Radiation Pattern Reconfigurable MIMO Antenna With Practical DC Bias Network

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***Abstract*— This paper presents a radiation pattern reconfigurable (RPR) based multiple-input multiple-output (MIMO) antenna. The proposed antenna operates at 3.5 GHz for all switching conditions with S_{21} results of less than -20 dB. This work specifically focuses on implementing a practical DC bias network for the previously proposed RPR-MIMO antenna. The DC bias design is crucial where the tilt angle is slightly affected. This could be due to the isolation loss and insertion loss provided by the actual switch; and the DC bias lines that were constructed using a few DC blocking capacitors and RF chokes. Finally, a comprehensive analysis was carried out to examine the beam steering performance of the antenna when implemented with the DC bias network.**

***Keywords*— Antenna and Propagation, Reconfigurable Antenna, MIMO antenna**

I. Introduction

A reconfigurable antenna can change its frequency, polarization, and/or radiation patterns dynamically in a controlled and reversible manner. Due to this additional capability, the reconfigurable antenna design could consume a lot of time and optimization work. Among the various reconfigurable antennas, the radiation pattern reconfigurable (RPR) antenna is much more challenging because the steering performance is usually affected by the isolation loss of the RF switch at OFF conditions [1]–[4]

The use of RPR antenna in multiple antenna systems MIMO can be considered new research since most of the existing works still have not fully investigated the performance degradation after the RPR is modelled as MIMO. A recent work [5] has investigated the performance of RPR when the RPR is modeled as a 2 x 1 MIMO and identified a suitable configuration to ensure the effect on the beam steering performance is minimized. However, this work only adopts the proof of concept switching where modification for DC biasing and actual RF switch representation were not considered.

There are different types of switching mechanisms used to design reconfigurable antennas. Among them, electrical switching consists of RF-MEMS, PIN diodes and varactors. The operation of a PIN diode is versatile with strong switching capabilities that may be biased to act as a short circuit and an open circuit with fast switching capabilities [6]. It is a low-cost device that is simple to install, lowering the entire antenna production cost [7].

This study is carried out to carefully examine and explore the effect of DC biasing in RPR-MIMO where such antennas can be considered for the use of small base stations or portable access points. In this study, a single RPR model was adopted to construct an RPR-MIMO and the performance is investigated after the introduction of the DC bias network. As mentioned earlier, work [5] has not implemented the DC biasing network and proof of concept switches (vias) were used. In this work, the RPR-MIMO was investigated using a 2 x 1 MIMO array by implementing a DC biasing circuitry. A detailed description of the RPR antenna design and DC biasing circuit is presented in the following section. The main focus of this study is to carry out investigation on the challenges and effects of implementing the DC Biasing circuit in the RPR-MIMO. Then a comprehensive investigation was conducted using RPR-MIMO and the results were presented in terms of S-parameter and polar radiation pattern.

II. RPR With DC Biasing and Analysis

A. Radiation Pattern Reconfigurable (RPR) Antenna

Fig. 1 shows the physical structure of the patch array antenna. The antenna is designed with three parallel patches which include the single driven element at the centre and two parasitic elements at the left and right of the driven element. The antenna was designed on a full grounded Rogers dielectric substrate with a thickness of 1.524 mm and a dielectric constant (ε_r) of 3.55. The loss tangent of the dielectric is 0.0027. The driven element or the centre rectangular patch has a width of X_p mm and a length of Y_p mm. The width and length were first calculated using the rectangular patch fundamental equations provided in [8]–[10] for a center frequency of 3.5 GHz. Besides that, the PIN diode (BAR 50-02V) is used as a switching element to implement electronic reconfigurability. The equivalent lumped element representation was used in the simulation software. For independent control of the switch, 0.5 mm width of the slot is introduced between switch 1 and switch 2 at the ground plane. This slot is also introduced between switch 3 and switch 4 respectively to provide the necessary isolation between the two ports of the PIN diode. A 27 nH inductor was used as a radio-frequency (RF) choke to block the RF signal leakage from each DC bias line. At the same time, the DC blocking capacitors with a value of 100 pF at the ground plane were placed to block the DC while ensuring smooth RF current flow among the slots created for DC bias lines. The DC bias lines were sidelined at right and left edge of the antenna to allow easy construction of 2 x 1 of RPR MIMO with a DC bias network. The RPR antenna can produce three pre-determined steering directions based on three switching configurations. Each configuration consists of four switches and each switch is identified as Switch 1, Switch 2, Switch 3 and Switch 4. The silicon PIN diode used as the switch has the model BAR 50-02V by Infineon Technologies having a working frequency range from 1 MHz to 6 GHz.

