S11 parameter results comparison in reconfigurable antennas under simulation and measurement

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ABSTRACT

In this paper, a simulation and measurement return loss parameter results comparison in frequency reconfigurable antenna is proposed. More low-profile and compact microstrip antennas have been developed in recent years for 5 GHz, 5G, WLAN, Wi-Fi, and ISM band applications. These antenna frequency bands may be single, dual, or multiband. The small microstrip antenna, without connecting any external devices like switches, resonators, and passive elements, does not show any variations in their simulation and measurement results like return loss (S11 parameter), gain, and efficiency. However, in the S11 parameter most frequency reconfigurable antennas show a mismatch between simulation and measurement results. The reason for this mismatch between the simulation and measurement results are given in the paper.

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1. INTRODUCTION

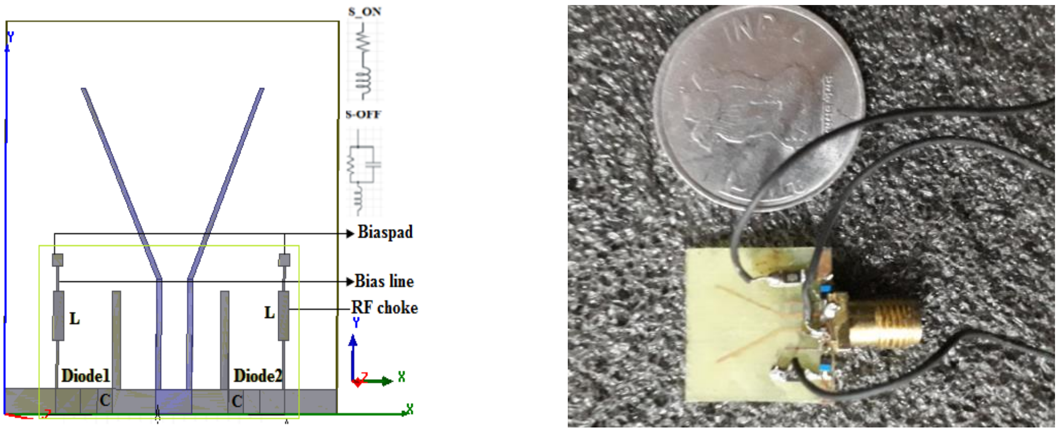
Reconfigurable antennas are attractive solutions for cognitive radio and multiband applications with different time slots. In the early days, to change the frequency bands and shift the radiation pattern of the antenna, some mechanical parts were used in the reconfigurable antenna. These mechanical parts were controlled manually, they had little influence on the antenna parameters. Later, very small microstrip antennas were developed to connect easily with portable electronic devices for reducing the complexity of big antenna structures. Recently, more microstrip reconfigurable antennas have been developed in small size for changing the frequency, pattern, and polarization of the antenna without connecting the big size mechanical rotary parts. But most of the frequency reconfigurable antennas are designed with different diode switches to shift the characteristics of the antenna. These diode switches can be connected easily with the substrate of the microstrip antennas, they are controlled by an externally applied DC bias voltage because the switches are commercially available in the market. Most of the frequency reconfigurable antennas have shown acceptable results in simulation and measurement of their gain and efficiency values, but they showed more variation in the return loss parameters of the antenna.

The return loss parameter of the antenna is also called the reflection co-efficient or S11 parameter. This parameter is more significant in the antenna design because it shows how much input power is accepted by the antenna. Based on the return loss (S11) value, the antenna gives its gain and efficiency. The gain of the antenna is the ratio of radiation intensity of the antenna to the total input power applied to the antenna and the efficiency is the ratio of the radiation intensity of the antenna to the total input power accepted by the antenna. Some dual, triband, and multiband antennas were demonstrated with small variation in simulation and measurement results [1]–[4]. Recently, electrically, and optically controlled reconfigurable antennas have been presented with small variations in their simulation and measurement results as mentioned [5], [6]. An antenna has been developed for frequency reconfiguration with two varactor diode switches. The antenna shows a minimum of -7 dB and a maximum of -12 dB variations between simulation and measurement results. The size of the antenna is (56x56x0.813) mm^3 [7]. Another filtering resonator frequency reconfigurable antenna was developed with three varactor diodes. It depicts the variation of the S11 parameter in all their reconfigurable switching frequencies. But the maximum return loss parameter variation was given in state 1 [8]. A frequency reconfigurable planar antenna with the dimensions of (44x14x3.2) mm^3 was presented in [9]. Two PIN diodes were used in this antenna for reconfiguration. A maximum of -8 dB variations were given by the antenna in the S11 parameter. Next, a (30x30x0.762) mm^3 antenna and a (37x 35x1.6) mm^3 antenna have been developed with two PIN diode switches. Both show a maximum of -12 dB and -15 dB variations in the simulation and measurement result of their S11 parameter [9], [10].

