Study of Decoupling between Closely Spaced Microstrip MIMO antennas using Microstrip Resonator

Swati Bhattacharjee
Asansol Engineering College
Chandan Kumar Ghosh (mcet_ckg@yahoo.com)
Dr BC Roy Engineering College https://orcid.org/0000-0003-1699-900X

Research Article

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Abstract

This paper presents a novel decoupling technique between two closely spaced MIMO antennas whose edge to edge spacing is0.03λ (1.975mm).A microstrip resonator is used in between the antennas that act as a decoupled device. The MIMO plays an important role in the current communication system due to its enhanced data transferring rate. However, the closely spaced MIMO antennas have a major disadvantage of high mutual coupling (MC). MC affects the entire characteristics of MIMO antennas and as a result, the performance of the antenna degrades. To overcome this problem, we have introduced a microstrip resonator that acts as an electrical wall between the MIMO antennas. The antenna has been simulated by using an IE3D EM simulator and a suppression of 48dB MC is achieved at a resonant frequency of 4.85 GHz. The MIMO antennas have been fabricated and the results are compared with the simulated ones. This antenna can be used in wireless communication, WLAN and satellite communication.

Introduction

Microstrip antennas are applicable to spacecraft, aircraft, and missiles as these antennas are light weight, low fabrication cost, flexible, and also support both linear and circular polarization [1]. Microstrip array and MIMO structures can easily be constructed therefore; it grows interest on the researchers to design various array and MIMO configurations for achieving better performances such as directivity and data throughput. In our attempt, we have designed a two-element MIMO structure and the MC between the closely spaced MIMO antenna elements has been optimized by introducing a microstrip resonator between the antenna elements. It has been seen that the MC is increased with decreasing the separation between antenna elements of the array [2]. Therefore, to design a compact array/MIMO structure, it is required to maintain low MC to achieve better array/MIMO performances. Few works on MC have already been reported in the open literature where researchers used Defected Ground Structure (DGS) [3, 4] and Electromagnetic Band Gap (EBG) [5] structure to tackle mutual coupling. These methods provide high back radiation and the results are the radiation loss in the principal plane [6]. Some other techniques have also been introduced to reduced mutual coupling, such as meander line resonators [7], microstrip U-shaped resonator [8], folded split-ring resonators [9], metamaterial inspired superstrate [10], slotted-complementary split-ring resonators [11], microstrip I-shaped resonator [12] etc. These structures also suffer from some disadvantages. In [7] Jeet Ghosh et al. proposed a meander line resonator in between two microstrip patch antennas. Here, the authors have achieved an 8dB reduction of MC at. Saeed Farsi et al. in [8] have used a simple microstrip U-section in between the two antennas. In this design, the center to center distance between the antenna elements is kept 0.6λ and this decoupling structure reduces the MC by 10 dB at a resonance frequency of 2.4 GHz. In [9]authors proposed folded split-ring resonators in between two closely spaced antenna elements (edge to edge spacing 0.039λ).In this design, MC is reduced by 30dB at a resonant frequency of 5.2GHz.Liming Si et al. have used metamaterial-inspired superstrate [10] as a decoupling structure and 29dB reduction of MC has been achieved in this design. In [11], MC of 10dB at 5.0 GHz has been suppressed at the cost of a complicated metamaterial structure used in between two antennas. A simple I-shaped resonator structure composed of two E-shaped microstrip antennas with centre to centre spacing of 0.45 λ is presented in [12].Here, 30dB suppression of MC has been achieved. In spite of few disadvantages, some good papers [13-17] in this line are referred to comparison (Table-1). In our work, we have proposed two-element MIMO antennas located extremely closed to each other (1.975mm or 0.03λ, edge to edge distance) with a decoupling structure loaded with few rectangular slots is placed in between the antenna elements. In this attempt, suppression of MC of 48 dB is achieved at a resonant frequency of 4.85GHz. The proposed design is simulated using the method of moment (MOM) based IE3D simulator and the electrical characteristics are thoroughly investigated.

Antenna Design And Result

To investigate the novel decoupling method two identical rectangular patch antennas with inset line feed technique has been considered. The single element rectangular patch antenna with dimensions is shown in Figure-1(a).The length and width of the basic antenna element is obtained from the standard design formulae. In this design, FR4 substrate of thickness 1.6 mm, loss tangent of 0.02, and dielectric constant of 4.4 are taken into consideration. Figure-1(b) shows the return loss characteristics for the single element antenna.