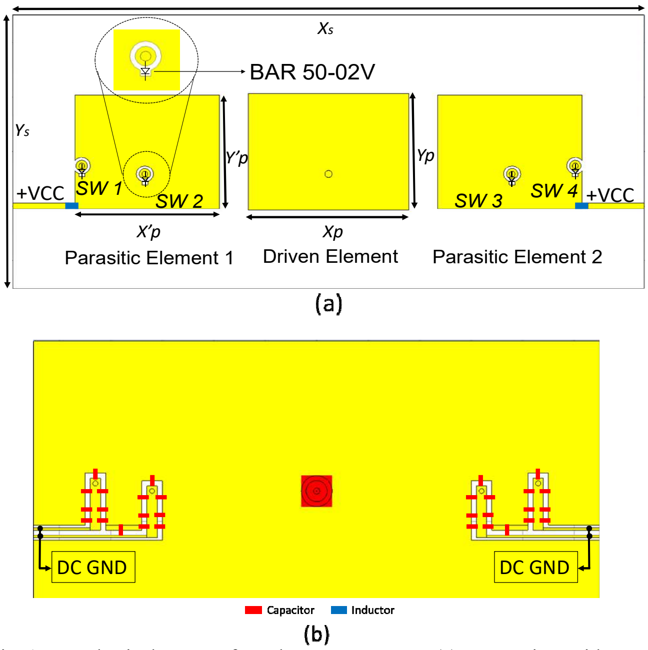

Fig. 1. Physical Array of Patch Array Antenna. (a) Front View with Dc Biasing, (b) Back View with Dc Biasing.

For simulation purposes, the lumped element equivalent of the BAR50-02V PIN diode at its 'ON' and 'OFF' states was used. The equivalent circuit of the PIN diode is shown in Fig. 2. The series resistance of R_{ON} was used for the ON state and the series capacitor of C_{OFF} was used for the OFF state. From the datasheet, the IL is 0.2 dB and the ISO is 15 dB at 3.5 GHz frequency. The R_{ON} and C_{OFF} values were calculated using the following equations,

$$IL = 20\log\left(1+\frac{R_{ON}}{2Z_0}\right) \tag{1}$$

$$ISO = 10\log\left[1+\left(\frac{1}{2\omega C_{OFF}Z_0}\right)\right] \tag{2}$$

where IL is the insertion loss when the diode is at the ON state, ISO is the isolation loss when the diode is at the OFF state ω is the angular frequency and Z_0 is the characteristic impedance. At the ON condition, the calculated R_{ON} is 6 ohm and C_{OFF} is 0.0297 pF was used for the OFF condition.

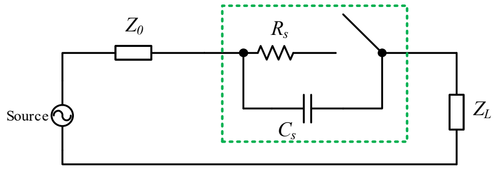

Fig. 2. The circuit consists of a switch with lumped elements.

B. *RPR Antenna Deployed as Multiple Antenna*

Very few works have investigated the deployment of RPR antenna as multiple antenna or MIMO. In this work, a 2 x 1 configuration of RPR-MIMO was adopted and the DC bias lines were carefully constructed. The RPR was implemented with DC Biasing to achieve the switching mechanism. The deployment of the DC Biasing is shown in Fig. 3.