Two optically controlled frequency reconfigurable antennas have been developed with two photoconductive switches and two photodiodes. Both antennas S11 parameter variations are -16 and -4 dB respectively as shown in [11], [12]. In this paper, the return loss parameter of the electrically and optically controlled frequency reconfigurable V-shaped long wire antennas [13], [14] is compared with the other reconfigurable patch antennas, and the explanations for the differences in simulation and measurement results are given in next section.

2. ELECTRICALLY CONTROLLED FREQUENCY RECONFIGURABLE ANTENNA

Figures 1 shows the electrically controlled frequency reconfigurable antenna. This antenna dimension is (16x16) mm^2 and the antenna is designed on the FR-4 substrate. The simulated antenna geometry is illustrated in Figure 1(a) and fabricated antenna geometry is illustrated in Figure 1(b). It consists of a V-shaped radiator on the top side and two tuning stubs on the bottom side. Two PIN diode switches are connected on the bottom side of the antenna for reconfiguration [15]. The logic states produced by these two switches are 00, 01, 10, and 11 (S_00, S_01, S_10, and S_11). The antenna is radiating at 5.8 GHz in S_00 switching condition, radiating at 5.3 GHz in S_01,10 switching conditions [16] and radiating at 5.2 GHz in S_11 switching condition. This electrically controlled frequency reconfigurable antenna shows the difference in results under S11 parameter measurement. The reasons are addressed in the next sections.



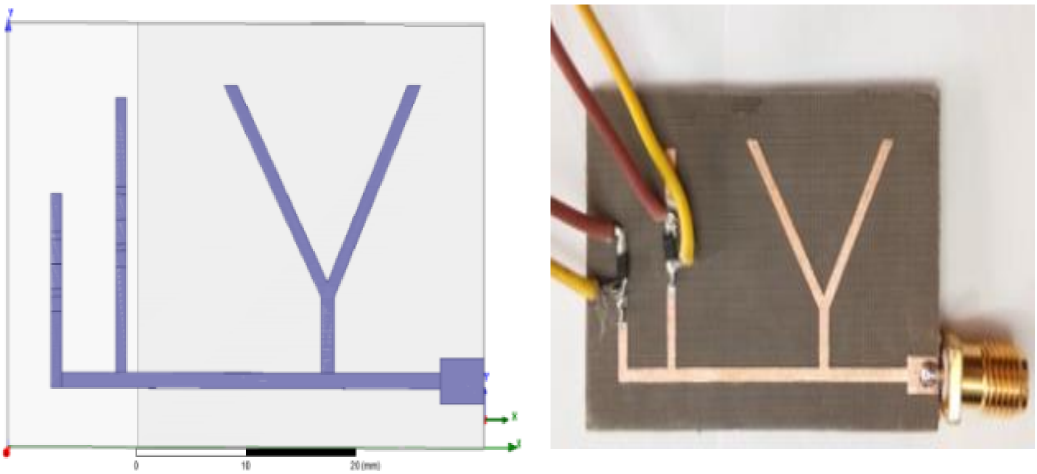
(a) (b)

Figure 1. Antenna structure (a) V-shaped electrically controlled frequency reconfigurable antenna structure and (b) fabricated electrically controlled frequency reconfigurable antenna

3. OPTICALLY CONTROLLED FREQUENCY RECONFIGURABLE ANTENNA

Figure 2 shows the structure of the optically controlled antenna, whereas Figure 2(a) shows the simulated antenna geometry and Figure 2(b) shows the fabricated antenna prototype. The dimension of the antenna is (44x28) mm^2. The antenna is designed for the Roger substrate, whose thickness is 1.6 mm. It has a V-shaped radiator and two parallel stubs. Two PIN photodiodes are connected on the stubs for reconfiguration. The antenna radiating frequency is 4.3 GHz in OFF state of the switches [17]. It reconfigures their frequencies to 3.5 GHz and 5 GHz under the ON condition. This antenna shows the difference in the

S11 parameter the simulation and measurement. The differences in results and their reasons are given in the chapters.



