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EGYPT-JAPAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
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E-JUST

DESIGN AND DEVELOPMENT MIMO ANTENNAS FOR WIRELESS COMMUNICATIONS

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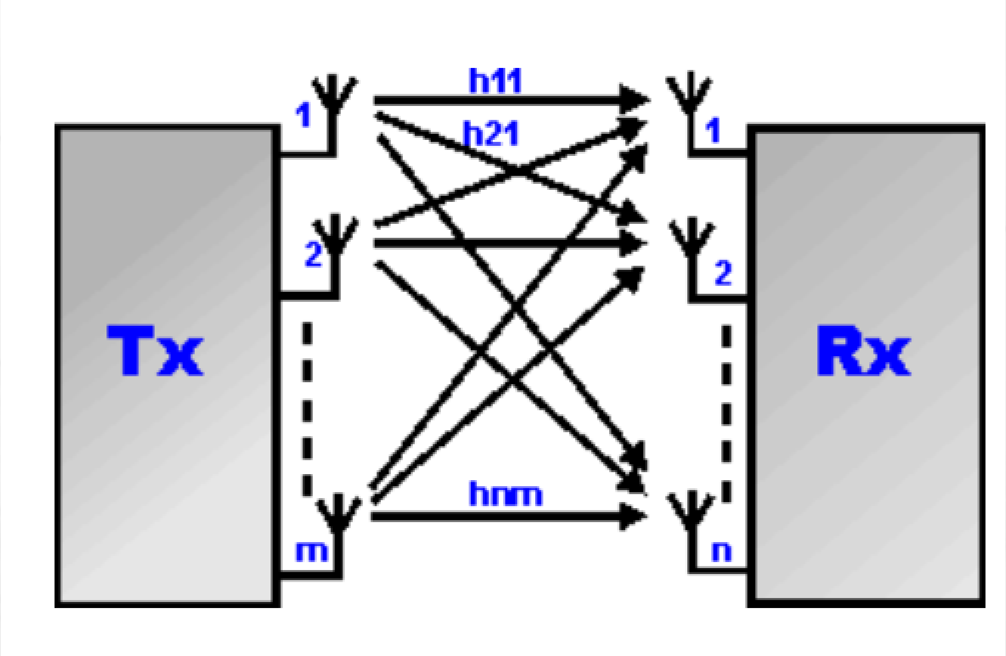
- Introduction
- Problem Statement
- Objective
- Proposed Work / Results
- Conclusion

Introduction

- **MIMO** is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used.



Introduction (Cont.)

Why MIMO

The use of MIMO (Multiple Input Multiple Output) technology in wireless communication systems

- Increases the channel capacity.
- Increases the reliability of wireless communication systems.

These characteristics are achieved without increasing the bandwidth and transmitter power.

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MIMO System

- Antenna Element
- Decoupling Technique

Introduction (Cont.)

MIMO System

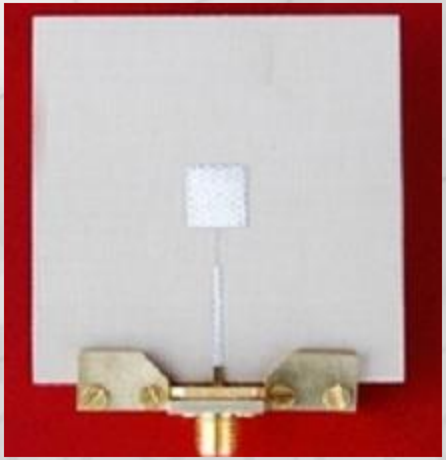
Antenna Element

Decoupling Technique

Introduction (Cont.)

Patch antenna

- One of the most useful antennas at microwave frequencies (f > 1 GHz).
- It usually consists of a metal "patch" on top of a grounded dielectric substrate.
- The patch may be in a variety of shapes, but rectangular and circular are the most common.



Microstrip line feed

Coax feed

Introduction (Cont.)

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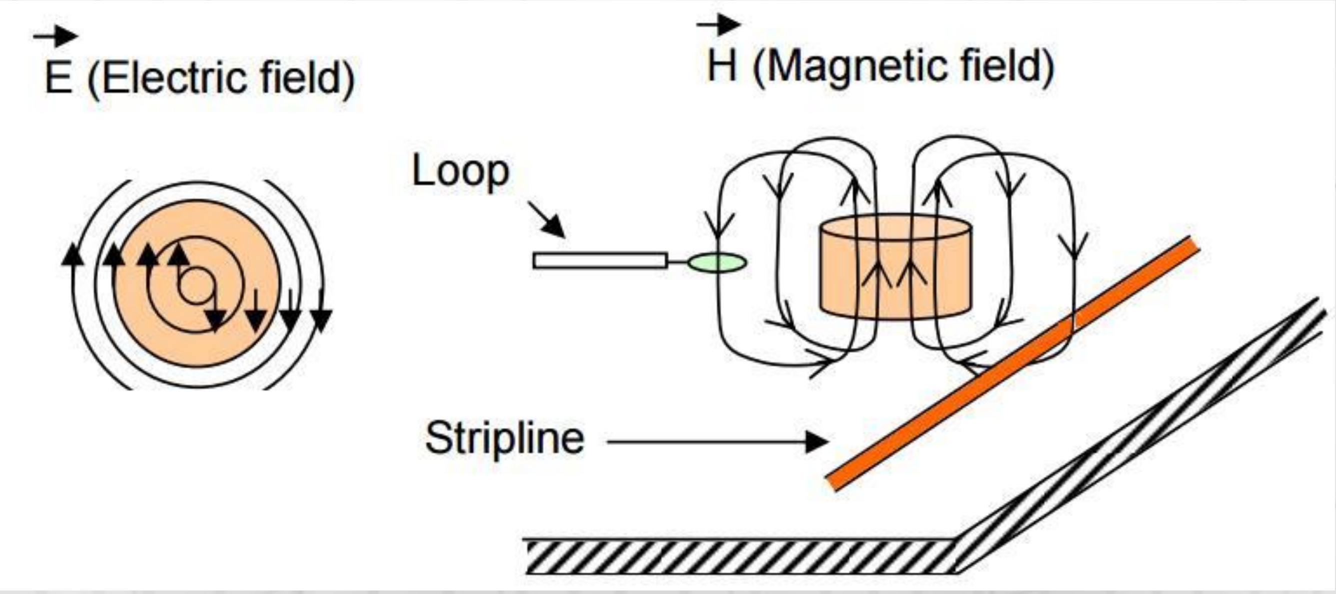
Advantages of patch antenna

- Low profile (can even be "conformal," i.e. flexible to conform to a surface).
- Easy to fabricate (use etching and photolithography).
- Easy to feed (coaxial cable, microstrip line, etc.).
- Easy to integrate with other microstrip circuit elements and integrate into systems.
- Easy to use in an array to increase the directivity.

Introduction (Cont.)

Dielectric resonator antenna

A **dielectric resonator antenna** (DRA) is a radio **antenna** mostly used at microwave frequencies and higher, that consists of a block of ceramic material of various shapes, the **dielectric resonator**, mounted on a ground plane.



Introduction (Cont.)

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Advantages of DRAs

- Compact size.
- Low cost.
- High efficiency due to the absence of surface wave and ohmic loss.
- 3-D structure of the DRA offers an additional freedom in exciting various modes in one antenna volume.
- Each mode can be employed for a different application, which makes the DRA a candidate for (MIMO) communication systems.

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MIMO System

- Antenna Element
- Decoupling Technique

Introduction (Cont.)

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Decoupling Techniques

- **Space diversity**
- **Defected Ground Structure (DGS)**
- **Complementary Split Ring Resonator (CSRR)**
- **Electromagnetic Band Gap structure (EBG)**
- **Polarization diversity**
- **Excitation of multiple orthogonal modes in DRAs**

Contents

Problem Statement

Challenges with Broadband antennas

- Design a compact antenna element to use it in MIMO system for providing a high data rate.
- Operate in the lower and mm-wave bands of 5G.
- Introducing an effective decoupling technique is still a challenge.

Challenges with multiband antennas

- Designing MIMO multiband antenna with small frequency ratios is greatly required for adjacent channels applications like WLAN, WiMAX, and 5G lower bands (4.1/4.8 GHz).

Problem Statement

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Challenges with increasing number of ports for MIMO

- Designing four ports MIMO with compact size and with good isolation is much more difficult than two ports and three ports MIMO.

- Need to consider ten parameters (S11, S22, S33, S44, S21, S31, S41, S32, S42 and S34) when designing a four ports antenna.

- Designing four ports MIMO system with single element is still a challenging task.

Contents

Objectives

- To design a compact dual broadband antenna for 5G applications to operate at both the lower and upper bands for the long and short distances 5G systems.

- To develop and introduce MIMO antenna for 5G by reducing the coupling between the two antennas using defected electromagnetic band-gap (EBG) structures by using different unit cells.

- To design quintuple bands with small frequency ratio rectangular dielectric resonator antenna (RDRA) for WLAN, WiMAX and 5G applications.

Objectives

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- To construct multiband DRA MIMO with good performance.
- To use the advantage of the DRA to excite various orthogonal modes to develop the MIMO using single DRA element.
- To develop new technique for coupling reduction and use it as the main idea for four ports single element DRA extension.

Contents

Part 1

A Compact CPW-Fed Slot MIMO Antenna for 5G Applications

Introduction

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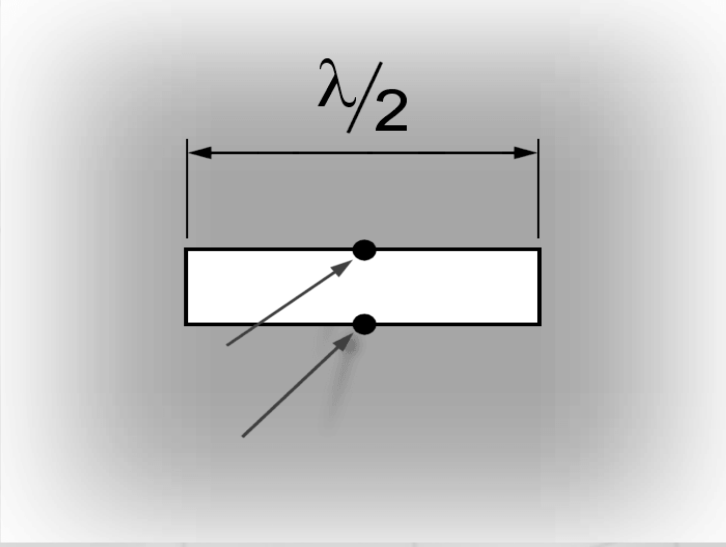
Slot antenna basics

- A slot antenna is about λ/2 elongated slot, cut in a conductive plate and excited in the center.

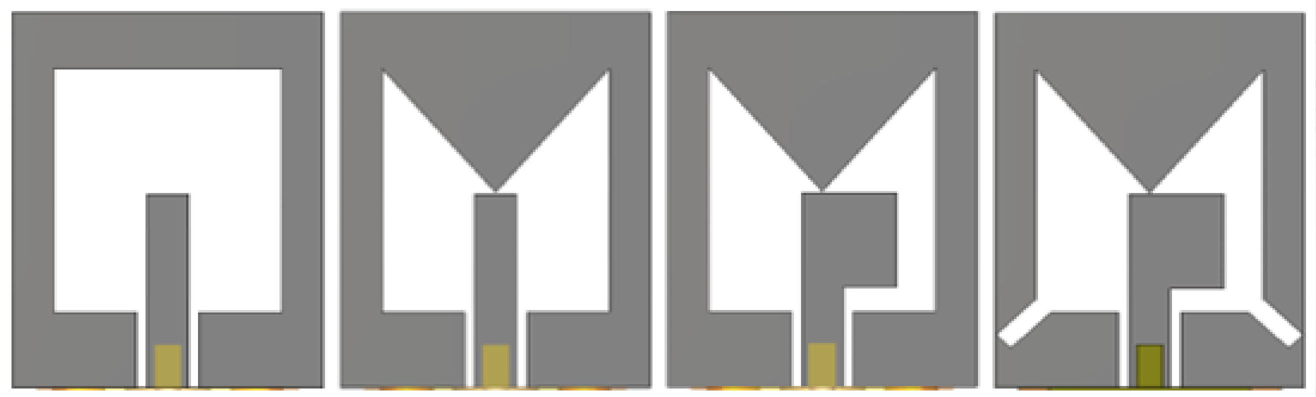
- The length of a slot determines the resonant frequency, the width of the slit determines the broad bandwidth of the slot radiator.



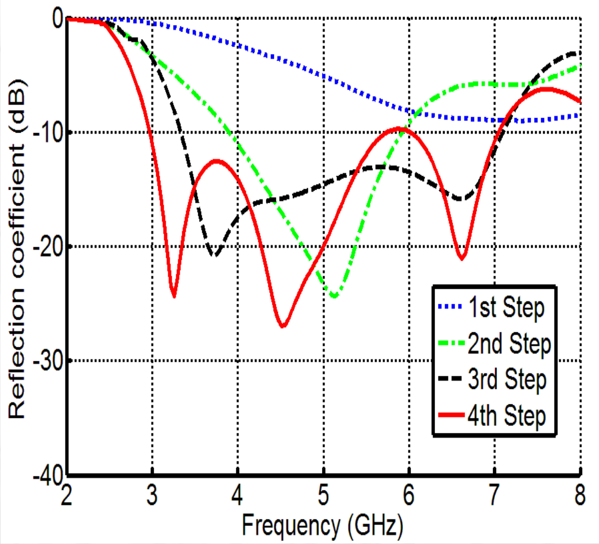
Antenna Design Procedures

- First, a CPW-Fed rectangular slot antenna is designed with size 13X10 mm^2 to generate the 4 GHz bandwidth at center frequency 7.5 GHz.
- Secondly, a triangle strip is embedded at the edge of the rectangular slot.
- Third, a rectangular patch is added at the end of the transmission line.
- Finally, to improve the matching at the lower bandwidth, shunt stubs are embedded in the corner of the slot.

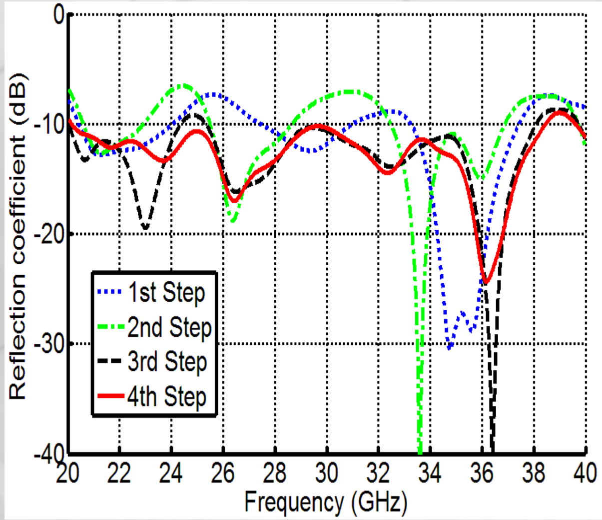
Antenna Design Procedures (Cont.)



Steps of antenna design procedures



(a)



(b)

Simulated reflection coefficient for all steps (a) lower band and (b) mm wave band

Antenna Design Procedures (Cont.)

Surface currents distribution

- At 3 GHz, the current distributes along the slot with the shunt stubs, around the triangle strip and along the rectangular patch as shown in (a).