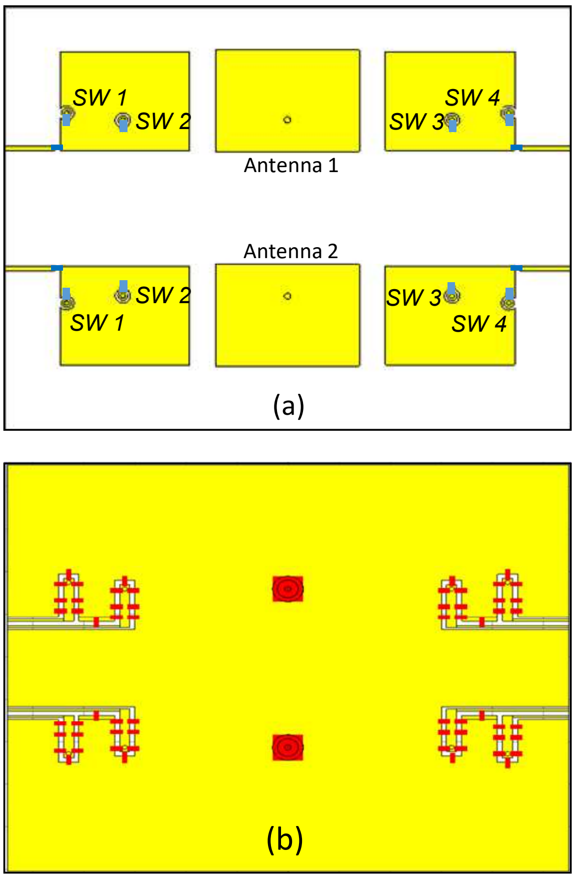

Fig. 3. The geometry of the antenna. (a) Front View; Dc Biasing, (b) Rear View DC Biasing

The performance difference between these two MIMO configurations with DC biasing and without DC biasing network was investigated and explained in the result section for a better understanding. Meanwhile as mentioned before, the modification of the antenna slot to place the capacitor, inductor and PIN diode as a switch plays a vital role in this investigation. To be more precise, the slotted region at the back of the antenna is carefully optimised to investigate the relationship between the DC biasing and MIMO antenna and the tilt angle of the main beam according to serve the user in a selective direction.

III. RESULTS AND ANALYSIS

This section presents a comparison of simulated results of the RPR antenna with DC biasing and without DC biasing in terms of S-parameter and radiation pattern results. The main focus of this research is to investigate the radiation characteristic of the RPR when implemented with DC biasing network. Secondly, this section also compares the simulation result of the RPR-MIMO based on the previous work [5].

A. Results of RPR Antenna with DC biasing

The operation principle and results of a single RPR antenna are presented. Table I presents the switching conditions and the respective beam steering directions. The presented switching configurations attain the optimum result in terms of tilt angle and gain. Without SW2 and SW3, the tilt angle at 0 was unable to attain high gain, where the gain was approximately 6 dBi. Therefore, additionally, SW2 and SW4 were needed. The respective beam pattern is depicted in Fig. 3. The polar radiation pattern shows that three sets of beam patterns that are almost identical in terms of shape and gain could be attained. Compared to previous work [5], the switching configuration of the antenna is changed in this paper to obtain a better radiation pattern. For example, the switch configuration 1000 is now changed to 1100 meanwhile 0001 is changed to 0011. Configuration 0011 produces steering at -*x* direction on *xz* plane, and this direction is named as LEFT (L) steering direction. On the hand, 1100 is identified as the RIGHT (R) steering direction. Configuration 0110 steered to *x* = 0° with maximum gain, thus named as CENTRE (C) direction.

TABLE I. BEAMFORMING CHARACTERISTICS BASED ON SWITCHING CONDITIONS

Switching Conditions				Steering Direction	With DC Biasing		Without DC Biasing	
SW1	SW2	SW3	SW4		θ	Gain (dBi)	θ	Gain (dBi)
0	0	1	1	L	-23°	7.74	-31°	7.38
0	1	1	0	C	0°	7.52	0°	7.42
1	1	0	0	R	+23°	7.74	+31°	7.38

Fig. 5 shows the reflection coefficient results for the RPR antenna when implementing the DC Biasing network as a switching mechanism to change the pattern behaviour to serve the user. It can be noticed that the common S_{11} bandwidth for all switching conditions is from 3.447 GHz to 3.545 GHz where approximately 98 MHz bandwidth is attainable. Note that, 1100 and 0011 conditions produced similar results due to the symmetric location of the ON switches.