(a) (b)

Figure 2. Antenna structure (a) V-shaped optically controlled frequency reconfigurable antenna structure and (b) fabricated optically controlled antenna

4. POSSIBLE ERRORS IN RECONFIGURABLE ANTENNA DESIGN

The above two antennas are showing the S11 parameter results difference between their simulation and measurement. There are many factors that affect reconfigurable antennas. The possible reasons for these variations are listed out in this section [18].

- Substrate and dielectric constant selection
- Feeding method and connectors
- Switching diodes
- Applying light signal to the optically controlled antenna

4.1. Substrate and dielectric constant

The selection of substrate materials and their dielectric constants is important in the design of a frequency reconfigurable antenna. Basically, for low frequencies up to 5 GHz the FR-4 substrate material can be considered to reduce the loss. But for high frequencies from 5 GHz a good choice is Roger substrate. The Fr-4 substrate does not maintain a uniform dielectric constant for high frequencies [19]. The tolerance value is less than 2%, and it also presents challenges for maintaining the impedance values. If the FR-4 substrate is used in a frequency reconfigurable antenna for high frequencies, it shows more variations in the simulation and measurement results. As explained in chapters 2 and 3, the FR-4 substrate is used for electrically controlled frequency reconfigurable antenna, and the Roger substrate is used for optically controlled frequency reconfigurable antenna. But the optically controlled antenna is designed on a FR-4 substrate instead of a Roger substrate the antenna return loss performance is very poor as -15 dB at S_01,10 and 11 switching state illustrated in Figure 3.

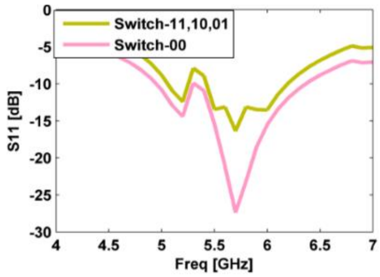


Figure 3. S11 parameter of antenna at different switching states

4.2. Feeding method and connectors

Microstrip and coaxial feed methods are suitable for microstrip antennas. If the substrate thickness of the antenna is too small, microstrip edge feed techniques can be used to get good results. Another factor that creates the mismatch between the simulation and measurement results is the feeding methods and connectors. When the connector impedance is exactly matched with the antenna impedance, the antenna gives good results in simulation and measurements. Figures 4 illustrate the three different feeding methods used for the reconfigurable antenna design. Figure 4(a) represents the CPW feed method, Figure 4(b) shows the lateral feed method and Figure 4(c) represents the bottom feed method. Figure 4(d) shows their return loss parameter analysis for the three different feeding methods. The comparison shows the variation in the three feeding methods. The bottom feed method is suitable for this V-shaped frequency [20] reconfigurable antenna design. Because the connector impedance is matched with the V-shaped radiator impedance compared with other antennas. So, this method produced a minimum return loss value of -32 dB at 5.2 GHz.