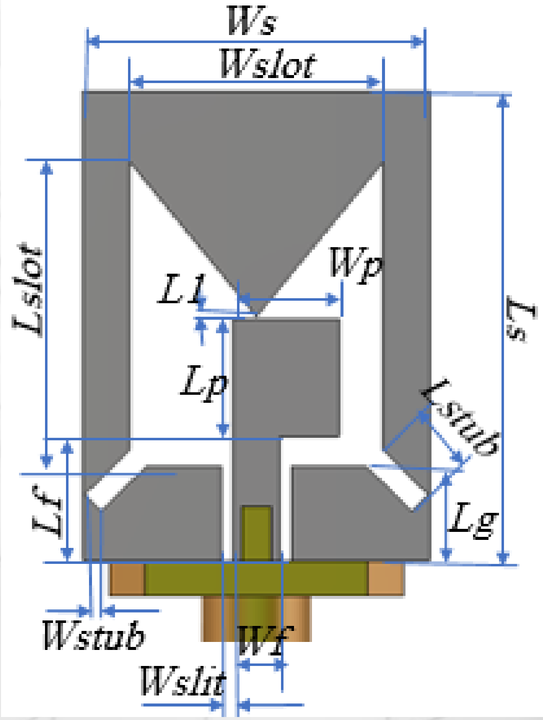
- At 4.5 GHz, the current concentrates around the patch, the transmission line and along some areas from the slot as shown in (b).

- At 6 GHz, 28 GHz and 38 GHz, as expected, the region of the current distributions are smaller than the lower frequencies as shown in (c), (d) and (e).

(a) (b) (c) (d) (e)

Surface current distributions of the proposed antenna at (a) 3 GHz, (b) 4.5 GHz, (c) 6 GHz, (d) 28 GHz and (e) 38 GHz

Proposed Antenna



Geometry and dimensions of the proposed antenna

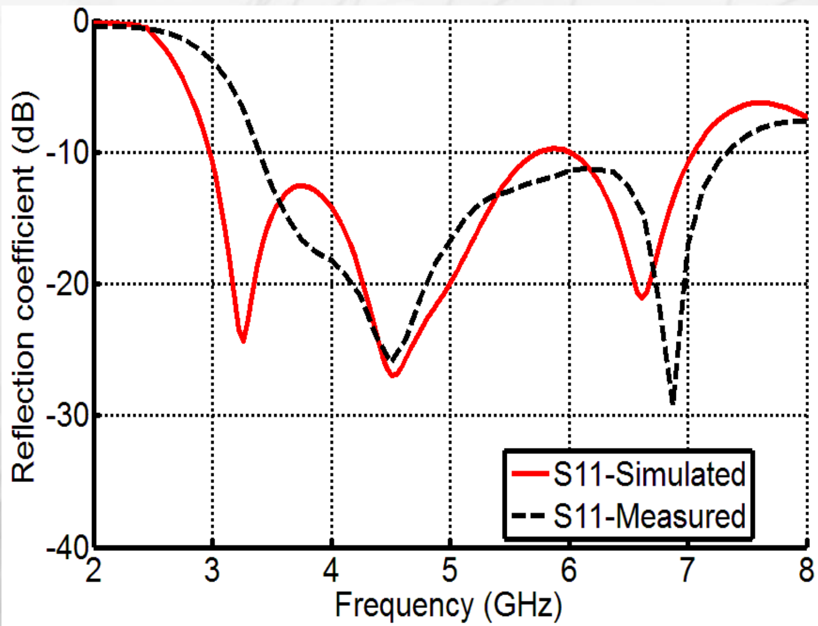
Fabricated SMA and SSMA antenna

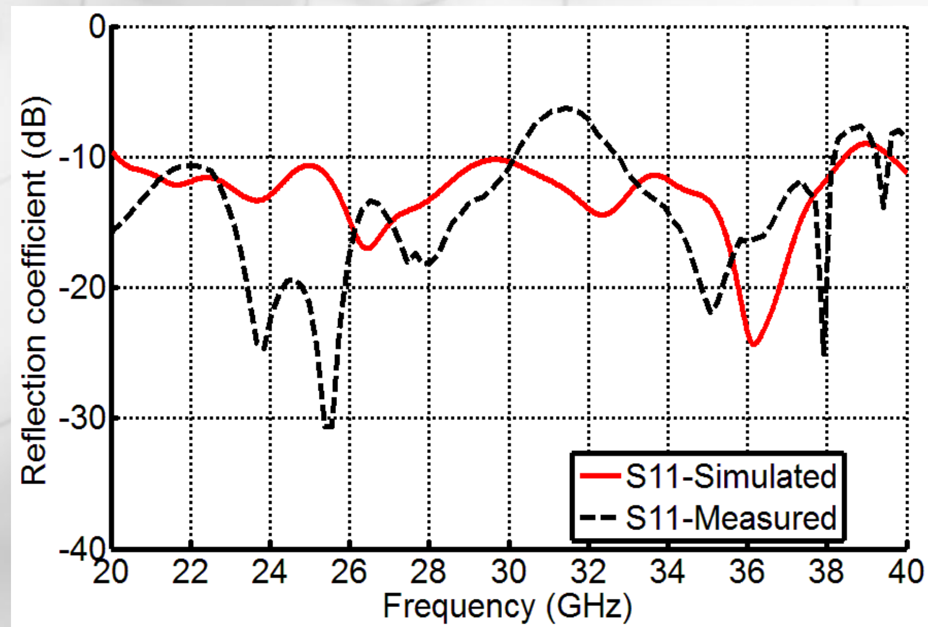
Geometrical parameters of the antenna (all dimensions are in mm)

W_s	L_s	W_f	L_f	W_{slot}	L_{slot}	L_g
15	20	2	5.3	11	13	4
W_p	L_p	L_1	h	W_{stub}	L_{stub}	W_{slit}
4.6	5	0.1	1.6	1	2.8	0.5

Simulation and Measurement Results

Reflection Coefficient

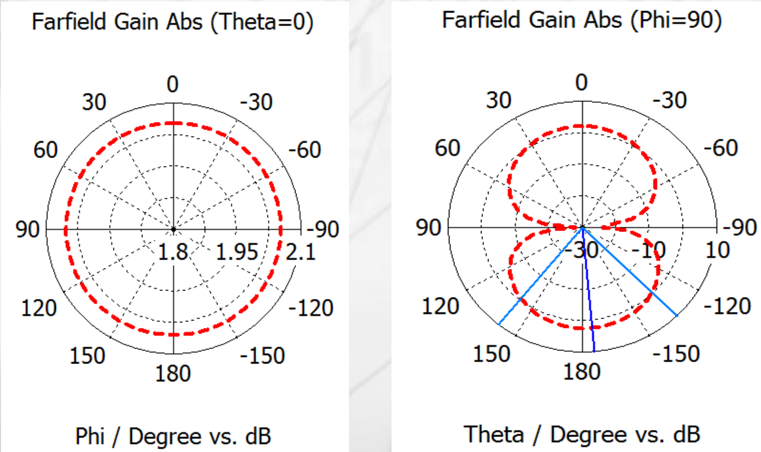




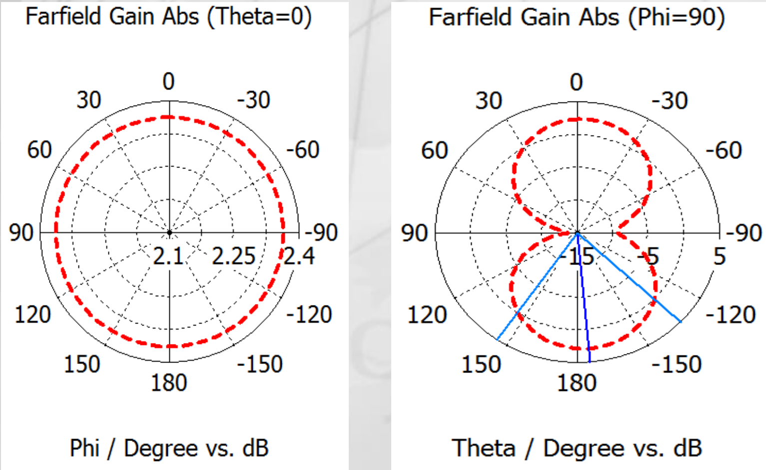
(a) **(b)**

(a) Simulated and measured lower reflection coefficient and (b) Simulated mm-wave reflection coefficient

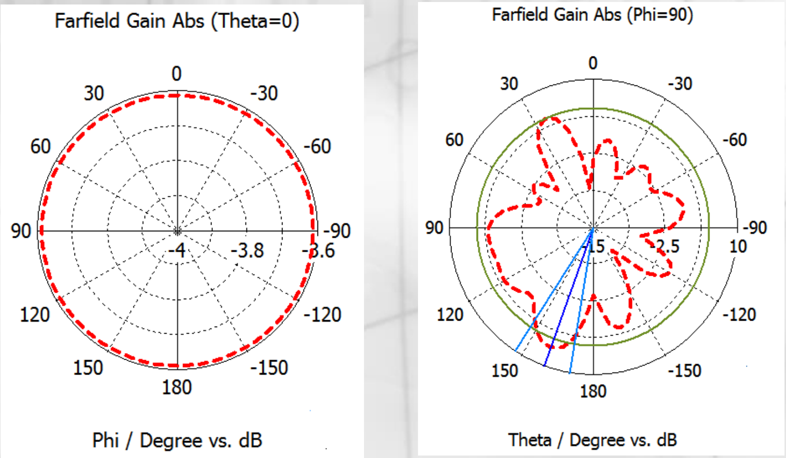
Simulated Radiation Patterns



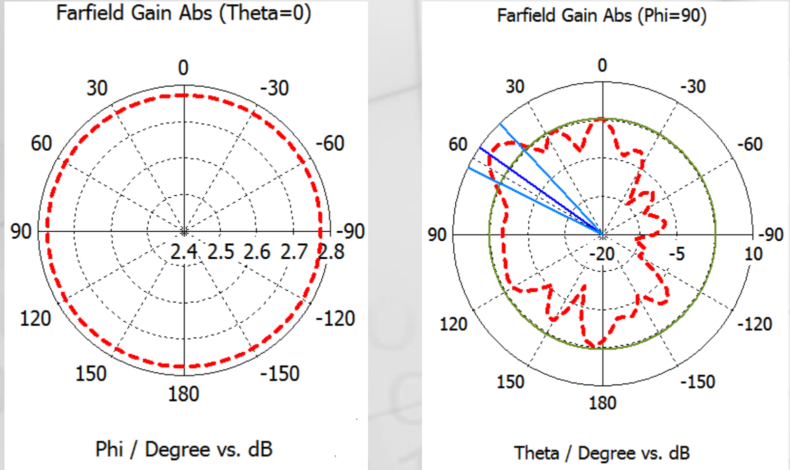
(a) 4.5 GHz



(b) 6 GHz



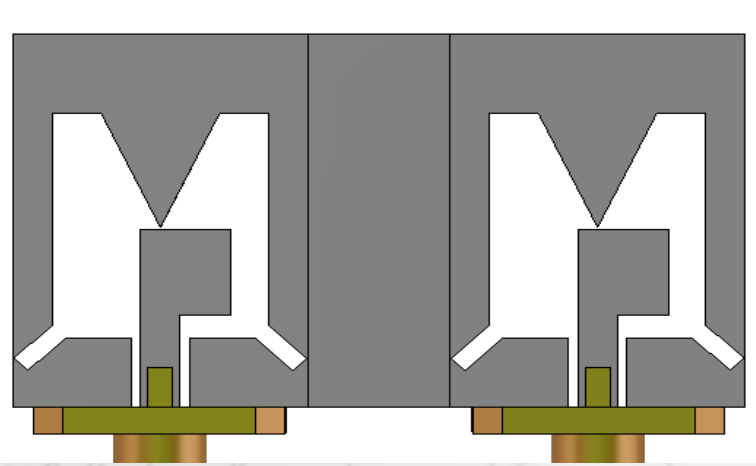
(c) 28 GHz



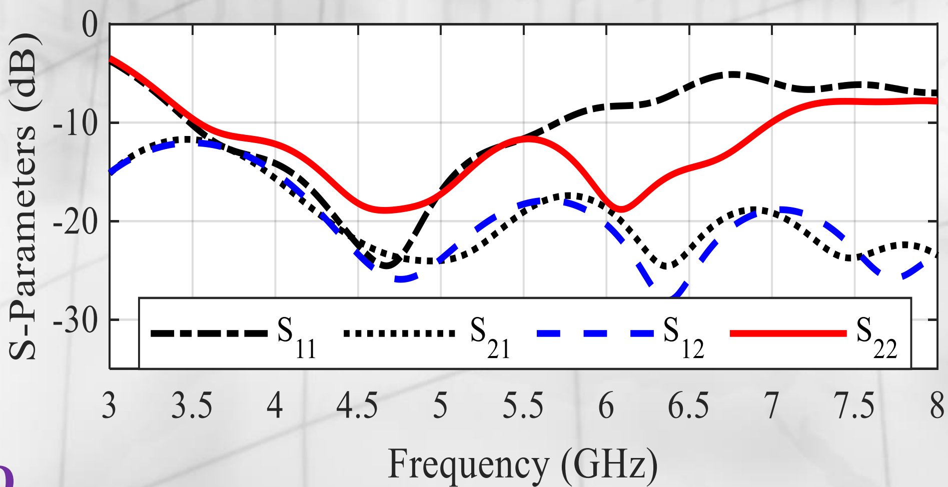
(d) 38 GHz

MIMO Antenna Configuration

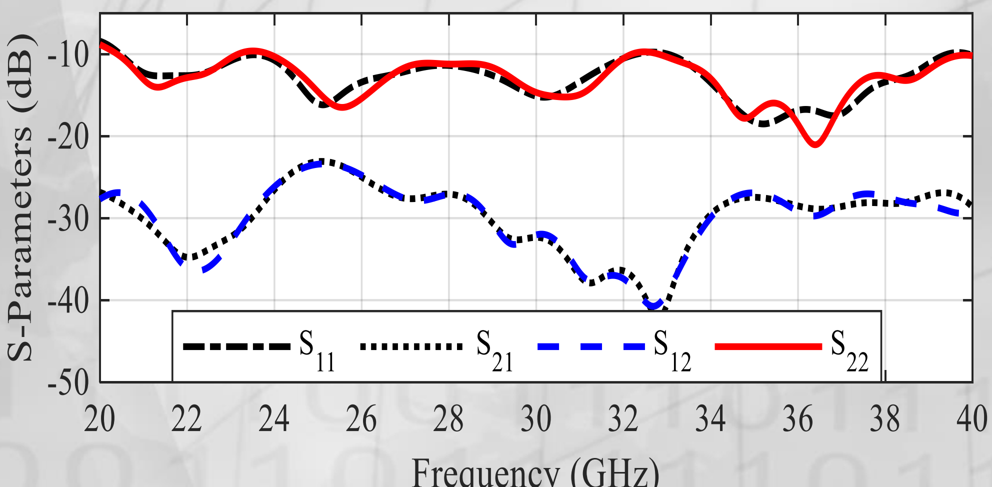
Dual elements MIMO CPW antenna



Geometry of the parallel two ports MIMO



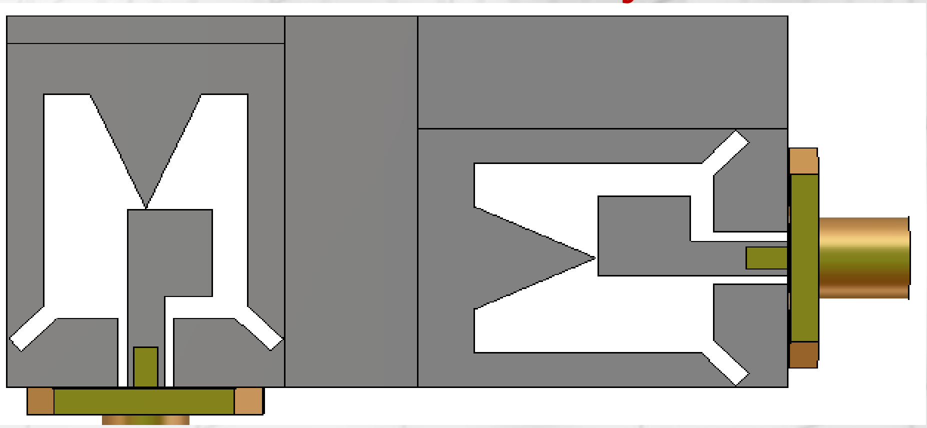
Simulated S-parameters of the parallel dual elements MIMO for the lower band