A return loss (S_{11}) of -30 dB at resonance (4.85 GHz) is observed from Figure-1(b)

.Figure-2(a) shows the schematic of the proposed antennas with inset line feed where edge to edge spacing of 0.03λ and center to center distance between the two antenna elements is 0.25λ. Table-1 shows the design parameter (mm) of the proposed antenna. As the two antenna elements are in close proximity the MC between the antenna elements will degrade the MIMO antenna characteristics including radiation patterns in the principal plane as the surface current and near fields take a major role for MC between the patches. The simple microstrip resonator of length 21.8mm (0.35λ) loaded with rectangular slots is introduced in this design to reduce MC as shown in Figure-2(b).Figure-3 illustrates the S-parameter characteristics with and without resonator structure. From Figure-3, it is observed that the MC is suppressed by 48 dB when the resonator is inserted between the patches. In this investigation, MC of 7dB without resonator and 54dBwith resonator at resonance is observed.

Table-1 Design parameters of the proposed antenna

Parameter	L	w	r	s	t	p	q
mm	44.05	42.225	6.85	20.425	3.45	15.3	8.775

From Figure-4(b), a stop band at the resonant frequency of 4.85 GHz is observed. Hence, the slotted microstrip resonator acts as a filter at the resonant frequency and as a result the MC is suppressed. Here, the resonator creates an extra indirect coupling path so the direct MC between the two antenna elements is canceled out as shown in Figure-4(c). This inserted decoupling structure does not affect the radiation pattern, antenna gain, return loss characteristics of the antenna.

Figure-5 illustrates the 3D radiation pattern of the proposed antenna and a gain of 6.66 dBi at 4.85GHz frequency is noticed.

The simulated current distribution patterns of the MIMO antenna with and without resonator are shown in Figure-6.

From Figure-6(a), it is seen that when port-1(antenna-1) is excited, antenna-2 affects by MC. Similarly, when port-1(antenna-1) of Figure-6(b) is excited in presence of a resonator, antenna-2 hardly affects by MC. Here, the resonator acts as an electrical wall which caused the suppression of MC in presence of resonator. Figure-7 shows a study of simulated co-polar and cross-polar radiation with and without resonator

From Figure-7, we observed that there is no significant difference between co-polar radiations in both cases (with and without resonator). It is also seen that 7 dBi cross-polar radiations is suppressed when a resonator is introduced in between the two antenna elements of the MIMO structure. A parametric study of S_{21} is done (Figure-8) by varying the length (mm) of the resonator.

Parametric Study And Comparison Of Performance

Figure-7 shows the variation of S_{21} by increasing and decreasing the length (mm) of the resonator. The best result is obtained when the length of the resonator is 21.8mm (optimized).Table-2 shows a comparison of some recent related works to show the novelty of our design which provides maximum reduction of MC.

Table- 2 Comparison table for performance analysis of previous works with our proposed works

Reference	Methodology used	Resonating Frequency (GHz)	Reduction of Mutual Coupling (dB)	Remarks
3	Dumbbell shaped DGS	5.6	35.6	Back Radiation
4	U-Shaped DGS and inverted and U-shaped microstrip resonator	2.45	20	Back Radiation
5	EBG	5.8	23	Back radiation
6	Dumbbell-shaped split-ring DGS	2.45	36	Back radiation
7	Meander line resonator	2.8	8	Low mutual coupling reduction
8	Microstrip U-shaped resonator	2.44	<20	Low mutual coupling reduction
9	Folded split-ring resonators	5.2	30	Complicated structure
10	Metamaterial inspired superstrate	4.9	23	Very complicated structure used
11	Slotted-complementary split-ring resonators	5	10	Low mutual coupling reduction
12	I-shaped resonator	3.94	30	Antenna elements are not too closely spaced
13	Slot structure on the ground between the microstrip antennas	5.8	40	Back radiation
14	CPW structure	2.4	36	High cross-polarization radiation
15	Mesh type resonator	5.9	19.5	Low mutual coupling reduction
16	Multiband application using dumbbell DGS	2.3 3.3 5.8	2 - 5 0.6 - 2.3 2.9	Low mutual coupling reduction
17	Electromagnetic Soft Surface	3.65	35	Complicated EM soft surface structure
Proposed design	**Slotted Microstrip resonator**	**4.85**	**48**	**Simple structure, High MC suppression, Compact design**

Antenna Fabric And Measurements

The prototype antennas with and without resonators are fabricated using FR4 substrate as shown in the Figure-9.