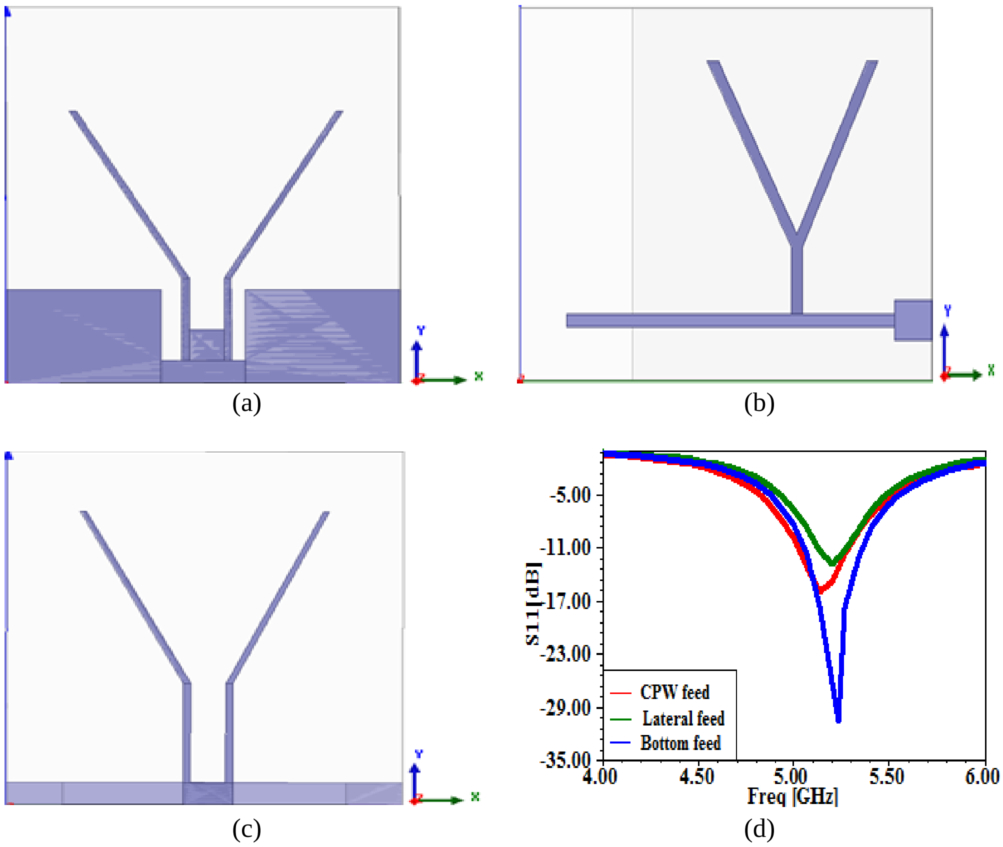
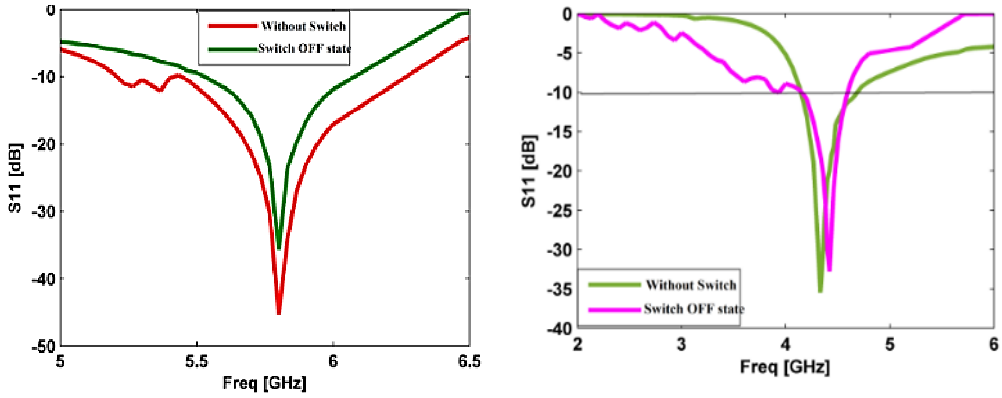


Figure 4. V-shaped antenna with different feeding method (a) CPW feed, (b) bottom feed, (c) lateral feed, and (d) S11 parameter of the antenna with various feeding method