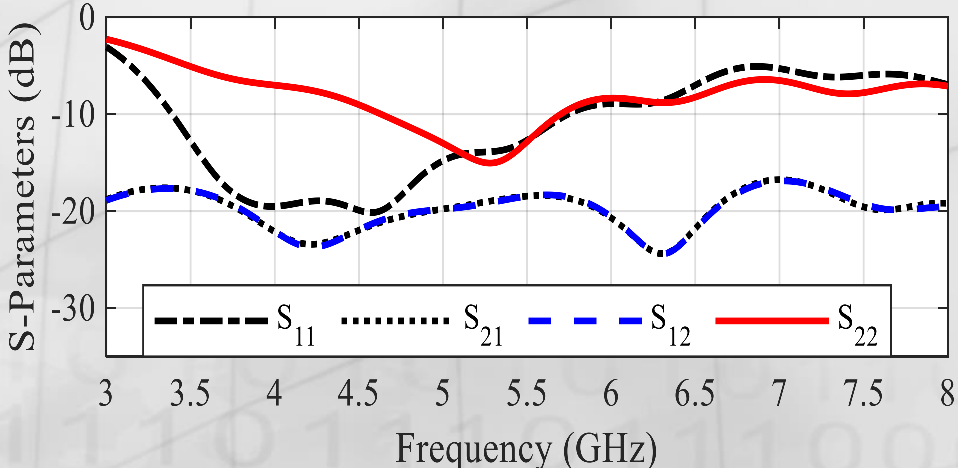
Simulated S-parameters of the parallel dual elements MIMO for the upper band

MIMO Configuration (Cont.)

Polarization diversity



Geometry of the polarization diversity dual elements MIMO CPW slot antenna



Simulated S-parameters of the polarized diversity dual elements MIMO antenna

MIMO Configuration (Cont.)

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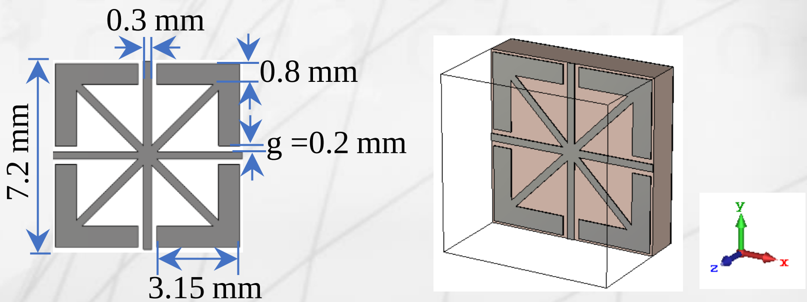
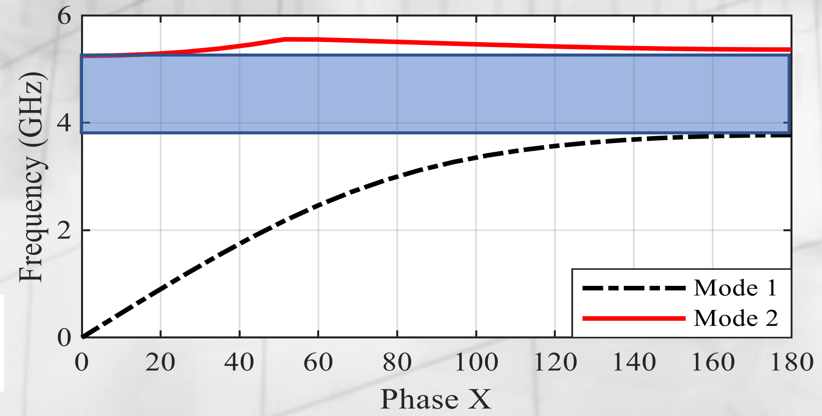
Electromagnetic band-gap structures

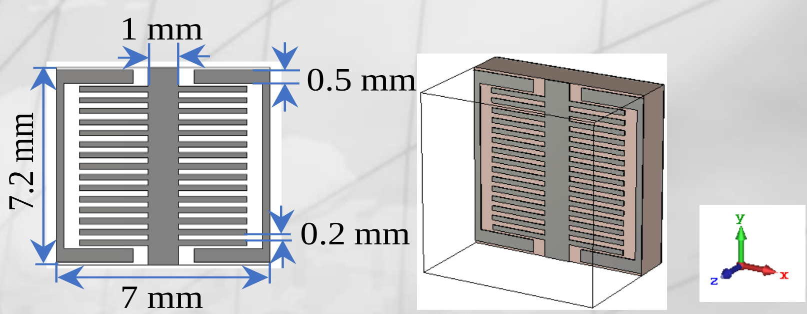


(a)

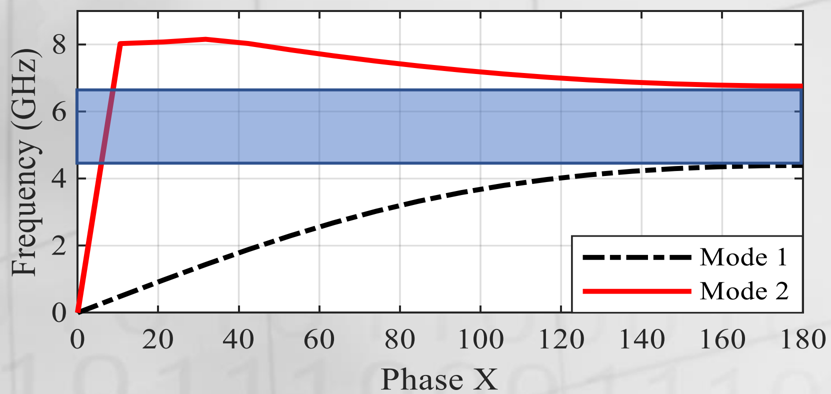


(b)

(a) 1st EBG unit cell, (b) Dispersion diagram of the 1st EBG unit cell



(a)



(b)

(a) 2nd EBG unit cell, (b) Dispersion diagram of the 2nd EBG unit cell

MIMO Configuration (Cont.)

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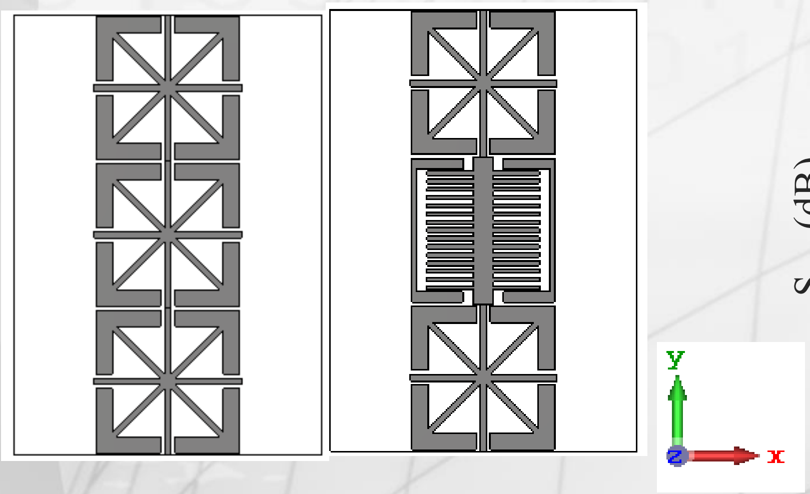
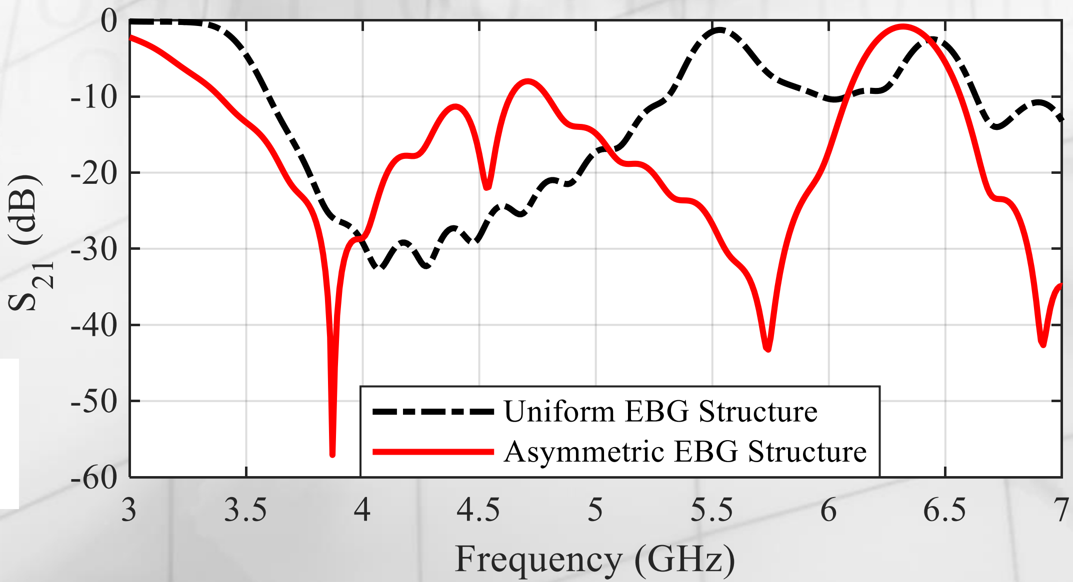
Filter structures with similar and defected EBG Structures



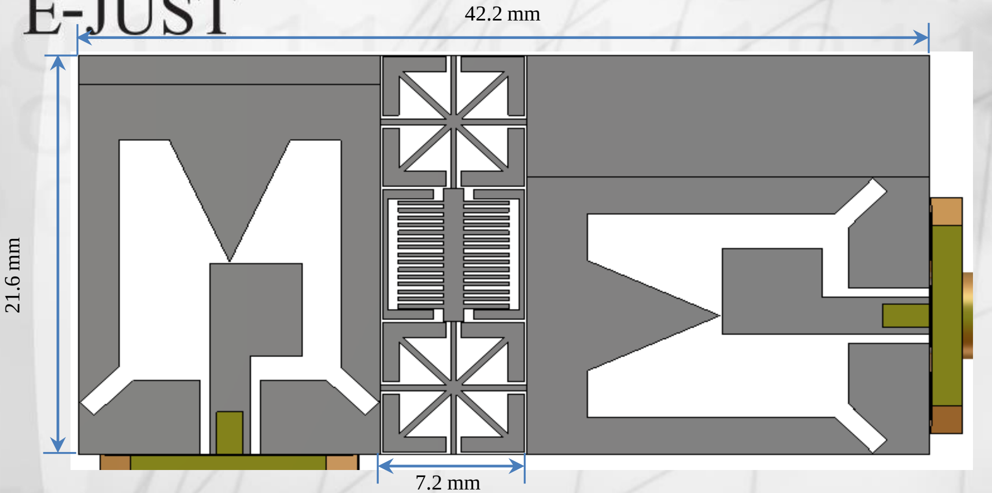


(a) **(b)**

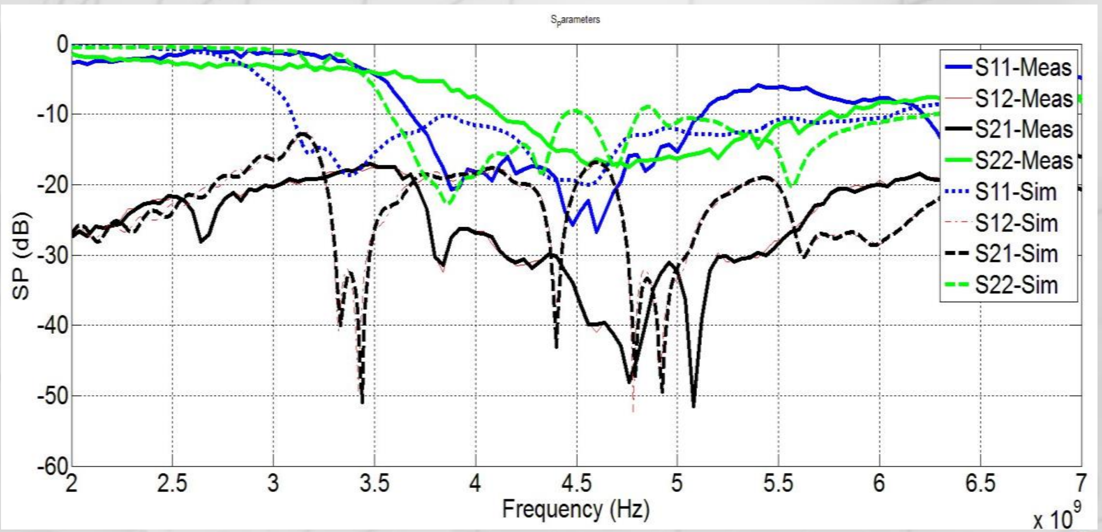
(a) Geometry of similar and defected EBG structures connected with microstrip lines,

(b) Simulated S_{21} parameters of the EBG structures.