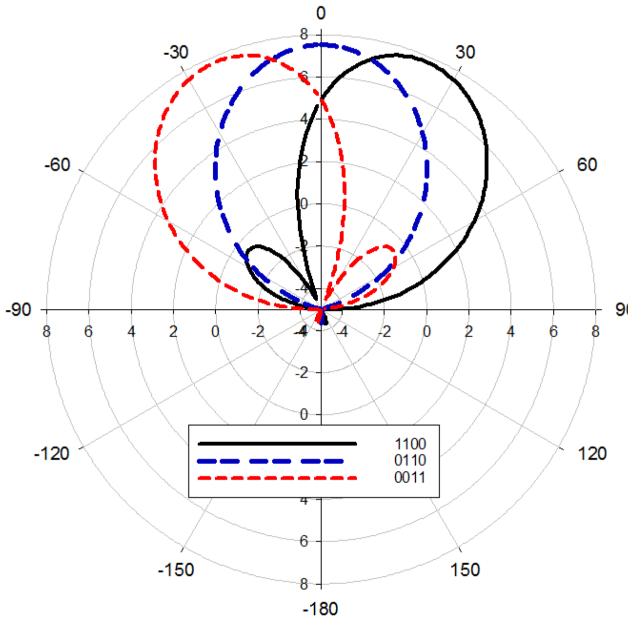

Fig. 4. The polar radiation pattern of RRP antenna at three switching conditions when implemented with the DC Biasing.

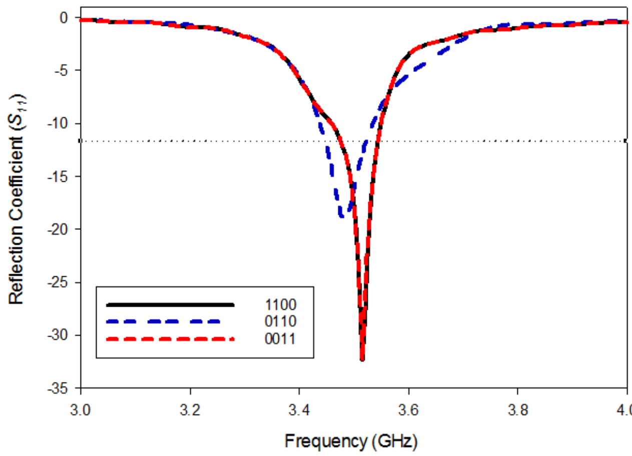

Fig. 5. The reflection coefficient of the RRP antenna at three switching conditions.

B. Results of RPR MIMO Antenna with and without DC biasing

Referring to previous studies [5], the antenna consists of one driven element at the center and two parasitic elements on both sides of the driven element. The parasitic elements act either as a reflector/director and they are tasked to push the radiation pattern in both the left and right direction based on the ON and OFF switch configuration.

Meanwhile, in this paper, the MIMO antenna from previous research is used to investigate the effect of the DC Biasing network which acts as the switching mechanism.

Therefore, based on previous research, nine possible sets of steering combinations were obtained and the result is tabulated in Table II. This work specifically focuses on the analysis when the MIMO is implemented with the DC biasing network. However, the S-parameter results were also observed to see any significant changes. Fig. 6 shows the S-parameter results of the MIMO antenna with implementing the DC Biasing network and without implementing DC Biasing network at all possible switching conditions.

For certain switching conditions and configurations, the resonant is slightly shifted from 3.5 GHz frequency. However, it can be noticed that regardless of the switching conditions and type of configuration, the S parameter results are not much affected. The S_{11} and S_{22} results are less than -10 dB at 3.5 GHz. Meanwhile, the S_{12} and S_{22} results are approximately less than -20 dB.