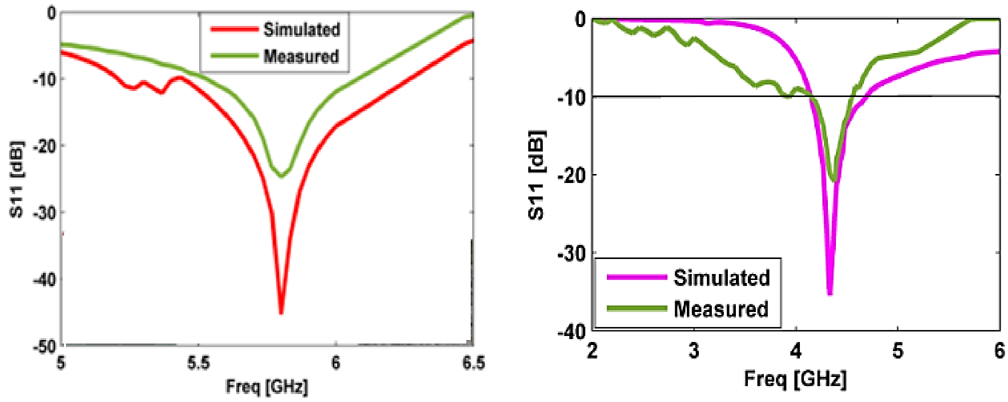
4.3. Switching diodes

The above two (sub section 4.1 and 4.2) electrically and optically controlled frequency reconfigurable antenna shows minimum return loss values as given in Figure 5 without connecting any switching diodes for reconfiguration. Where Figure 5(a) represents the S11 parameter of electrically controlled antenna and Figure 5(b) represents the S11 parameter of optically controlled antenna without connecting switch. But to reconfigure their frequency, two switches are connected in the reconfigurable antennas. After connecting the switches, their return loss value of the antennas is increased as shown in Figures 6. The simulated return loss values of the electrically and optically reconfigurable antennas before connecting the switches are -45 dB, -35 dB respectively [21] and their measured values are -35 dB, -33 dB respectively as illustrated in Figure 6(a) and Figure 6(b). But after connecting the switches to the antenna, the antennas give their measured values are -25 dB and -20 dB. So, the externally connected switches produces the insertion loss. It leads the results differences in S11 parameter under their simulation and measurement.



(a) (b)

Figure 5. S11 parameter of the frequency reconfigurable antenna without connecting switch (a) electrically controlled and (b) optically controlled



(a) (b)

Figure 6. S11 parameter of the frequency reconfigurable antenna with switch (a) electrically controlled and (b) optically controlled

4.4. Electrically controlled antenna

Figure 7 depicts a comparison of the results using an electrically controlled V-shaped long wire antenna. Two PIN [14] diode switches (SC79 package BAR63-06 PIN diodes) are used in this frequency-reconfigurable antenna. It gives four logical states: 00, 01, 10, and 11 (S_00, S_01, S_10, S_11). Table 1 illustrates the S11 parameter difference between simulation and measurement. All the states produce good results when the model is simulated, but they show more variations in S_00 and S_01 switching conditions when the antenna parameters are measured. The possible reasons for these variations are, the specifications of the switching diodes are not perfectly matched with the given lumped element values in simulation. The internal resistance, capacitance, and inductance values used to simulate the electrically controlled antenna are 1.4 Ω, 0.6 nH in the ON state, and 2 kΩ, 0.4 pf in the OFF state. When these values are created in the real diodes by adjusting DC bias voltage to the diode switches, their ON and OFF state values of the switches do not match with the simulated values. So, the antenna gives high return loss values in the measurement results. From the illustration of Figures 7(a)-7(d), the antenna shows the result differences in the simulation and measurement not only by the connection of the switch and parasitic elements but also in the selection of the switch and its specifications.

4.5. Optically controlled antenna

The optically controlled frequency reconfigurable antenna shows more variations in simulated and measured results than the electrically controlled reconfigurable antenna because an optical signal is also applied to the photodiode switches [22]. The switches and passive components in the optically controlled antenna produce more loss than the electrically controlled frequency reconfigurable antenna. In optically

controlled antennas, the switch is simulated in the following two ways, both methods create the mismatch when the antenna is fabricate:
- All internal passive component values are assigned through lumped element assignment.
- A small box is assigned in the place of a switch, and it is activated by changing the conductivity values to create a poor conductor (OFF state) and a good conductor (ON state).

Another possible mismatches are created by, when the optical signal is not correctly [23] focused on the photodiodes, the light source is not tightly coupled to the photodiodes diodes, and the wavelength of the photodiode is not correctly selected, which leads to more variations in the simulated and measured return loss values. Two TEMD71001TX01 PIN photodiodes are used as a switch. The photodiodes are activated by an LED lamp and reverse-biased DC voltage. Figure 8 and Table 2 show the variations in optically controlled antenna simulation and measurement results variations [24]. Whereas Figures 8(a) and Figure 8(c) illustrate more variations and Figures 8(b) and Figure 8(d) illustrate the less variations in S11 parameter simulation and measurement. If the LED lamp method is used for measurement, the antenna shows more variations between the simulation and measured results. Another problem with this method is that both switches are activated at the same time [25], [26]. The intermediate switching states of 01 and 10 are not created by this method; only 00 and 11 states can be created. By avoiding this, photodiodes can be activated separately by using LEDs coupled optical fiber cables.