The return loss characteristic of the prototype antenna with resonator has been measured and the results are illustrated in the Figure-10. From Figure-10, it is seen that there is a little difference between simulated and measured return loss characteristic. This may be due to the little imperfection of fabrication process of the antenna.

Measured and simulated S-parameters result with and without resonator are shown in the Figure-11.

From Figure-11, it is observed that there is a slight mismatch between simulated and measured S21 characteristics. This may be due to the measurement and fabrication error of the antenna. The measured S21 values show that there is a suppression of MC of 42 dB which is noticeable suppression of MC.

Figure-13 shows the antenna efficiency with resonator. From figure-11, it is seen that the the efficiency of the antenna at resonance is 97%.

Figure-14 shows measured radiation patterns with and without a resonator. These results show that there is no significant difference between the two measured co-polar radiations. The cross-polar radiations between ‘with resonator and without resonator’ differ much. Here, cross-polar radiation is suppressed by 7 dB when a resonator is used.

Conclusion

This article presents a novel decoupling microstrip resonator structure loaded with rectangular slots of optimized length21.8mm ($0.35\lambda_0$) between closely spaced ($0.03\ \lambda_0$) microstrip antennas. Using the proposed design, we have achieved a maximum 42.5dB reduction of MC, the suppression of cross-polarization of 7 dB, gain of the antenna of 6.67 dBi and antenna efficiency of 97%. This design is successfully examined using IE3D EM simulator. The resonator used in this design does not affect the other parameters of the antenna. This antenna can be used in wireless communication especially mobile communication, GPS and radar.

Declarations

The submission is an original one which is based on microstrip antenna entitled, “Study of Decoupling between Closely Spaced Microstrip MIMO Antennas using Microstrip Resonator” authored by Swati Bhattacharjee, Chandan Kumar Ghosh and submitted by Chandan Kumar Ghosh (corresponding author). This paper is original and it has not been submitted elsewhere for publication.

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Figures

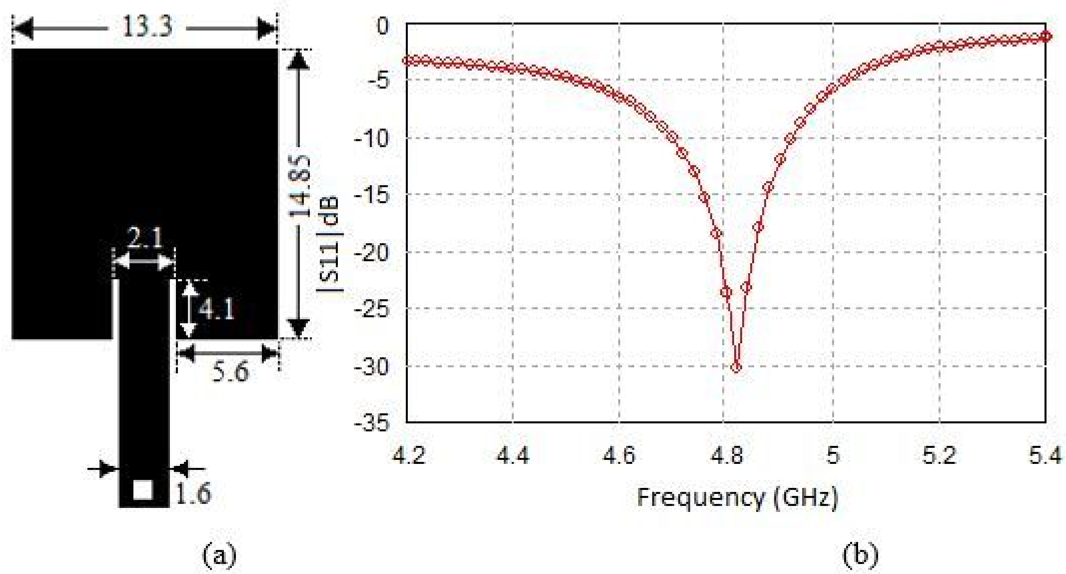

Figure 1

(a) Single element rectangular patch antenna (dimensions are in mm). (b) return loss characteristics