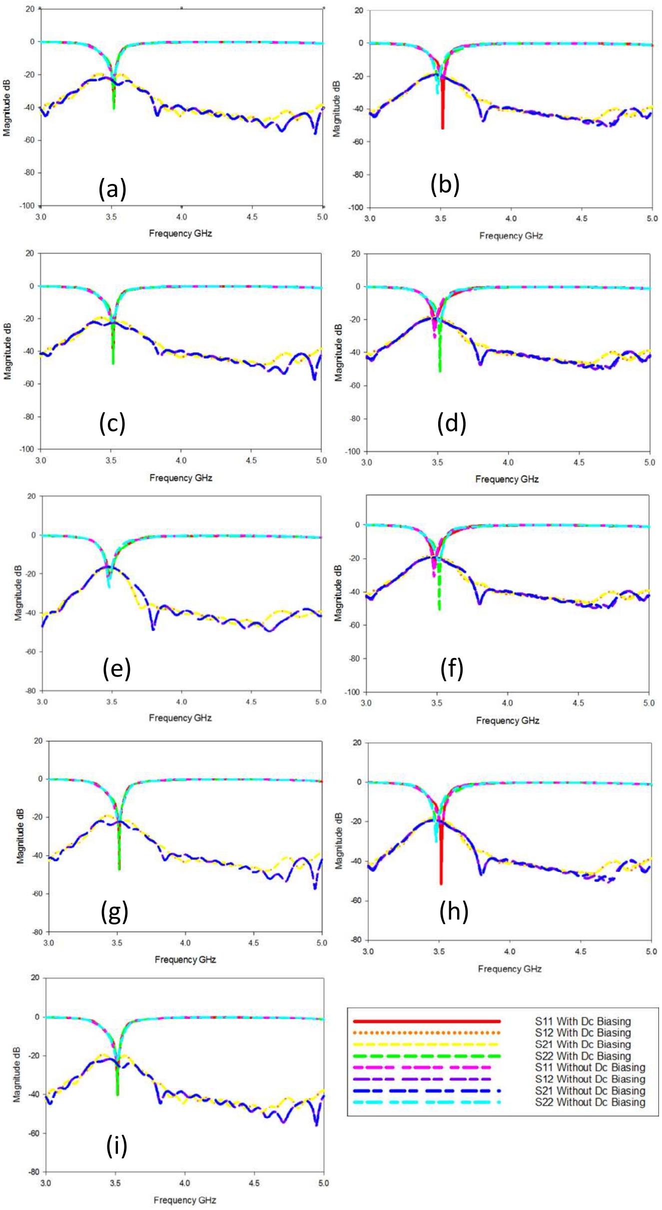

Fig. 6. S-parameter results for RPR MIMO with and without DC Biasing network: (a) L:L, (b) L:C, (c) L:R, (d) C:L, (e) C:C, (f) C:R, (g) R:L, (h) R:C and (i) R:C.

The main interest of this investigation is in the steering performance of the RPR-MIMO after implementing the switching mechanism. From Fig. 7, it can be seen that the tilt angle is improved after implementing the DC Biasing network. The related steering angle and gain of the MIMO antenna after implementation and before implementing the DC Biasing network are tabulated in Table III.