MIMO Antenna Results



Geometry of the orthogonal two ports MIMO antenna with EBG

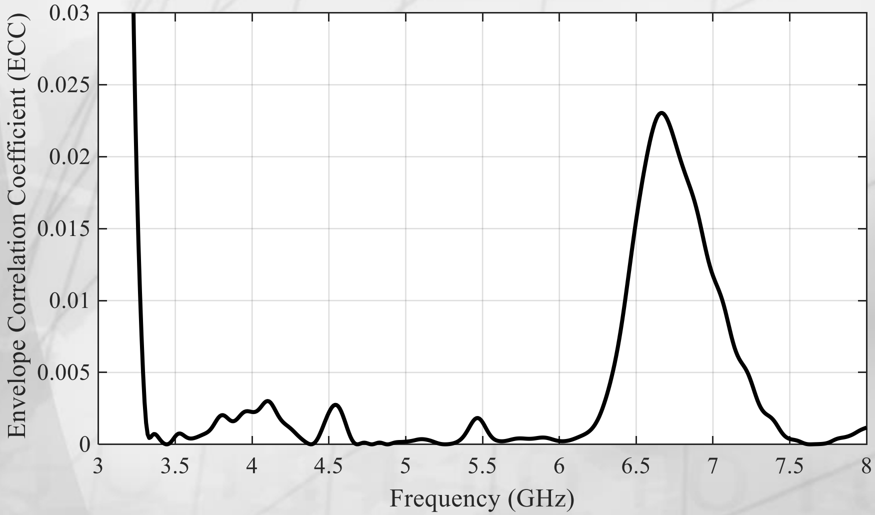


Simulated and measured S-parameters

MIMO Performance Evaluation

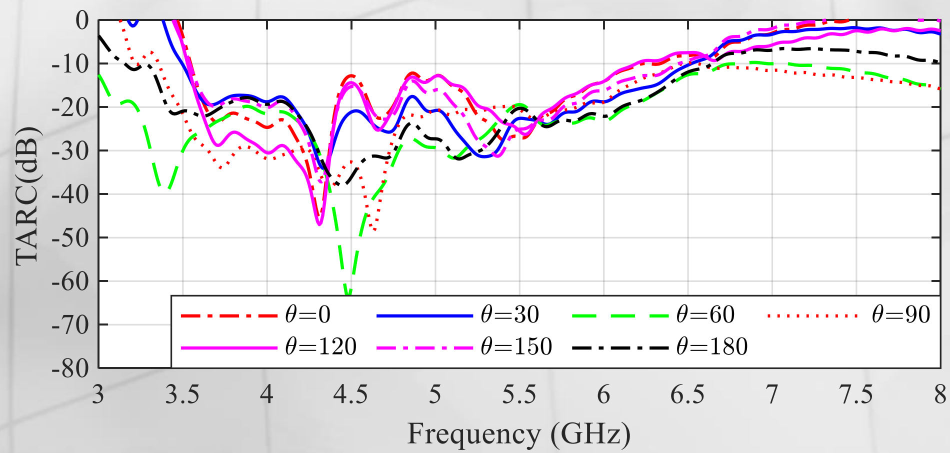
- According to the MIMO performance evaluation parameters, the results show good performance of this MIMO CPW slot antenna.

Envelope Correlation Coefficient



Envelope correlation coefficient (ECC)

Total Active Reflection Coefficient (TARC)

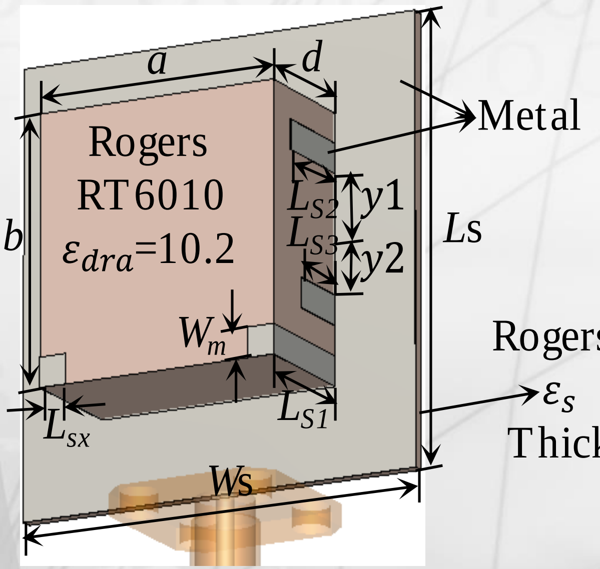


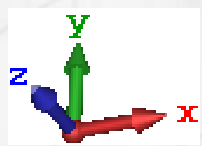
Total active reflection coefficient (TARC)

Part 2

Small Frequency Ratio Multi-Band MIMO RDRA

Antenna Geometry





Geometry of the proposed multiband RDRA

Antenna Geometrical Parameters in mm

W_s	L_s	h	W_f	L_f	S	W_{slot}	L_{slot}	a
30	30	0.813	2	15.8	3	1.5	17.5	18
b	d	W_m	L_{S1}	L_{S2}	L_{S3}	L_{sx}	y_1	y_2
18	9	2	9	6.5	5	2	5	3

Antenna Design Procedures

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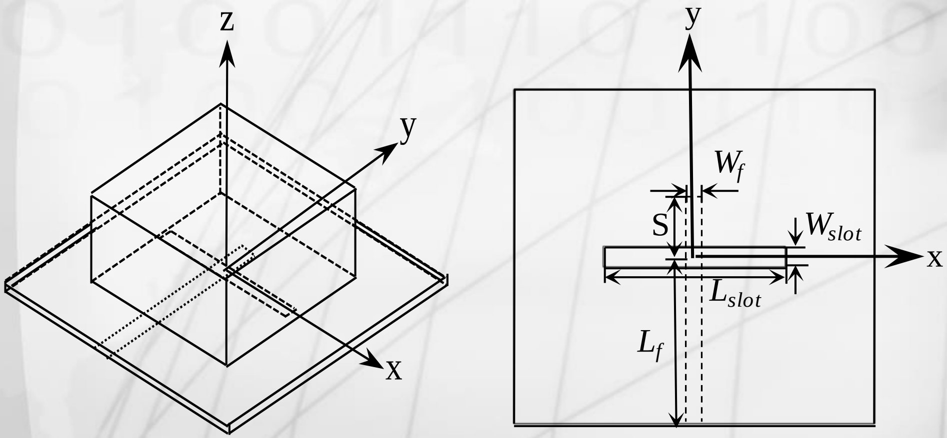
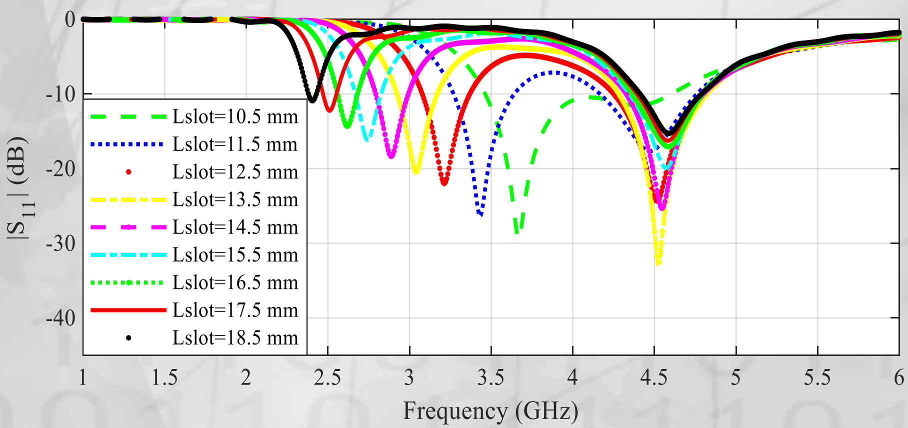
➢ Aperture Feeding Approach



The proposed antenna without VMSPs, 3D and Top views



The antenna reflection coefficient in terms of the slot length (L_{slot})

Slot as a resonator

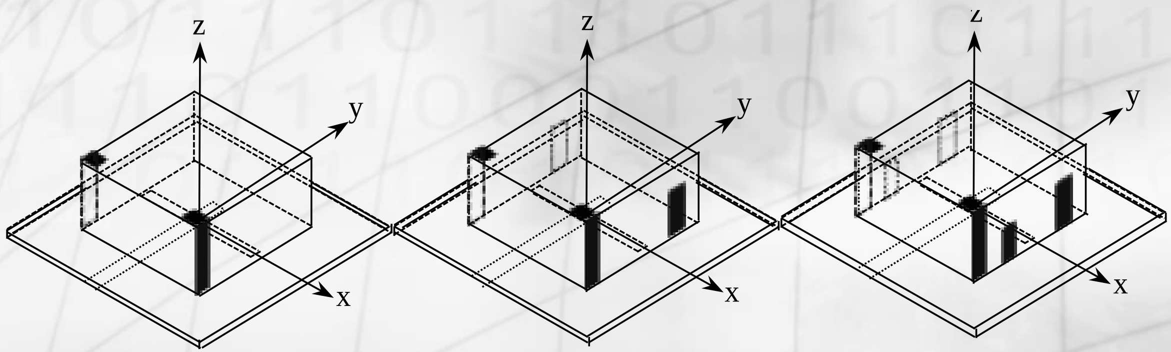
$$\left(\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}\,\mu_{eff}}}\right) \quad \varepsilon_{eff} = \frac{H_{total}}{h_d/\varepsilon_{dra} + h/\varepsilon_s}$$

Slot as a feeding

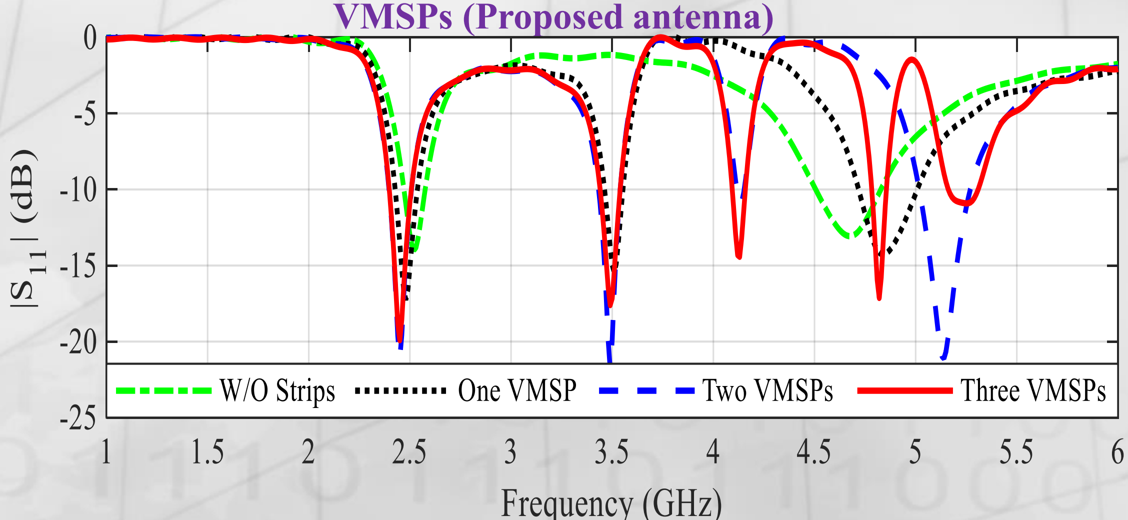
$$H_x = A\frac{k_y^2 + k_z^2}{j\omega\mu_0}\cos(k_x x)\cos(k_y y)\cos(k_z z)$$

For TE^x_{111} mode, the component H_x is maximum at $y=0$ and $z=0$

Antenna Design Procedures (Cont.)

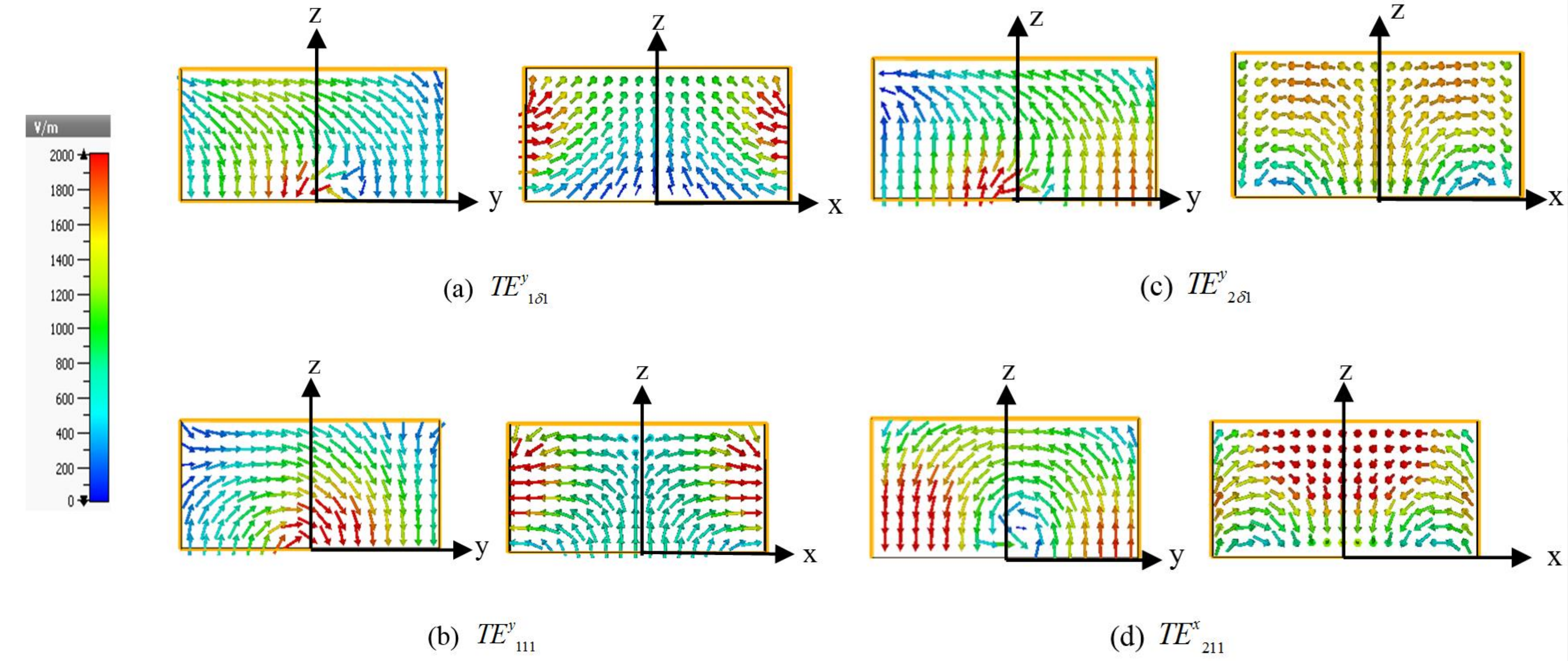


Geometry of various antennas used in the design procedure, (a) One VMSP, (b) Two VMSPs and (c) Three VMSPs (Proposed antenna)



Effect of adding VMSPs on the reflection coefficient

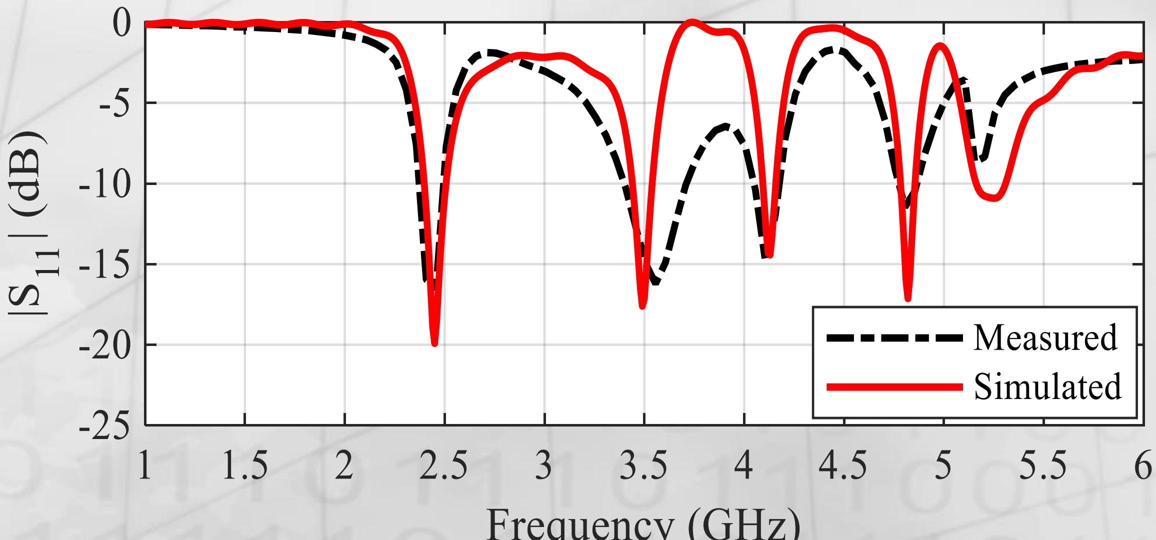
E-field distribution



Simulated E-field distribution inside the proposed RDRA in both *yoz* and *xoz* planes at, (a) 3.5 GHz. (b) 4.1 GHz. (c) 4.8 GHz. (d) 5.2 GHz