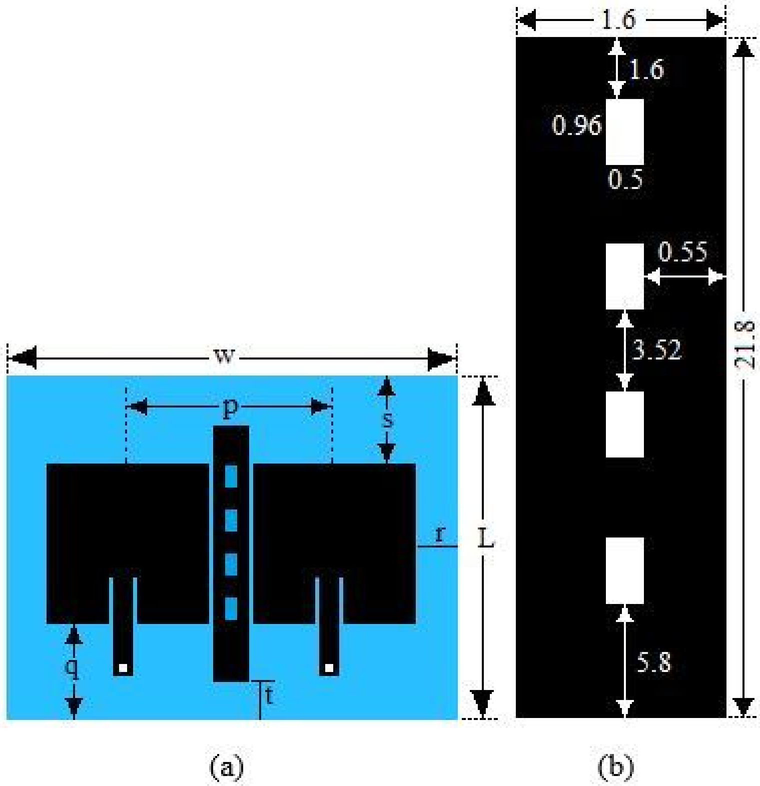

Figure 2

(a) Schematic of the MIMO antennawith decoupling structure (b) microstrip resonator with rectangular slots (all dimensions are in mm)