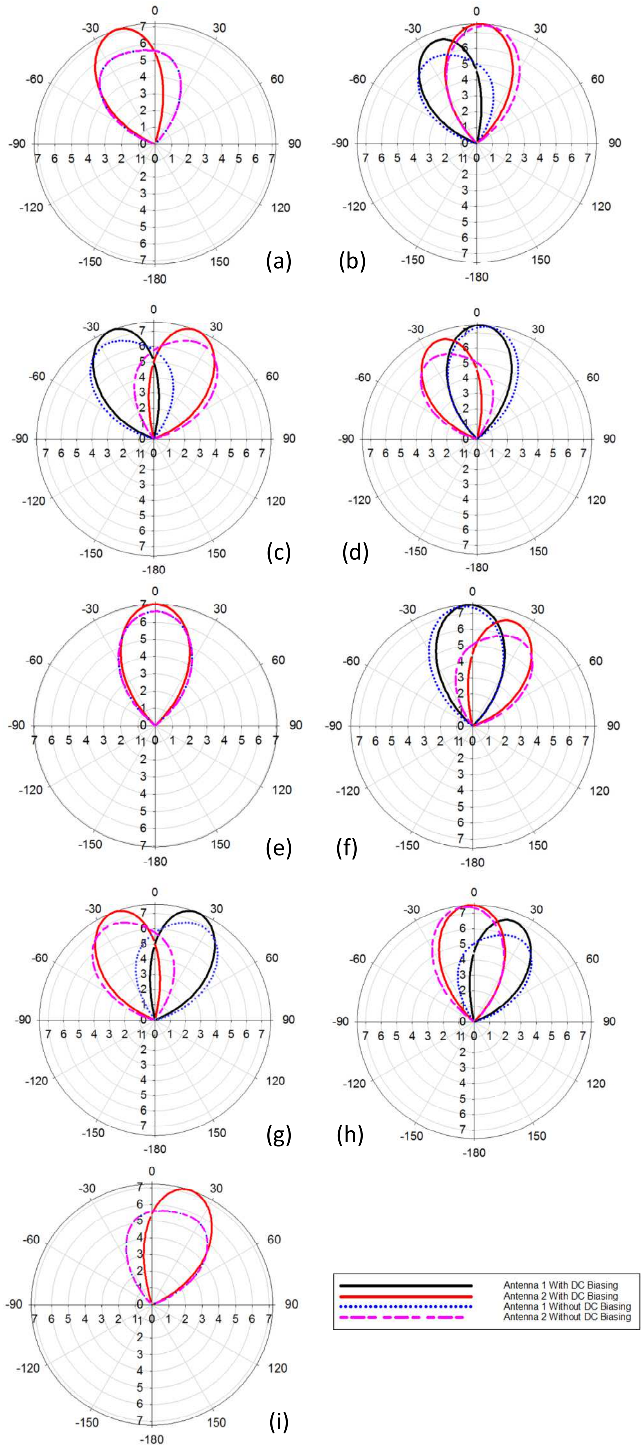

Fig. 7. Polar Radiation Pattern Result for RPR MIMO with and without DC Biasing network: (a) L:L, (b) L:C, (c) L:R, (d) C:L, (e) C:C, (f) C:R, (g) R:L, (h) R:C and (i) R:C.

TABLE II. BEAMFORMING CHARACTERISTICS BASED ON SWITCHING CONDITIONS FOR RPR-MIMO

Desired Direction	Steering Directions	With DC Biasing		Without DC Biasing	
		θ	Gain (dBi)	θ	Gain (dBi)
Ant 1 = -30°	L	-19°	7.22	-22°	5.74
Ant 2 = -30°	L	-19°	7.22	-22°	5.74
Ant 1 = -30°	L	-22°	6.97	-28°	6.09
Ant 2 = 0°	C	-2°	7.54	-5°	7.45
Ant 1 = -30°	L	-21	7.58	-26°	6.88
Ant 2 = +30°	R	+21	7.58	26°	6.88
Ant 1 = 0°	C	+2	7.54	-5°	7.45
Ant 2 = -30°	L	-22	6.97	-28°	6.09
Ant 1 = 0°	C	0	7.05	0°	6.64
Ant 2 = 0°	C	0	7.05	0	6.64
Ant 1 = 0°	C	-2	7.54	+5°	7.45
Ant 2 = +30°	R	+22	6.97	+28°	6.09
Ant 1 = +30°	R	+21	7.58	+26°	6.88
Ant 2 = -30°	L	-21	7.58	-26°	6.88
Ant 1 = +30°	R	+22	6.97	+28°	6.09
Ant 2 = 0°	C	+2	7.54	+5°	7.45
Ant 1 = +30°	R	+19	7.22	+22°	5.74
Ant 2 = +30°	R	+19	7.22	+22°	5.74

CONCLUSION

This work primarily investigates the performance of the RPR MIMO antenna which is implemented with the DC biasing network as a switching mechanism. A single RPR with DC biasing network arranged in form of 2 x 1 MIMO. Lumped element equivalent used to represent the RF switch model in simulation. The investigation conducted has shown that the S-parameter results of RPR-MIMO with and without DC biasing network were not much affected. However, the steering performance was slightly affected. The steering angle was slightly dropped. However, the MIMO antenna implemented with the DC Biasing network shows a better gain in the radiated pattern results. Future work may consider the fabrication of the RPR-MIMO antenna with actual PIN diodes. Other MIMO characteristics could be also investigated through the measurement results.

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