the increasing demands being placed on wireless MIMO communications, pattern reconfigurable antennas have received much attention because of their diversity functions in radiation patterns, polarisation states, and operating frequencies. The directional characteristics of pattern reconfigurable antennas can be used to improve security and system gain, avoid noisy environments, and mitigate electronic jamming. Juan *et al.* [1] proposed a pattern reconfigurable dipole antenna with four switchable reflectors and parasitic strips. A pattern reconfigurable strip monopole with eight switchable printed parasitic elements was presented [2]. Another pattern reconfigurable antenna was designed based on the collinear dipole array, but only three radiation patterns were generated [3]. A Yagi patch antenna with a switchable slot can change the character of parasitic elements between reflectors and directors [4]. In [5], a dual-band pattern diversity antenna with reconfigurable frequency-selective reflectors was introduced. Another dual-band pattern reconfigurable Yagi-Uda antenna was designed based on LC parallel circuits and dual parasitic elements [6].

The aforementioned pattern reconfigurable antennas are available only in a single band, or the sizes are comparatively large. In this study, we propose a compact dual-band pattern reconfigurable antenna using switched parasitic array (SPA) for 2.4 and 5.8 GHz wireless MIMO applications. The antenna is designed to provide nine radiation patterns in three states at the frequencies of 2.4 and 5.8 GHz bands, respectively.

Design considerations: The proposed pattern reconfigurable antenna is designed based on a driven radiator (DR), a parasitic radiator (PR), and a DC line for the dual-band operation of 2.4 and 5.8 GHz. It is fabricated on a 22-mm-wide, 120-mm-long, and 0.8-mm-thick ROGERS RO4350B substrate, and two substrates are assembled orthogonally. The total volume of the antenna is $22 \times 22 \times 120$ mm ($0.17\lambda_0 \times 0.17\lambda_0 \times 0.96\lambda_0$, where λ_0 is the free space wavelength at 2.4 GHz). The geometry of the proposed antenna is illustrated in Fig. 1. The DR consists of long and short dipole elements with the lengths of 60 and 25.5 mm, respectively. The spacing and width of the elements are 1 and 1 mm, respectively, and the distance between the DR and PR is 4 mm ($0.032\lambda_0$). The PR is composed of linear elements with the length and width of 110.5 and 2 mm, respectively, and four RF switches. The linear element is divided into five short elements (26.5, 23, 9.5, 23 and 26.5 mm) with a gap of 0.5 mm for mounting RF switches. The RF switches are MACOM MADP-008120-12790T having low loss and high isolation characteristics. The length and distance of the DRs and PRs and the position of the RF switches affect the dual-band resonance frequencies and input impedance of the antenna. Thus, the radiation performance of the antenna is tuned and optimised by varying the length and distance of those radiators and the position of the RF switches. The DC line consists of strip lines with the width of 0.5 mm and choke coils for isolating RF and DC signals. The choke coils are conventional multilayer chip inductors whose values are 22 and 5.1 nH. These two inductors are optimised and connected in a series in order to isolate the dual-band of 2.4 and 5.8 GHz, simultaneously. The DC signals are supplied from a DC control board with a five-pin socket to the ground through the PRs and DRs. The DC control board is also made up of ROGERS RO4350B substrate whose diameter is 18 mm and thickness is 0.8 mm. Four pins in the five-pin socket are used to supply a +3 V DC voltage to each DC line. The remaining pin is used for the DC ground. A coaxial cable with an SMA connector is used to feed the RF signal to the DRs whose upper and lower radiators are combined and connected to the inner and outer wires of the coaxial cable, respectively. Four pairs of DRs, PRs, and DC lines are symmetrically positioned at a 90° interval in a horizontal plane.