Measurement Results and Discussion

Fabrication of the proposed quintuple-band RDRA

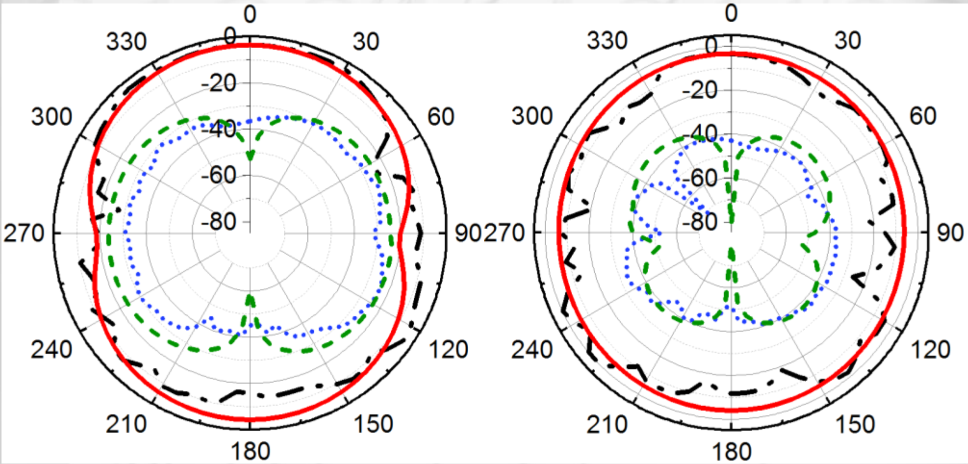


Simulated and measured reflection coefficient of the quintuple-band RDRA

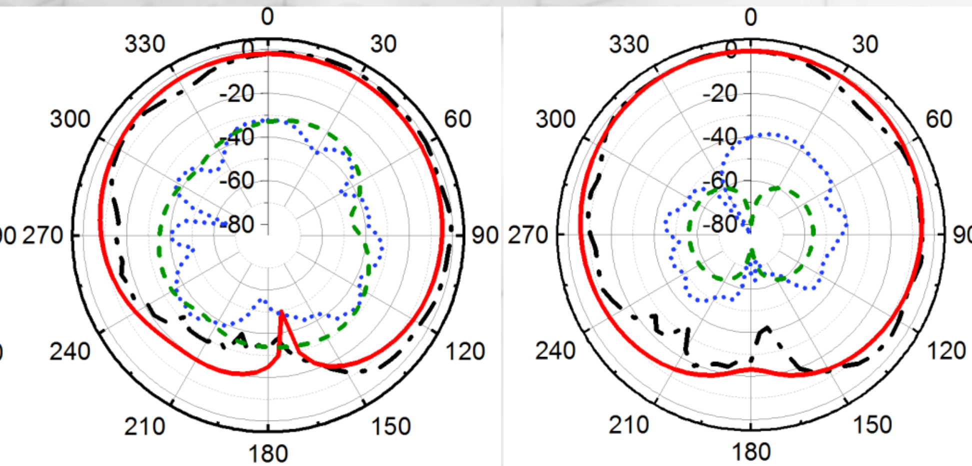
Measurement Results and Discussion (Cont.)

Radiation Pattern

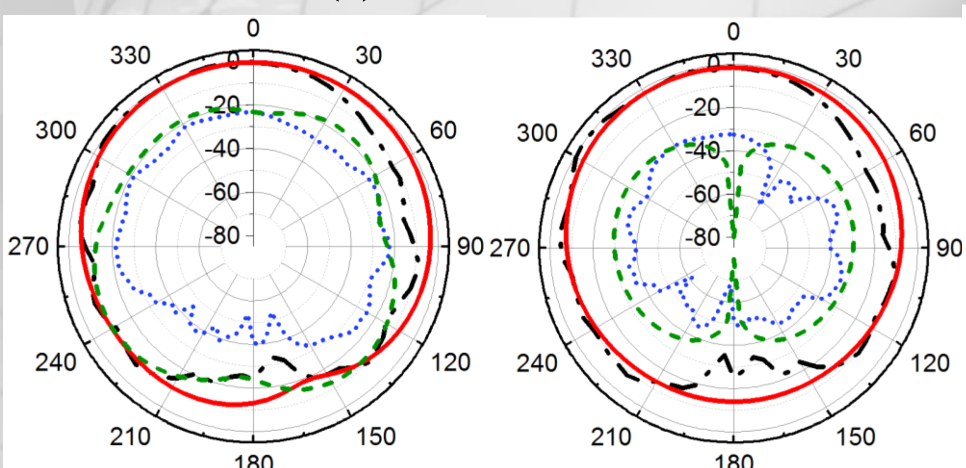
YZ_Plane XZ_Plane YZ_Plane XZ_Plane



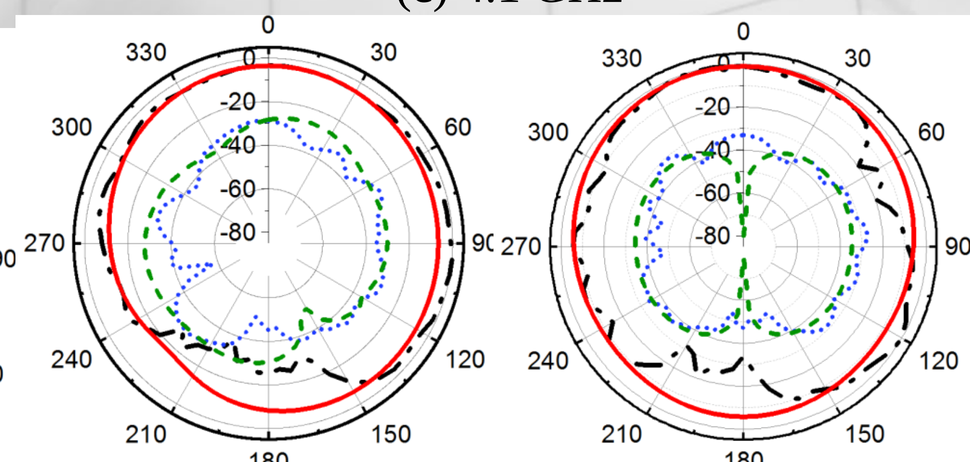
(a) 2.4 GHz



(c) 4.1 GHz



(b) 3.5 GHz



(d) 4.8 GHz

Measurement Results and Discussion (Cont.)

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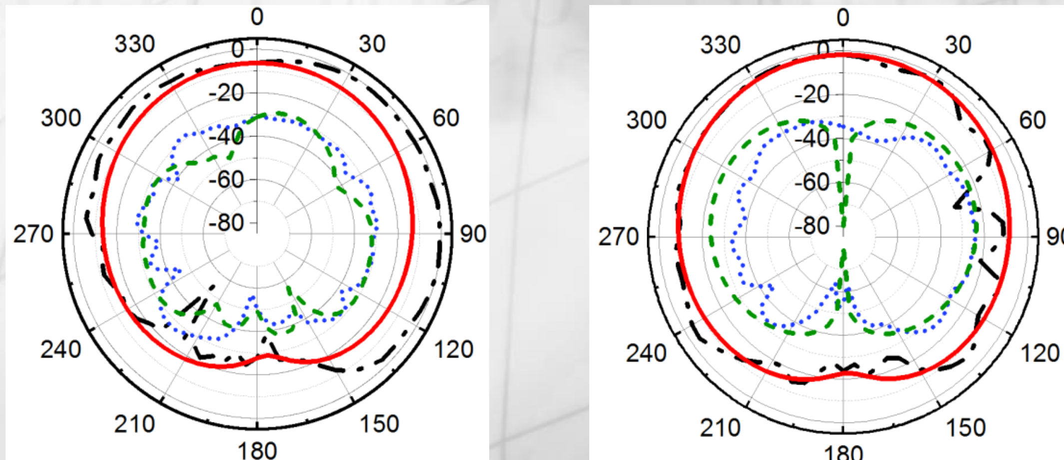
Radiation Pattern. Cont

YZ_Plane XZ_Plane



(e) 5.2 GHz

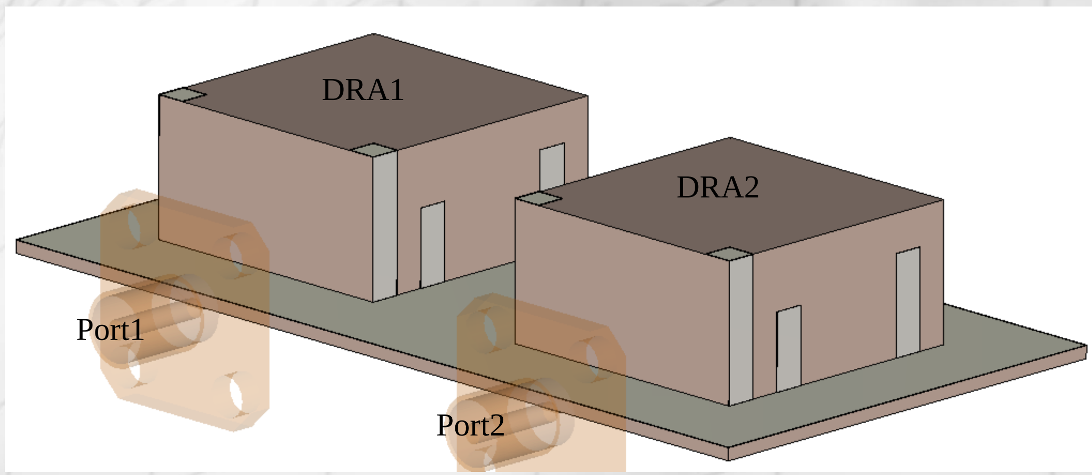
Measured Co-pol · Measured X-pol
Simulated Co-pol · Simulated X-pol

Measured and simulated radiation pattern of the proposed RDRA

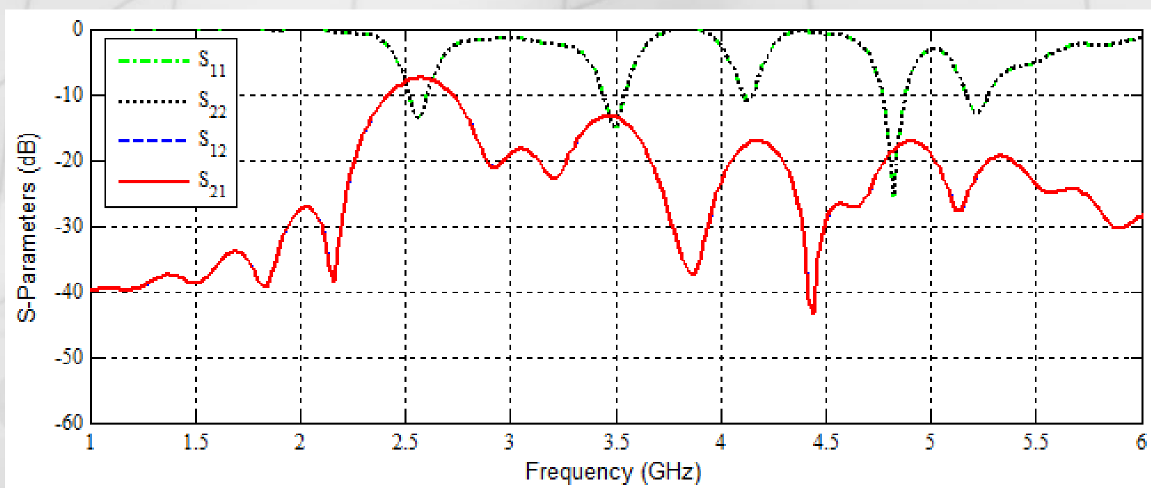
The fabricated prototype provides a good measured gain of 2.65 dBi, 3.7 dBi, 3.3 dBi, 2.73 dBi, and 4.68 dBi at 2.4 GHz, 3.5 GHz, 4.1 GHz, 4.8 GHz, and 5.2. GHz, respectively.

Dual Elements MIMO DRA

Parallel Configuration



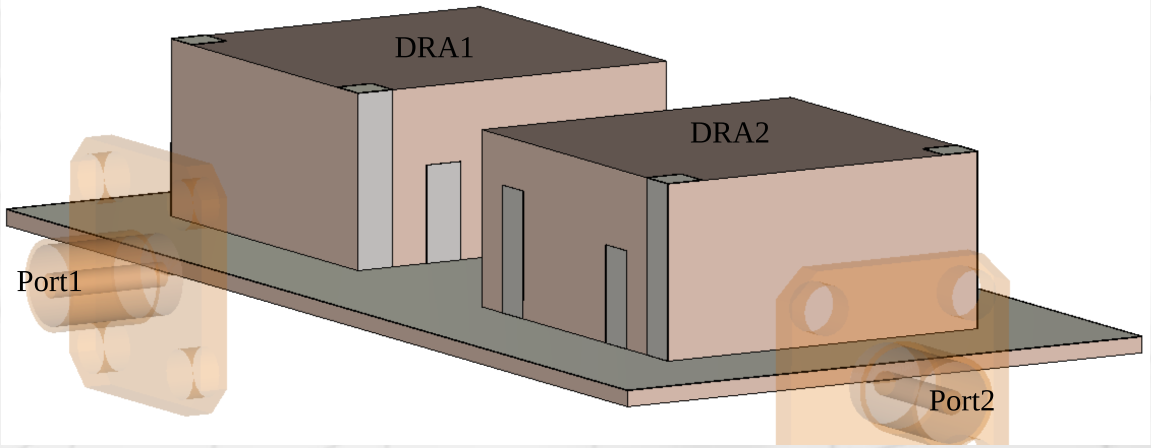
Parallel scheme dual elements MIMO DRA



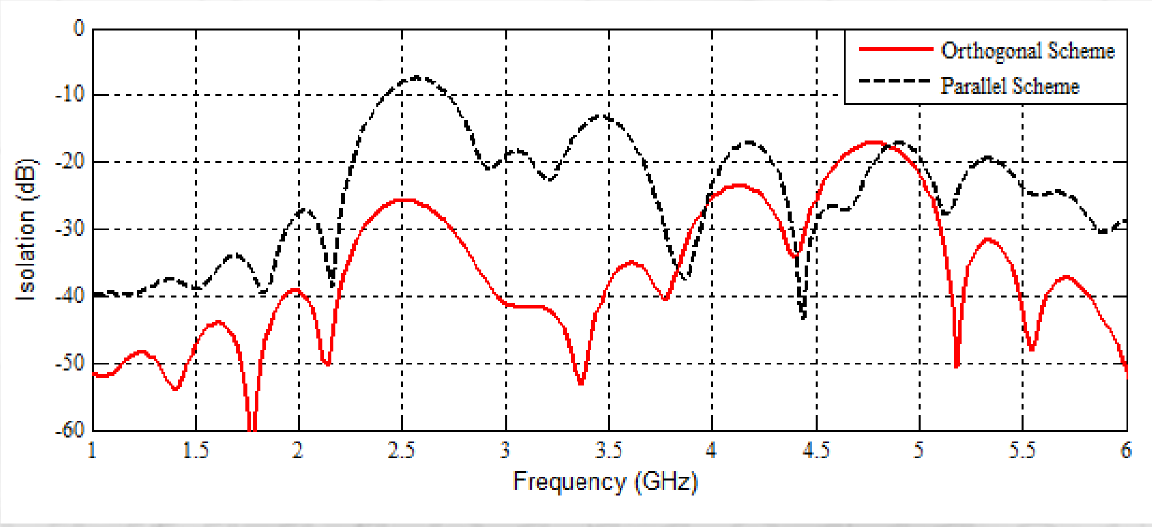
Simulated S-parameters of the parallel dual elements MIMO DRA