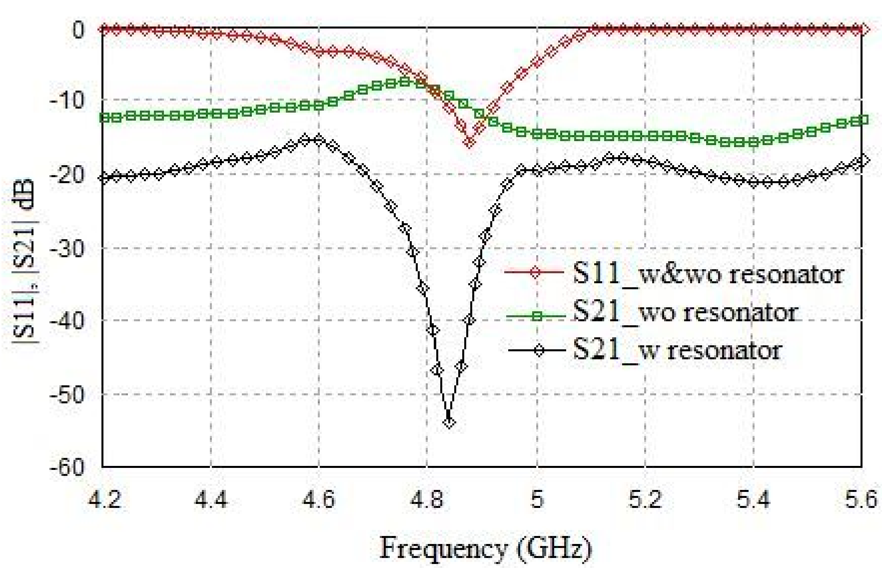

Figure 3

S11and S21 parameter with and without resonator

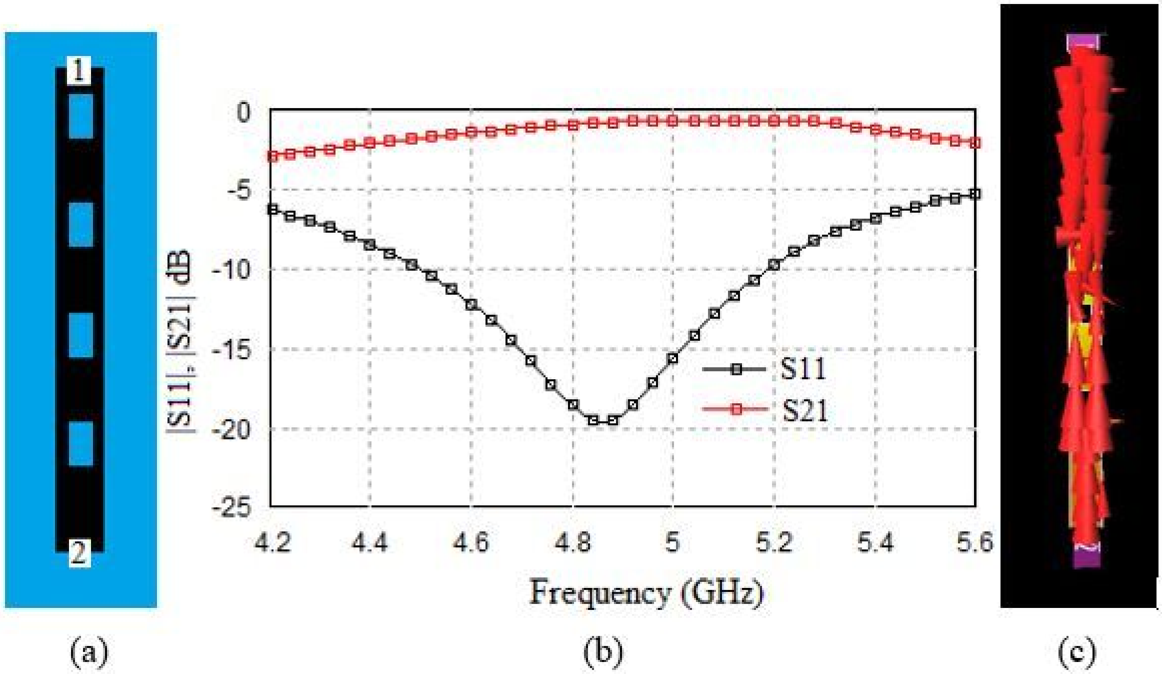

Figure 4

Microstrip resonator with ports (b) Simulated electrical characteristics of the

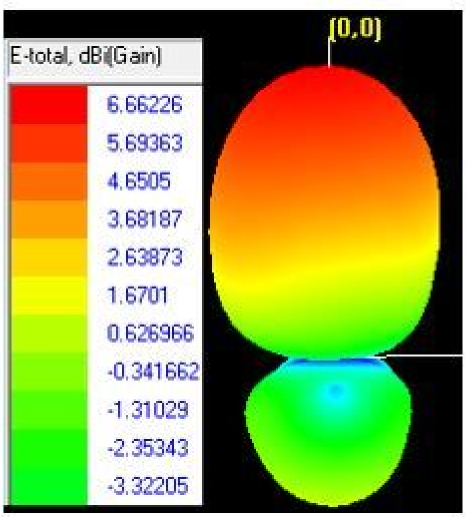

Figure 5

3D radiation pattern with resonator at 4.85 GHz

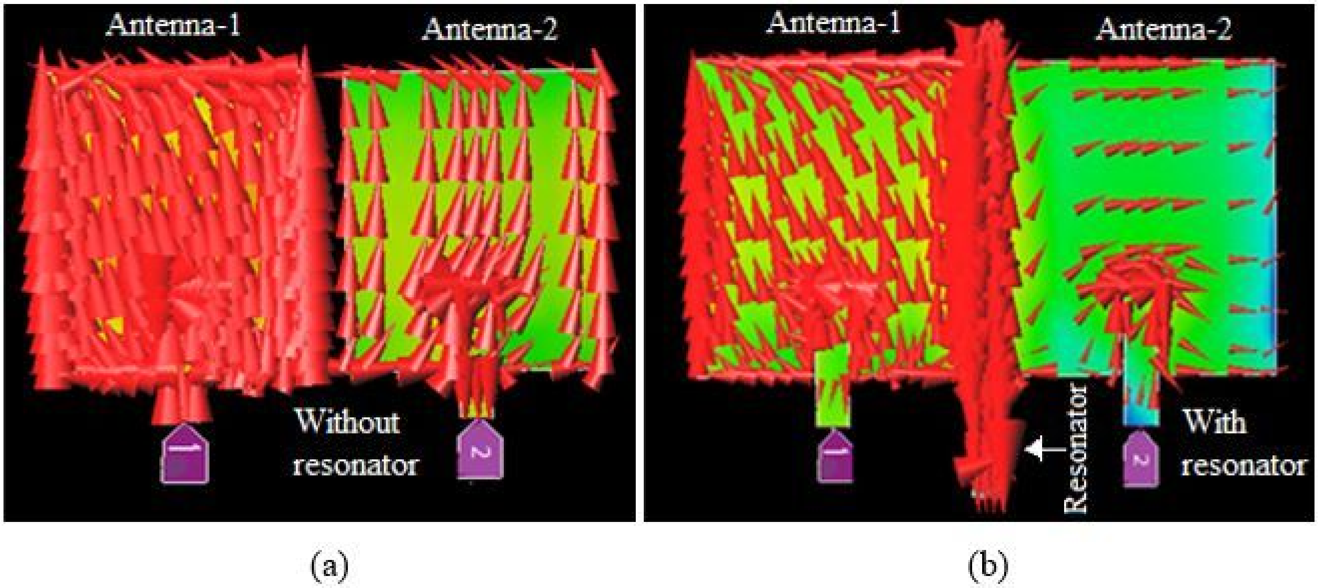