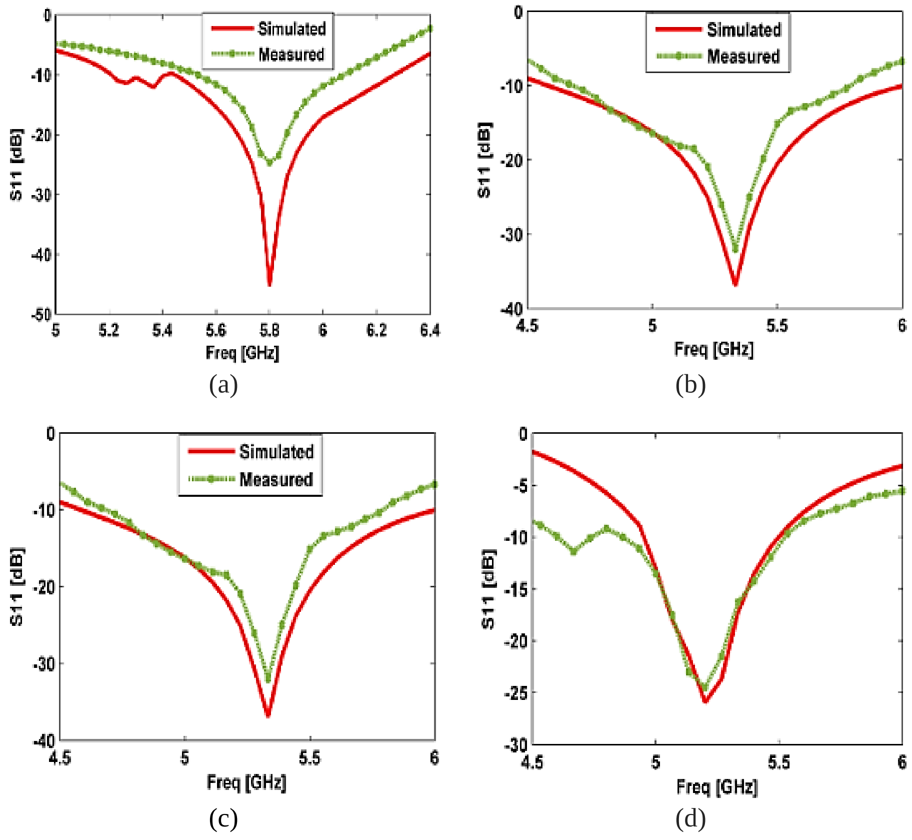


Figure 7. S11 parameter of the antenna with PIN diode switch (a) OFF OFF, (b) OFF ON, (c) ON OFF, and (d) ON ON

Table 1. Simulation and measured results variation in electrically controlled antenna

Switching condition	Frequency (GHz)		Return loss(dB)		Difference
	Simulated	Measured	Simulated	Measured	simulation and measurement
S_00	5.8	5.81	-45	-25	-20
S_01	5.3	5.3	-40	-31.6	-8.4
S_10	5.33	5.3	-37	-31.6	-5.4
S_11	5.2	5.2	-28	-25	-3