Proposed Dual Elements MIMO DRA

Orthogonal Configuration

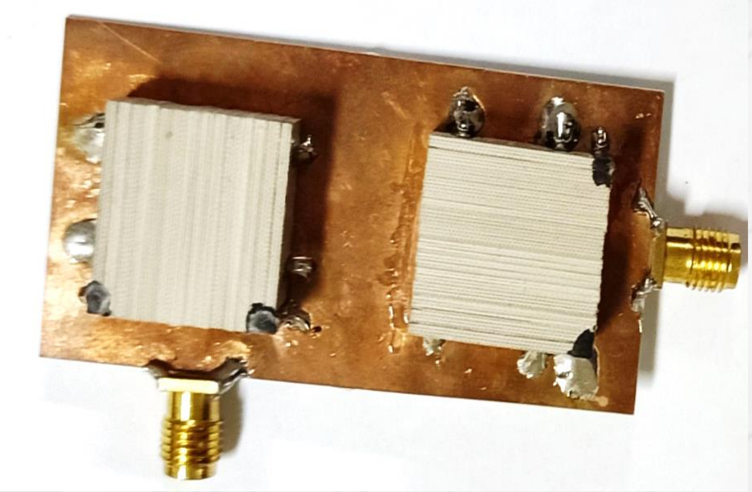


Orthogonal scheme dual elements MIMO DRA

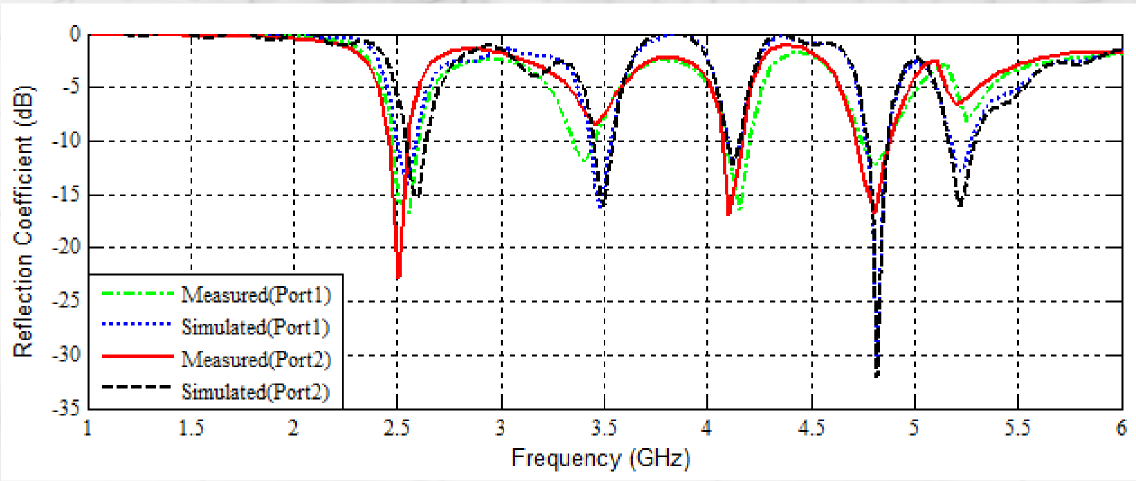


Isolation performance comparison between parallel and orthogonal schemes of MIMO DRA

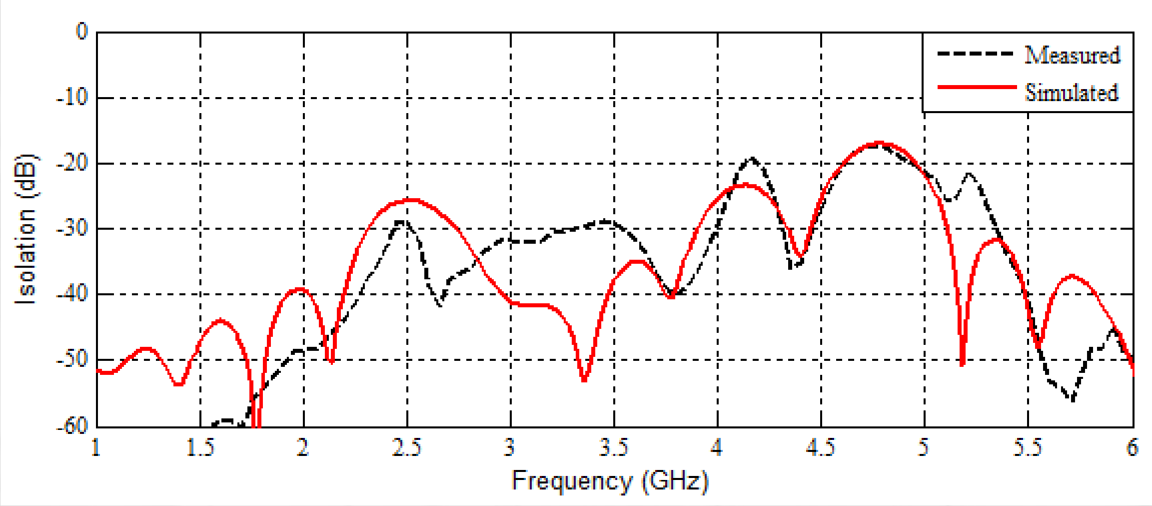
MIMO RDRA Results



Fabrication of the proposed MIMO DRA



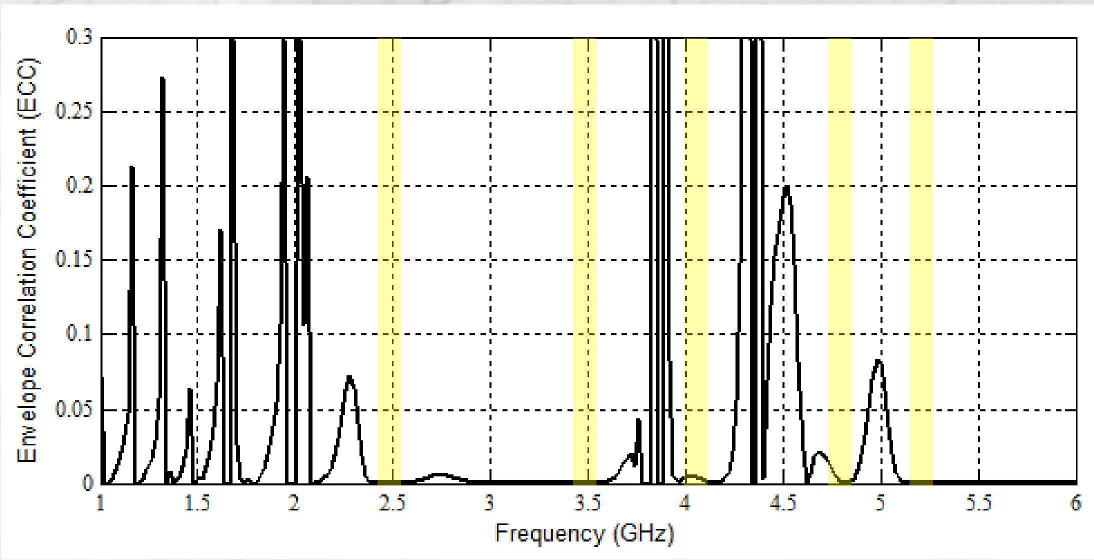
Measured and simulated reflection coefficient of the proposed MIMO DRA



Measured and simulated isolation of the proposed MIMO DRA

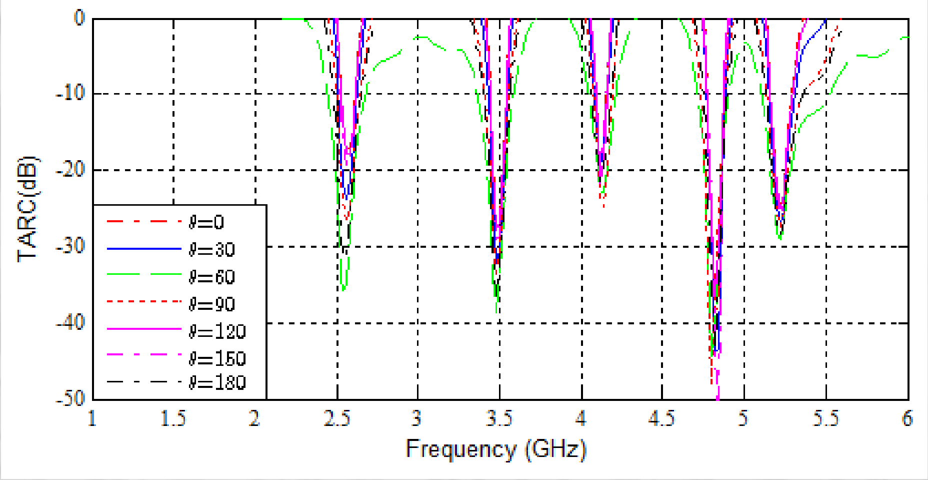
MIMO Performance Evaluation

Envelope Correlation Coefficient



Envelope correlation coefficient (ECC)

Total Active Reflection Coefficient (TARC)



Total active reflection coefficient (TARC)

Part 3

FOUR PORTS MIMO SINGLE ELEMENT DRA

Introduction

Problem

- As compared with the multi antenna MIMO system, a single-element antenna is more attractive because its size is more compact.
- Thus far, in the previous researches, studies of single-element DRAs have been concentrated on two and three ports designs only.
- It is well known that the port isolation is the major challenge of MIMO antenna design.
- Introducing four port MIMO DRA with single element is still a challenging task due to:
  - The difficulty of generating different modes at the same frequency with low coupling between them.
  - The difficulty of improving the isolation between ports of the MIMO antenna.

Introduction (Cont.)

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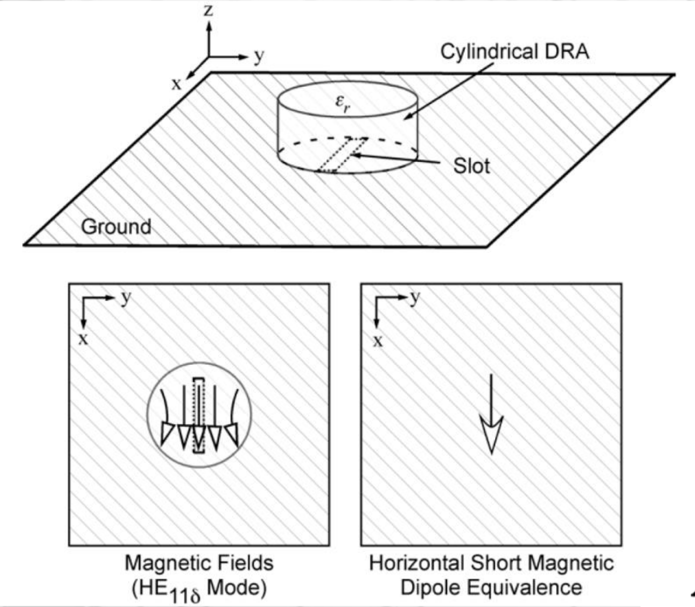
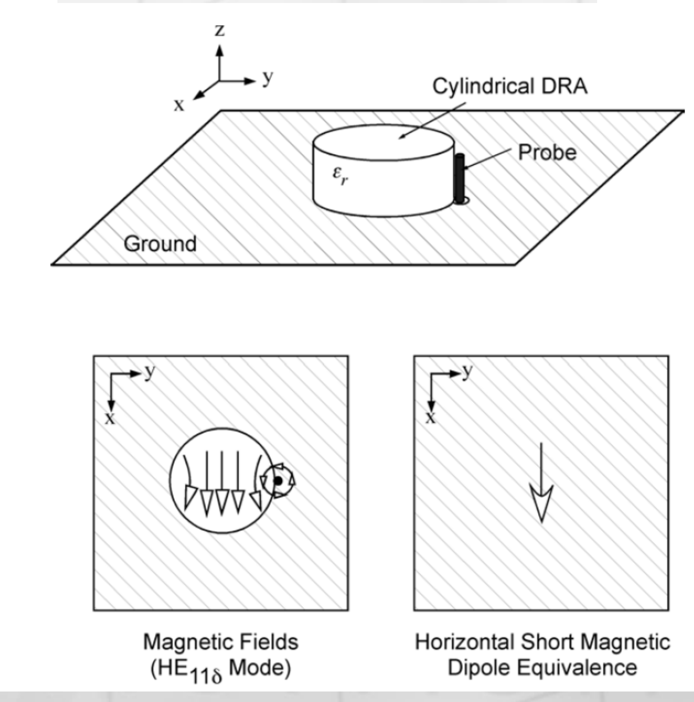
Solution

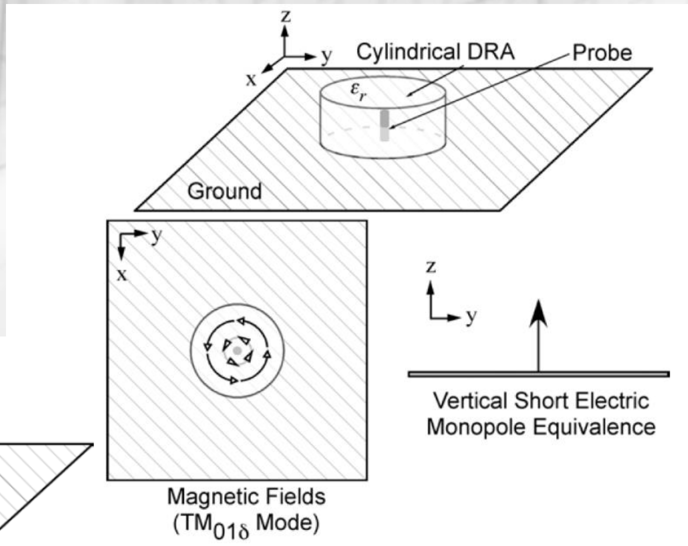
- New approach for designing quad ports single CDR MIMO antenna with satisfactory port to port isolation across wide bandwidth for x-band is introduced and based on:
  - Selecting the suitable feeding techniques which are two probes and two aperture feedings. Proper configuration is adopted for the feeding structures to mitigate the coupling between the CDRA ports.
  - Novel decoupling scheme which depends on VMVs is used for further isolation enhancement.