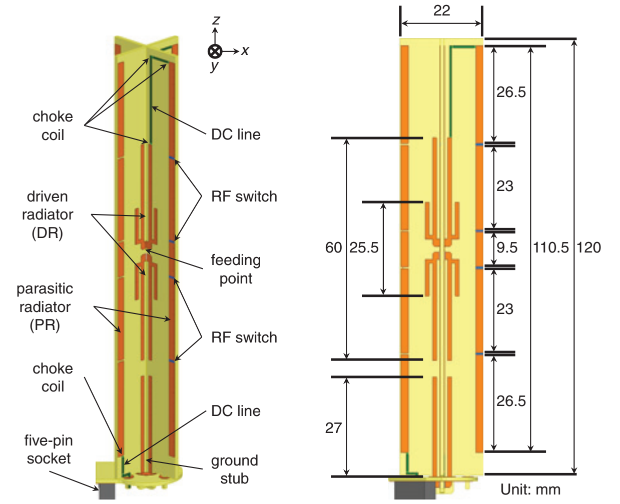
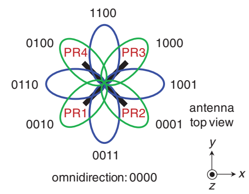


Fig. 1 *Geometry of proposed dual-band pattern reconfigurable antenna*

The DC line is connected to the PRs and DRs in order to control RF switches. The PR is in a short state and used as a reflector when a DC voltage is supplied to the DC line and four RF switches in the PR are turned on. However, it is in an open state and used as a director while the RF switches are turned off. When two adjacent PRs act like reflectors (State I), radiation patterns are produced at 0°, 90°, 180°, and 270° in the horizontal plane, respectively. When only one PR acts like a reflector (State II), radiation patterns are generated at 45°, 135°, 225°, and 315° in the horizontal plane, respectively. Finally, when all PRs act like directors (State III), an omnidirectional radiation pattern is realised in the horizontal plane. Therefore, the antenna provides nine radiation patterns in three states, as shown in Fig. 2.



State	Radiation direction	Scenario			
		PR1	PR2	PR3	PR4
I	0°	1	0	0	1
	+90°	1	1	0	0
	+180°	0	1	1	0
	+270°	0	0	1	1
II	+45°	1	0	0	0
	+135°	0	1	0	0
	+225°	0	0	1	0
	+315°	0	0	0	1
III	omni	0	0	0	0

0: OFF, 1: ON, DC voltage: +3 V

Fig. 2 *Scenario of radiation pattern reconfiguration*

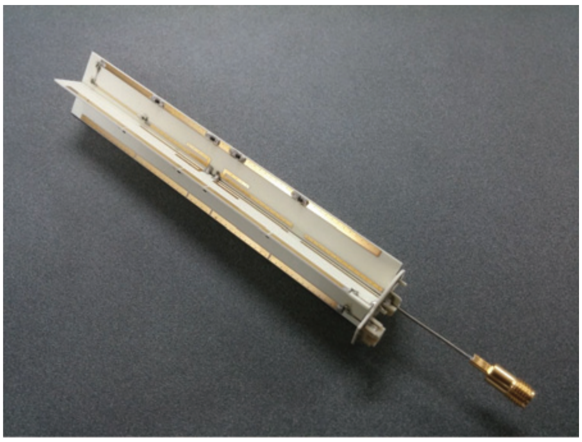


Fig. 3 *Photograph of fabricated antenna*

Experimental results: Fig. 3 shows the fabricated antenna, and the simulated and measured reflection coefficients of the antenna are shown in Fig. 4. The simulated and measured results were obtained using ANSYS HFSS full-wave simulator and KEYSIGHT E5071C vector network analyser, respectively. The dual-band resonance frequencies were approximately 2.4 and 5.75 GHz, and were optimised for State I. The measured results seemed to be better than the simulation. During fabrication, structural tolerance may be caused by such factors as conditions produced by soldering on and the tolerance of the RF switches, multilayer chip inductors, and coaxial cables.