Figure 6

(a) Vector current distribution without resonator (b) with resonator

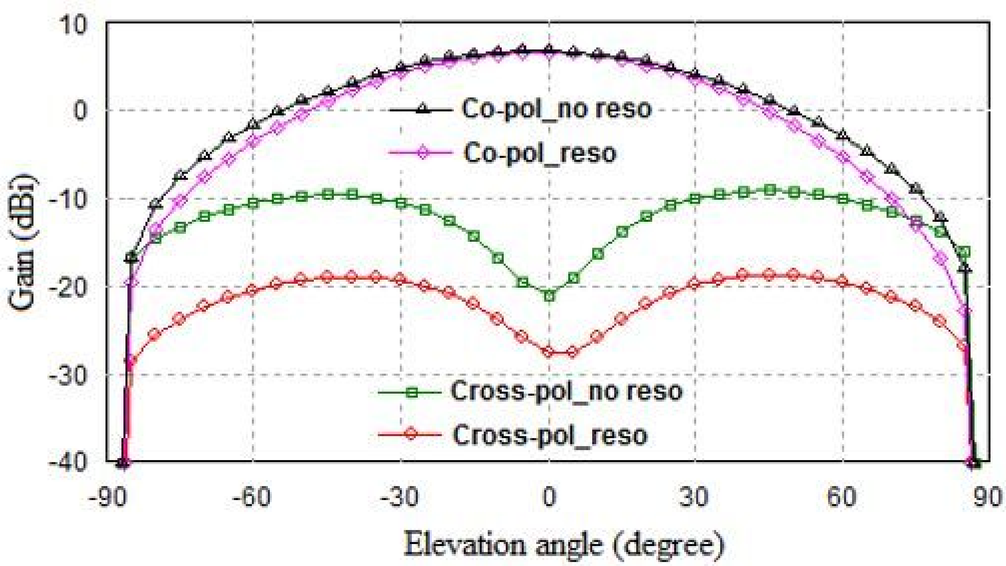

Figure 7

Simulated co-pol. & cross-pol. study with and without a resonator

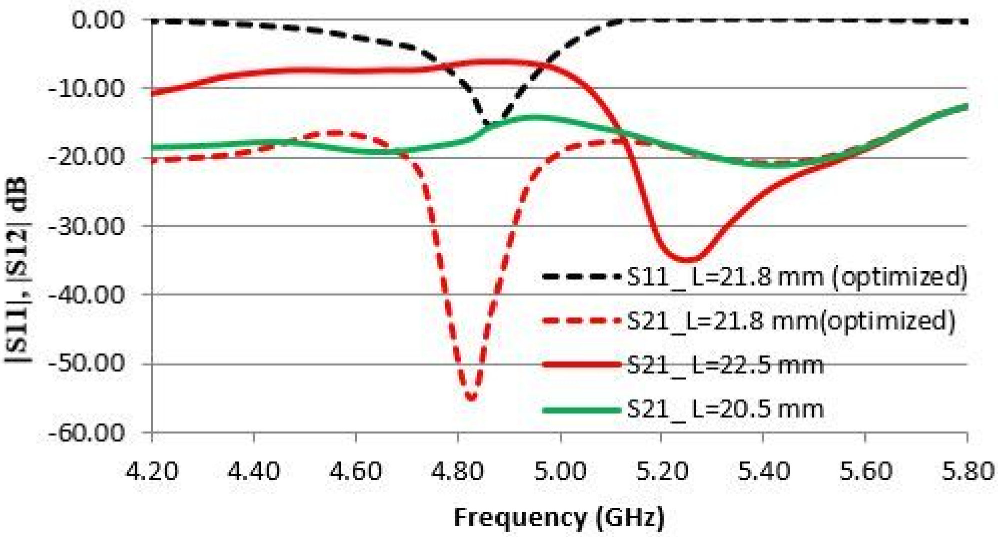

Figure 8

Variation of S21 by increasing and decreasing the length (mm) of the line resonator