Feeding Technique

Excitation Sources for CDRA Modes

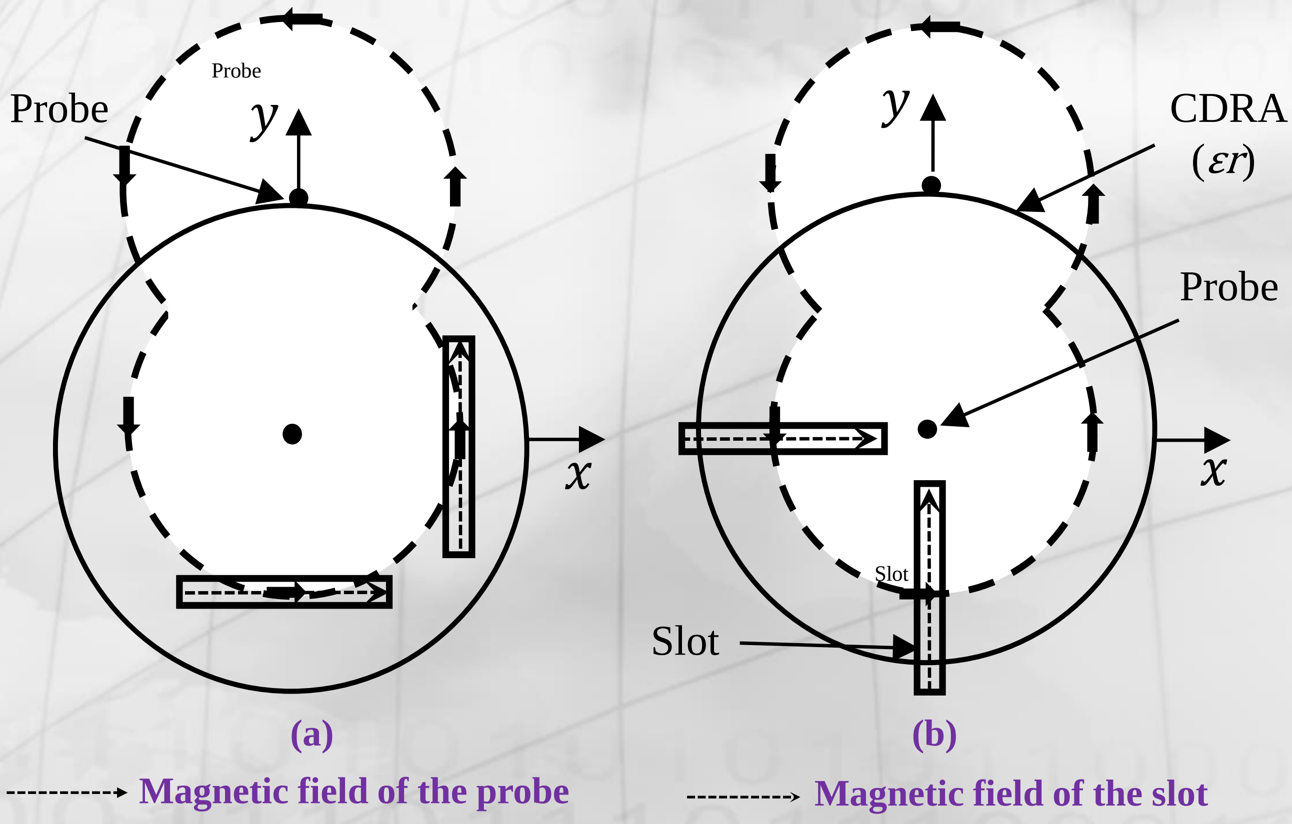






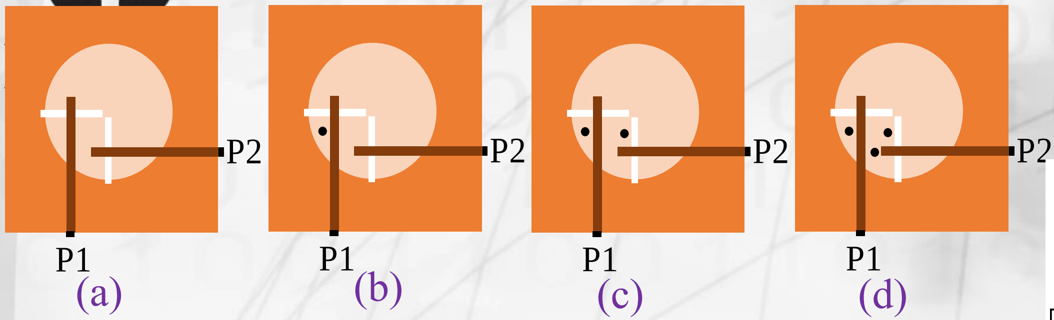
Feeding Technique (Cont.)

Coupling Between Excitation Sources

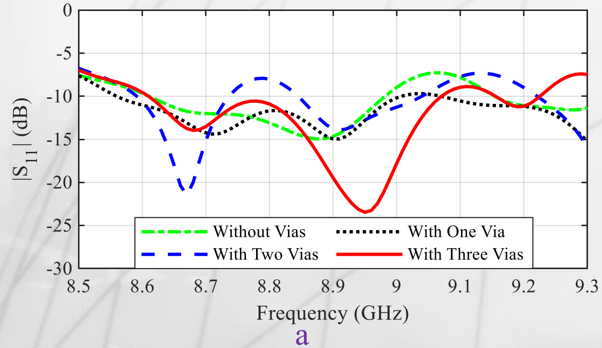


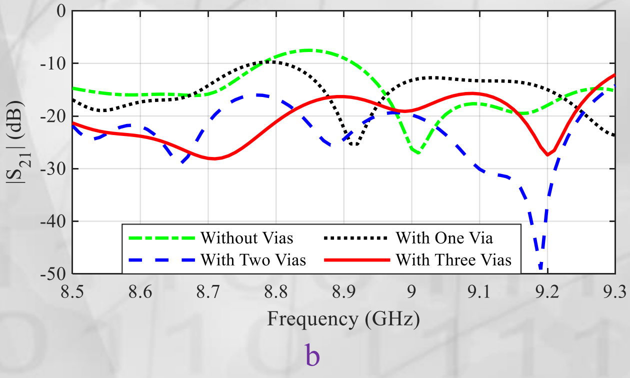
Magnetic fields of the probes and slots: (a) field probes align with the slots.; (b) field probes perpendicular with the slots

Decoupling Technique

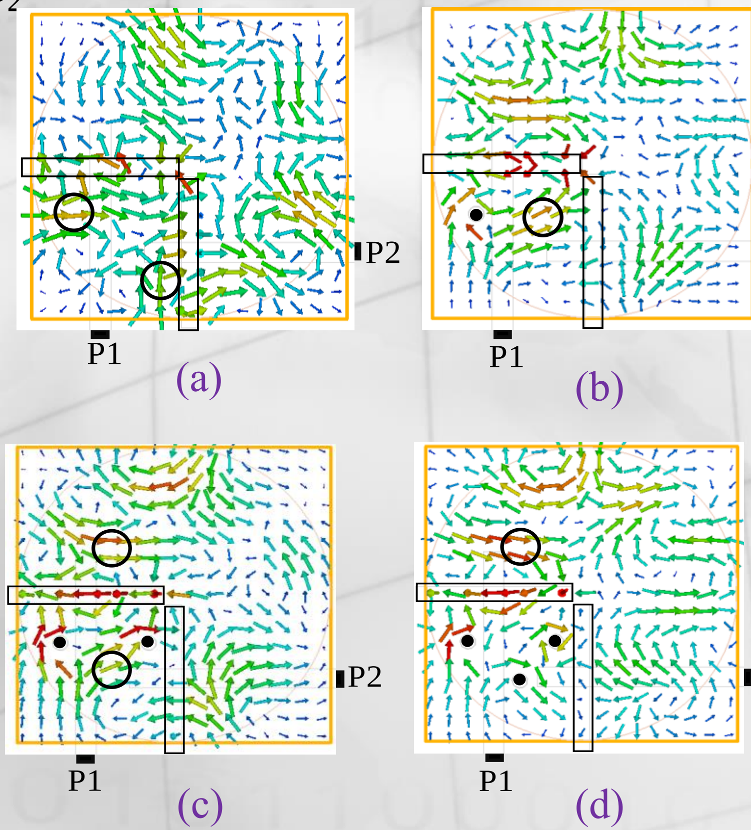


Geometry of various two ports CDR MIMO antennas, (a) Without vias, (b) With one via, (c) With two vias, and (d) With three vias



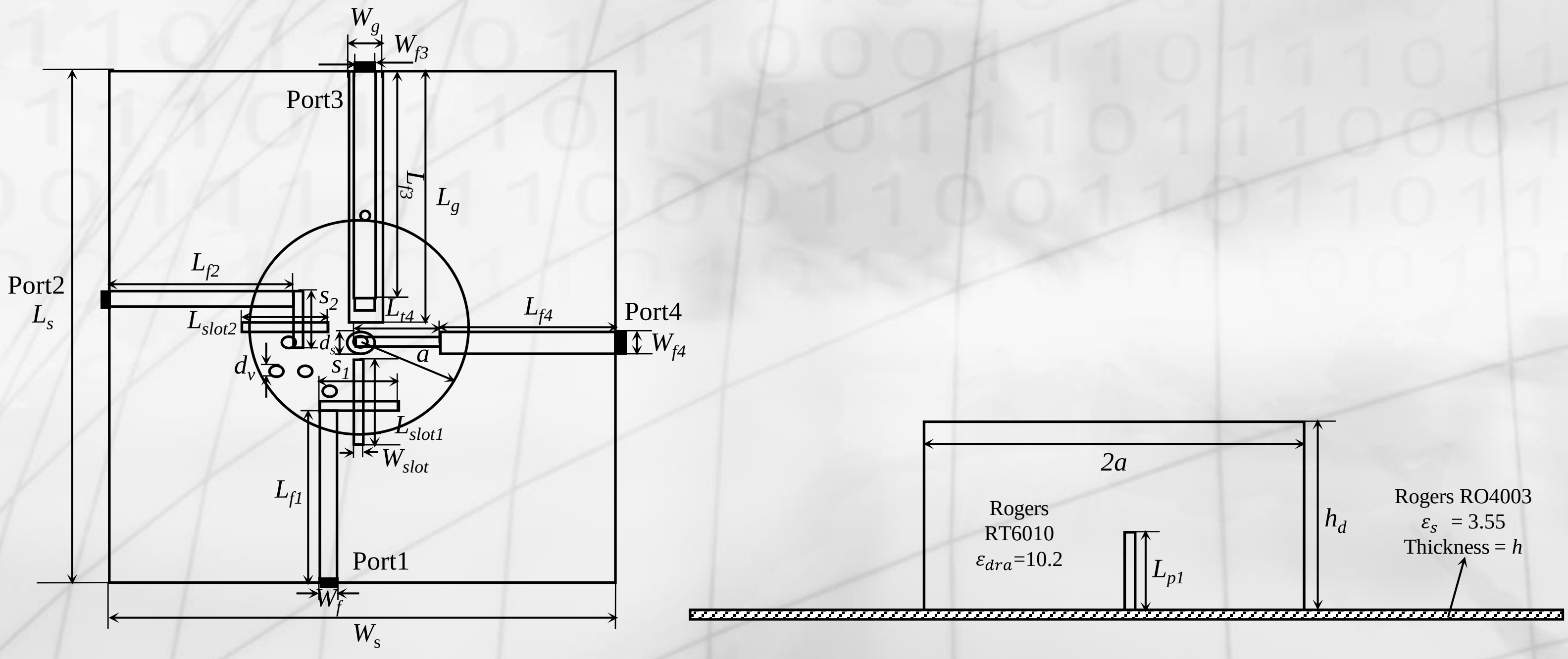


S-Parameters of the two ports CDR MIMO antenna structure with adding the vias, (a) $|s_{11}|$, (b) $|s_{21}|$



H-field distributions inside the two ports CDRA MIMO at 8.8 GHz i xy-plane for, (a) Without vias, (b) With one via, (c) With two vias, an (d) With three vias

Proposed MIMO Single Element DRA

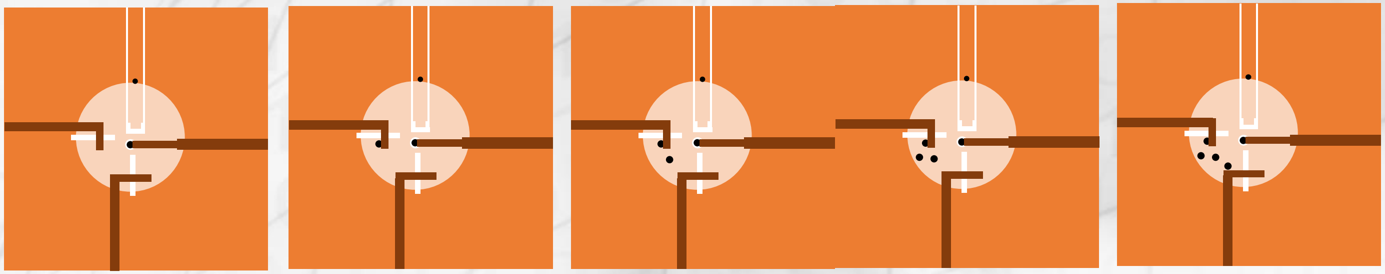


Geometry and dimensions of the proposed antenna top and side views

Geometrical parameters of antenna (all dimensions in *mm*)

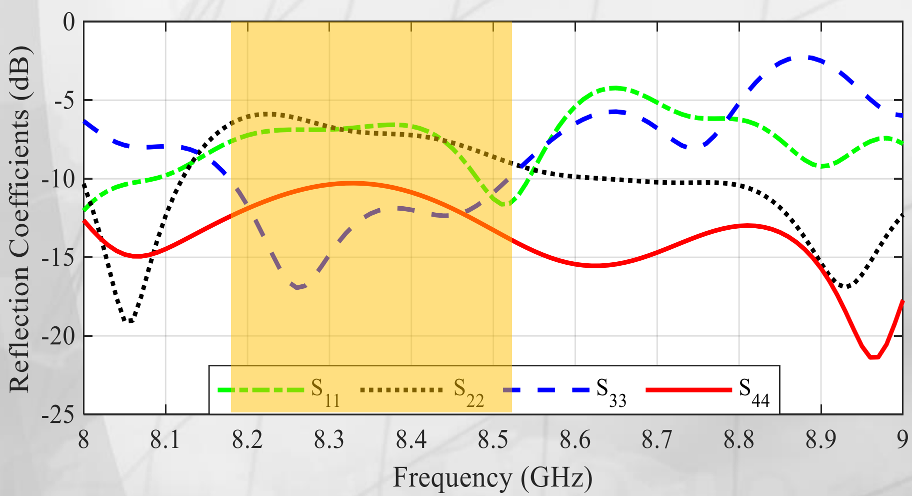
W_s	L_s	h	W_f	L_{f1}	L_{f2}	W_{f3}	W_{t3}	W_g	L_{f3}	L_{t3}	L_g	d	L_{p1}	L_{f4}
70	70	0.813	2	23.5	25	3	2.5	4.1	31.05	2	34.25	1	6	24
L_{t4}	W_{f4}	W_{t4}	d_p	d_s	W_{slot}	L_{slot1}	L_{slot2}	L_1	L2	S_1	S_2	a	h_d	d_v
11.75	3	2	1.5	3	1.5	11.5	12	10.5	11	10.5	8	15	15	1.5

Isolation Improvement

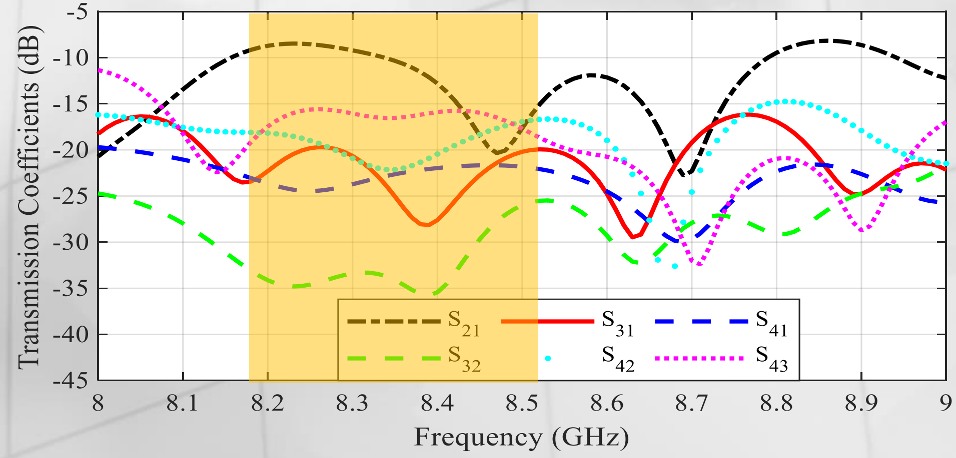


(a) (b) (c) (d) (e)

Geometry of various antennas used in the design procedure, (a) Without vias, (b) One via, (c) Two vias, (d) Three vias and (e) Four vias (Proposed antenna)



(a)



(b)

S-Parameters of the CDR MIMO antenna structure without vias.
(a) Reflection coefficients. (b) Transmission coefficients.