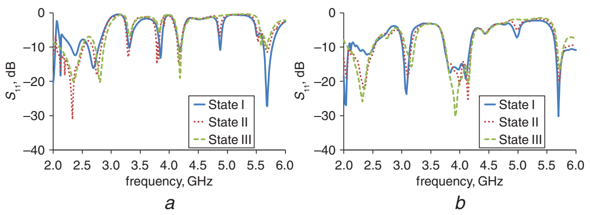


Fig. 4 *Reflection coefficients for State I, II, and III*

a Simulated results
b Measured results

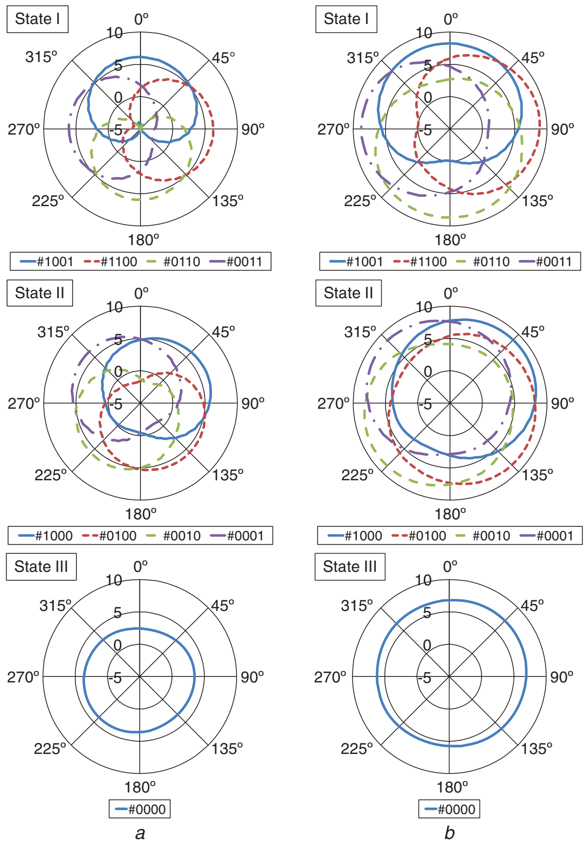


Fig. 5 *Measured radiation gain patterns in the horizontal plane*

a 2.4 GHz
b 5.8 GHz

The measured radiation gain patterns of the proposed antenna at 2.4 and 5.8 GHz are plotted in Fig. 5. State I and II produced four radiation patterns with a 90° interval in the horizontal plane, respectively. State III realised omnidirectional radiation patterns in the horizontal plane. Thus, the radiation patterns of State I and II were switched to eight directions with a 45° interval in the horizontal plane. The peak radiation direction was achieved at the elevation angles of 90° and 45° for 2.4 and 5.8 GHz, respectively, in all three states. The measured peak gain for all radiation patterns at 2.4 GHz band was approximately 6.5, 6.3, and 4.0 dBi in State I, II, and III, respectively. The peak gain at 5.8 GHz band varied from 6.5 to 9.7 dBi in State I, from 6.3 to 9.6 dBi in State II, and from 5.0 to 8.0 dBi in State III. The front to back ratio (FBR) at 2.4 GHz was about 12.2 dB and was about 9.1 dB at 5.8 GHz in State I. For State II, the FBR was around 8.3 and 6.2 dB at 2.4 and 5.8 GHz, respectively. Therefore, good directivity could be achieved in State I and II, while good omnidirectional patterns were observed in State III.

Conclusion: A compact dual-band pattern reconfigurable antenna using SPA was proposed and investigated. The antenna is designed to provide nine radiation patterns in three states at the frequencies of 2.4 and 5.8 GHz bands, respectively. Two states realise eight radiation patterns with a 45° interval in the horizontal plane. Another state generates omnidirectional radiation patterns as a dipole antenna. Moreover, the size of the antenna is extremely compact and good radiation performance is achieved. Thus, the proposed antenna can be used for various wireless MIMO applications.

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One or more of the Figures in this Letter are available in colour online.

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