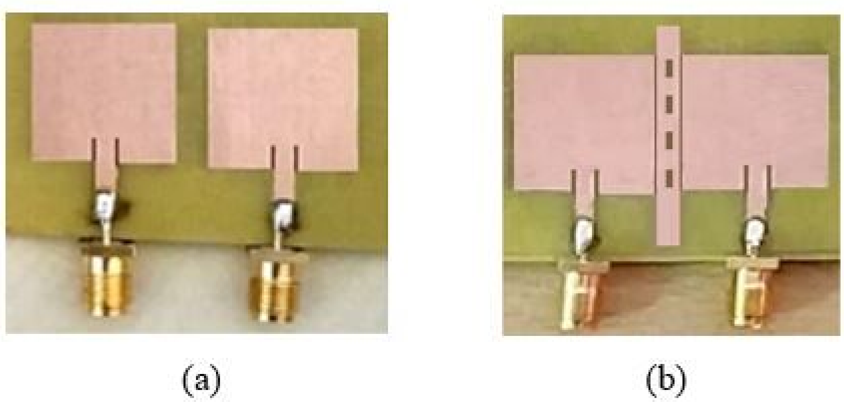

Figure 9

Prototype MIMO antenna, (a) without resonator and (b) with resonator

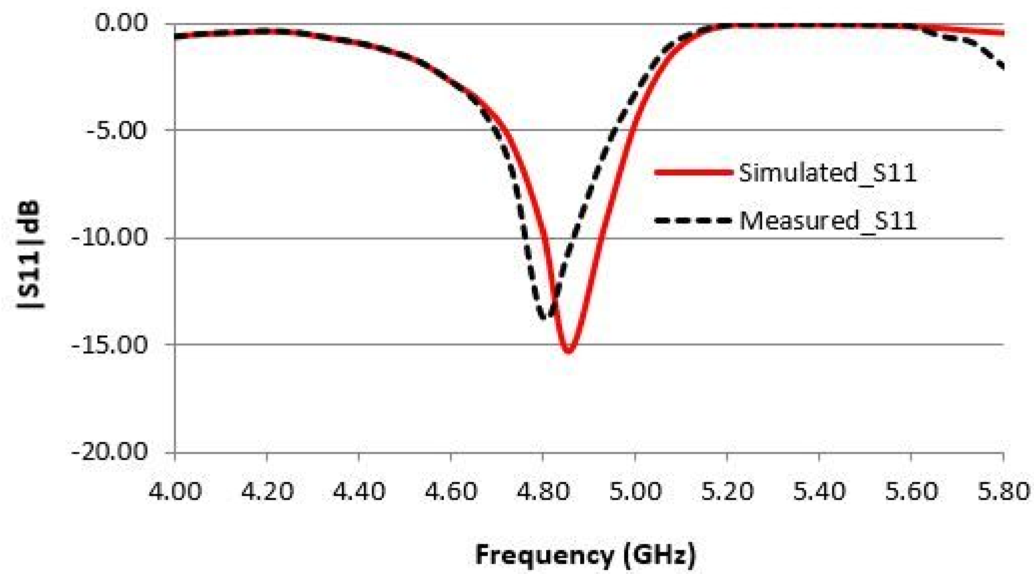

Figure 10

Simulated and measured return loss characteristic

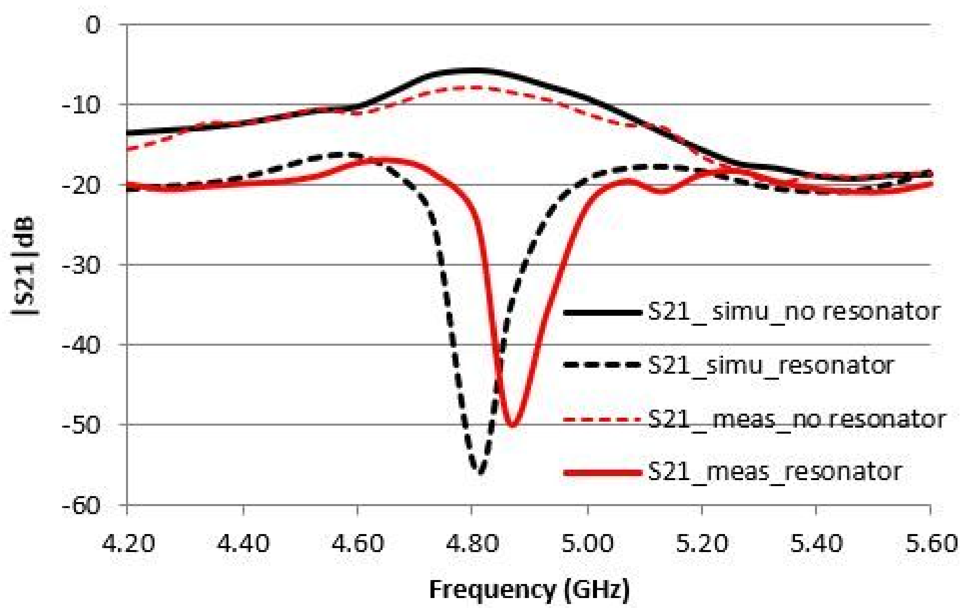

Figure 11