Isolation Improvement

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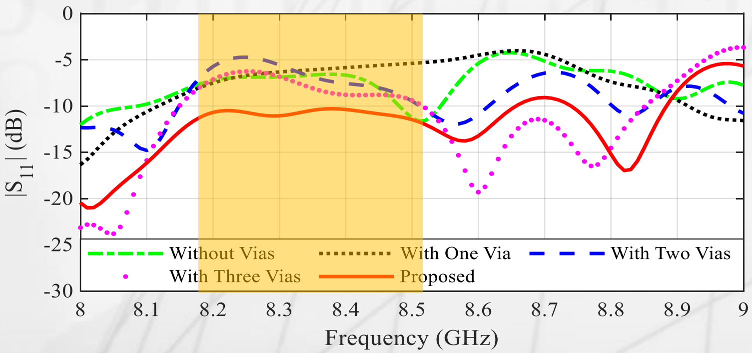
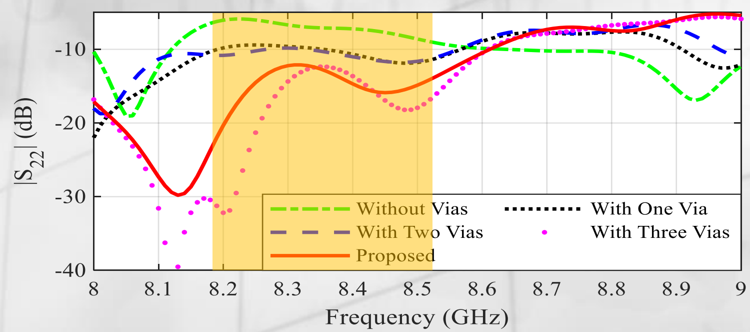
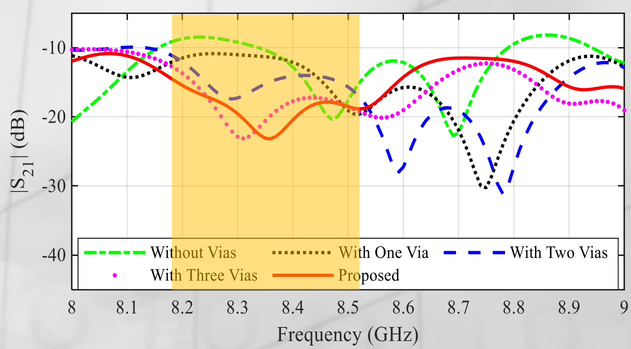


(a)



(b)



(c)

Effect of adding the metallic vias on the S-parameters, (a) S11, (b) S22 and (c) S21

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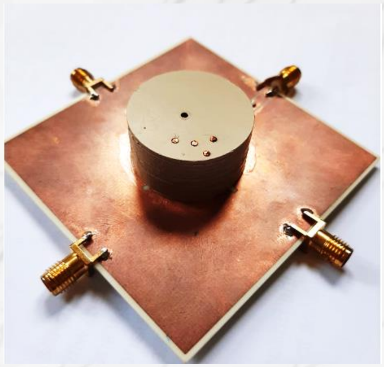
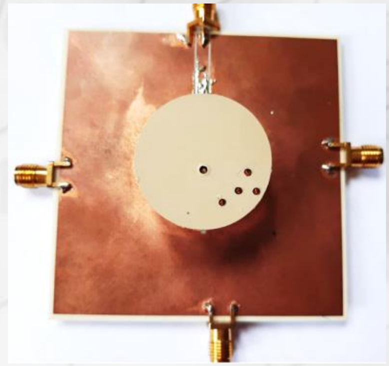
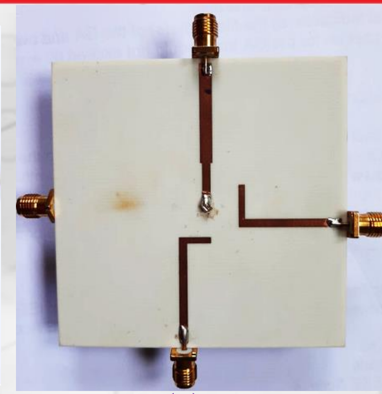
Results and Discussion



(a)

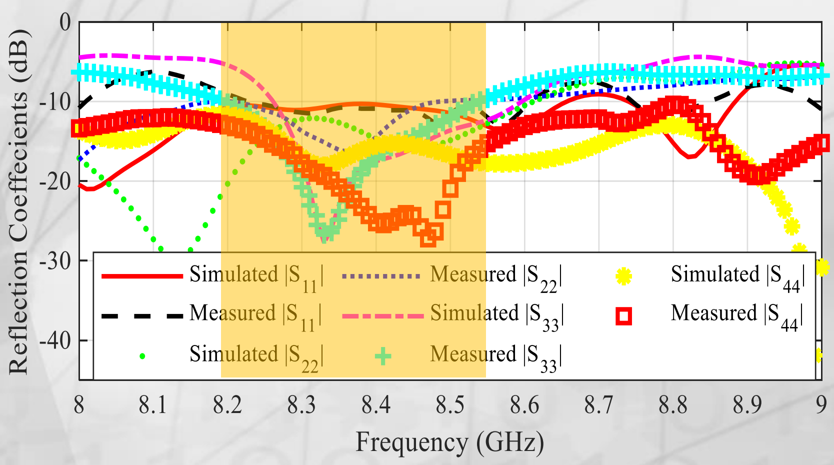


(b)

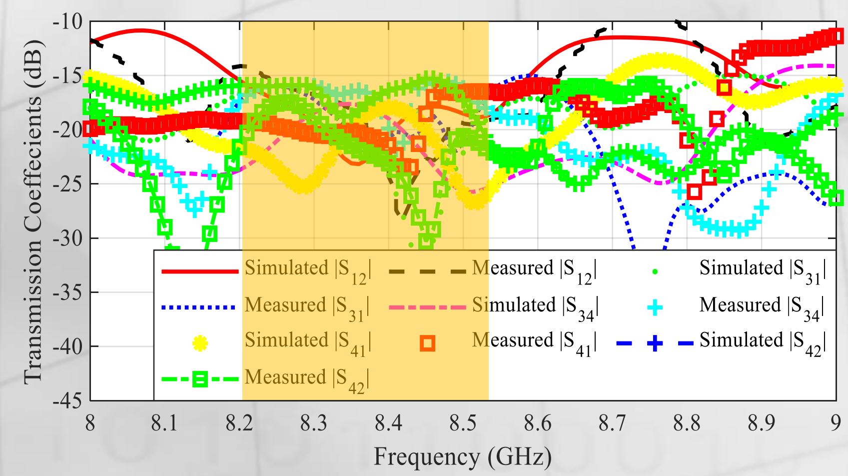


(c)

Fabrication of the proposed four ports single radiator CDRA MIMO. (a) 3D view, (c)Top view and (b) Bottom view



(a)

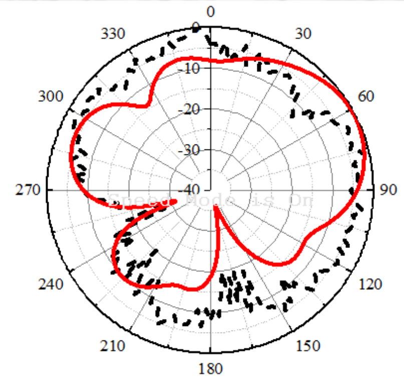


(b)

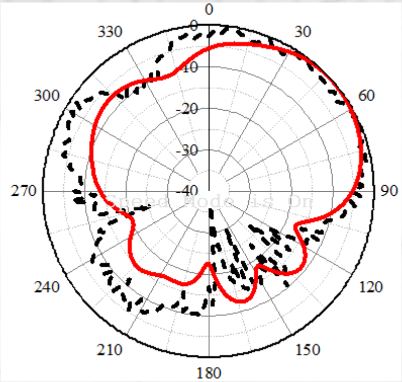
Simulated and measured reflection and coupling coefficient of the four ports single radiator DRA MIMO, (a) Reflection and (b) Coupling

Results and Discussion (Cont.)

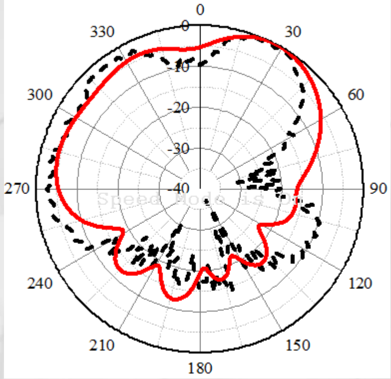
Radiation Patterns



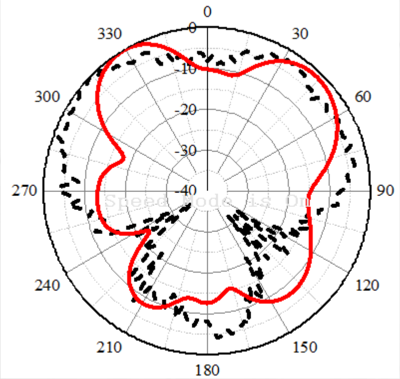
Port 1



Port 2



Port 3



Port 4

6.25, 7.65, 9.06, and 8 dBi gains are achieved corresponding to port 1, port 2, port 3 and port 4, respectively.

Results and Discussion (Cont.)

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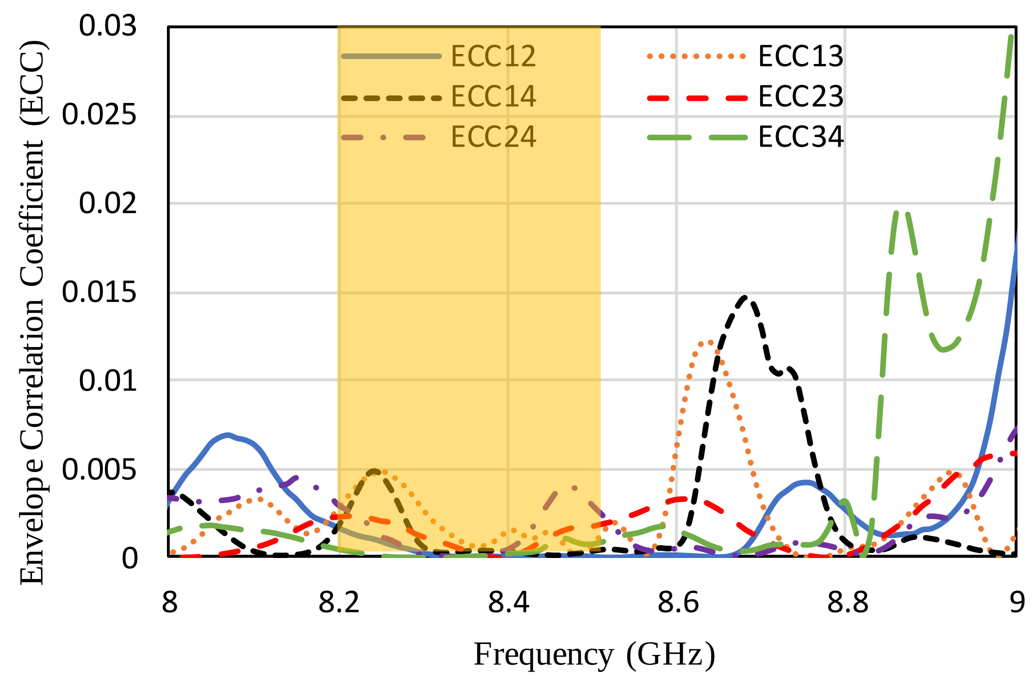
MIMO performance evaluation

Envelope correlation coefficient



Envelope correlation coefficient (ECC)

Contents

Conclusion

- A compact CPW slot antenna was presented and fabricated for 5G communications.
- The use of triangle strip and rectangle patch are introduced to improve the impedance matching of the antenna.
- The combination of the polarization diversity and EBG techniques are used for isolation improvement between the antenna elements in MIMO system.
- A multiband RDRA has been proposed for WLAN, WiMAX, and 5G applications.
- Three VMSPs with different lengths are engaged at both sides of the DR along the y-axis to excite three extra modes.

Conclusion

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- The use of this technique is introduced to excite adjacent modes with a small frequency ratio.
- The ECC is well below 0.01, satisfying the low ECC criteria (ECC <0.3) for a MIMO system and the diversity gain achieved by the antenna is 10 dB.
- Four ports MIMO single radiator DRA has been proposed for X-band operation.
- Excitation of orthogonal modes inside the CDRA is adopted for MIMO configuration.
- Inserting vias inside the DRA has been used to improve the coupling by perturbing the field to be perpendicular for all ports.

Published and Submitted Work

E-JUST

- **Journals**

1. A. I. Afifi, A. B. Abdel-Rahman, A. S Abd El-Hameed, A. Allam, and S. M. Ahmed, “Small Frequency Ratio Multi-Band Dielectric Resonator Antenna Utilizing Vertical Metallic Strip Pairs Feeding Structure.” *IEEE Access*, vol. 8, pp.112840-112845, Jun. 2020.

2. A. I. Afifi, A. S. Abd El-Hameed, A. Allam, S. M. Ahmed, and A. B. Abdel-Rahman, “New Approach for Designing Quad Ports Single Element Dielectric Resonator MIMO Antenna.” (**Submitted for publication**).

- **Conferences**

1. A. I. Afifi, D. M. Elsheakh, A. B. Abdel-Rahman, A. Allam, and S. M. Ahmed, “Dual Broadband Coplanar Waveguide-Fed Slot Antenna for 5G Applications” *In 13th European Conference on Antennas and Propagation (EuCAP)*, pp. 1-3, Mar. 2019, Krakow, Poland.

2. A. I. Afifi, A. S. Abd El-Hameed, S. M. Ahmed, A. Allam, and A. B. Abdel-Rahman, “Asymmetric EBG Decoupling Structure for Coupling Reduction Applications” *In 15th European Conference on Antennas and Propagation (EuCAP)*, Mar. 2021, Düsseldorf, Germany.

Thank you

谢谢
Спасибо
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Ευχαριστούμε
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Дякую
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شکر
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תודה
Diolch
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