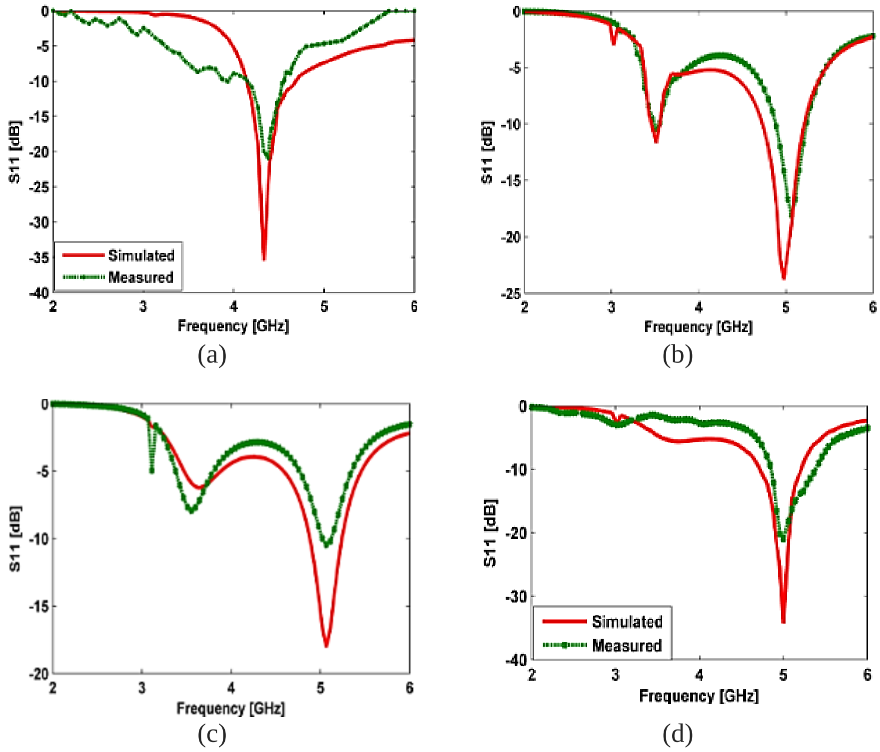


Figure 8. S11 parameter of the antenna with photodiode switch (a) experiment-1 (DC bias voltage and light signal not applied), (b) experiment-2 (DC bias applied but light signal not applied), (c) experiment-3 (DC bias not applied, light signal applied), and (d) experiment-4 (DC bias and the light signal applied)

Table 2. Simulated and measured results variation in optically controlled antenna

Experiments	Frequency (GHz)		Return loss(dB)		Variation between simulated and measured results (dB)
	Simulated	Measured	Simulated	Measured	
Experiment -1	4.3	4.32	-35.4	-21	-14.4
Experiment - 2	3.5 and 5	3.57 and 5	-6.2, -18	-8.3, -10	-2.1, -8
Experiment - 3	3.5 and 5	3.5 and 5.1	-11, -24.7	-10.2, -18.5	-0.8, -6.2
Experiment - 4	5	5	-35	-20	-15

Table 3 compares the maximum S11 parameter variations in simulation and measurement results in electrically and optically controlled [13], [14] frequency reconfigurable antennas with other reference antennas. From the table, we conclude that the reconfigurable antenna shows the difference between their simulation and measurement results because the selection and connection of diode switches, DC bias voltage, optical signal and feeding connectors.

Table 3. The simulated and measured table comparison with other antennas

Papers	Size of the antenna (mm^3)	Switching state	Frequency (GHz)		Return Loss(dB)		Maximum Variation between simulation and measured results (dB)
			Simulated	Measured	Simulated	Measured	
7	56x56x0.813	at 9V	5	5.16	-28	-40	-12
8	53x70x0.813	state1	2.3	2.3	-18	-13	-5
9	44x14x3.2	D 1 on, D 2 off	0.85	1.2	-25	-17	-8
10	30x30x0.762	Mode 3	3.4	3.4	-35	-15	-20
11	37x35x1.6	state3	5	5	-30	-12	-18
12	20.48x17.65x1.6	off state	5.8	6	-26	-42	-16
13	82.3x35.5x1.17	D1-OFF, D2-ON	2.7	2.7	-9	-5	-4
Proposed (electrically controlled)	16x16x0.32	D1-off, D 2-off	5.8	5.81	-35	-24.7	-11
Proposed (optically controlled)		experiment-1	5	5	-35	-20	-15

5. CONCLUSION

From the above analysis, the results show that the variation in the S11 parameter between simulation and measurement for small microstrip antennas are common. But this error can be reduced by proper selection of the dielectric substrate, selection of switches, and selection of bias voltage in electrically and optically controlled reconfigurable antennas. The reflection loss is high in very low profile microstrip reconfigurable antennas compared with other dimensions because, all the switches and their bias circuits, blocking capacitors are connected to the small substrate. But in an optically controlled frequency reconfigurable antenna, the loss can be reduced by using a proper experimental setup, and the light signal is closely passed to the photodiodes to select the peak sensitive wavelength of the photodiodes.

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