Measured and simulated S-parameters results with and without a resonator

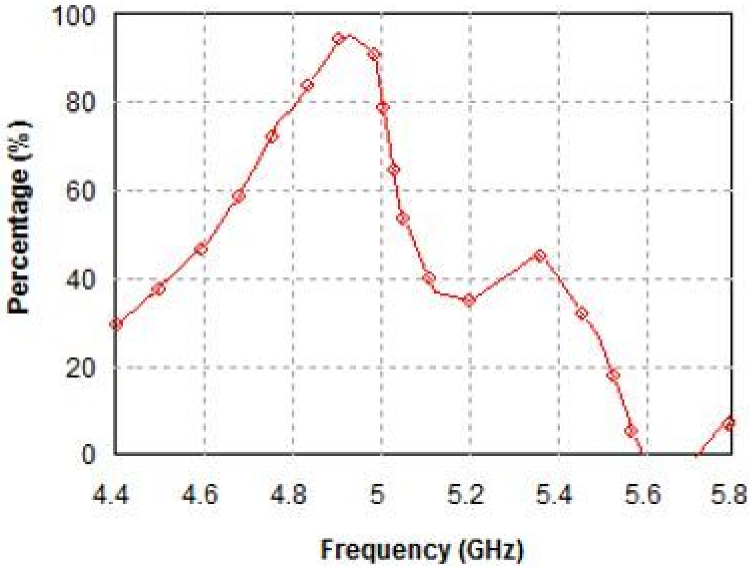

Figure 12

Antenna efficiency with resonator

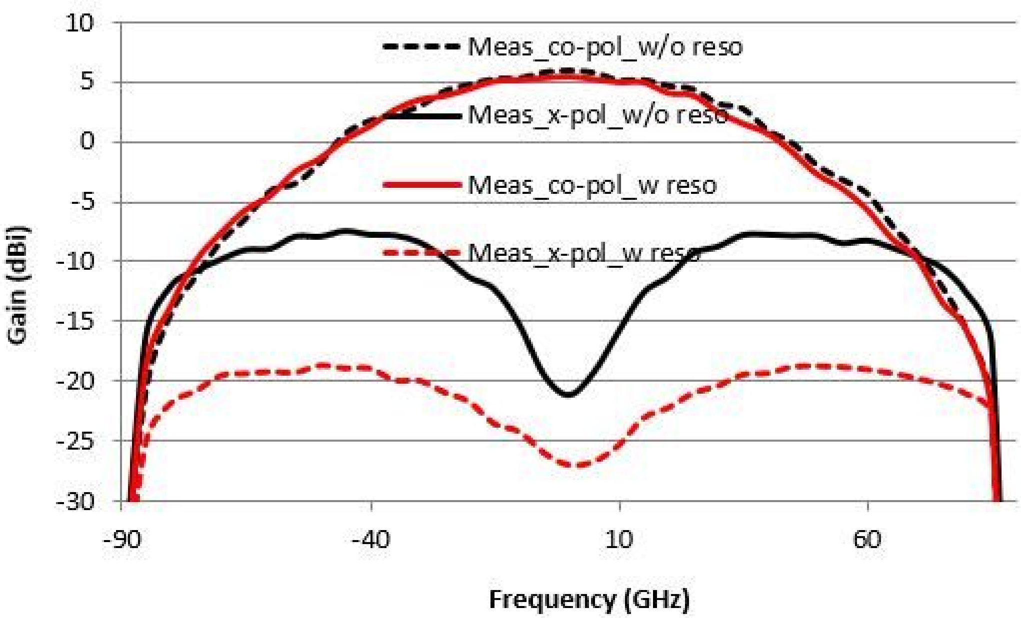

Figure 13

Measured radiation patterns with and without a resonator