New Design of Metamaterial Miniature Patch Antenna with DGS for 5G Mobile Communications

Fatima Z. Moussa[1], Souheyla Ferouani[2], Yamina Belhadef[3]

Abstract – **This work presents a new design of a miniature patch antenna with metamaterials for 5G mobile applications. We used 8-CSRR (Complementary Split-Ring Resonator) cells etched in the ground plane of the antenna structure. The simulated and measured results of reflection coefficients are –33.51 dB and –28 dB respectively at 3.5 GHz and the gain reaches the value of 3.44 dB. The DGS (Defected Ground Structure) has been used to further improve the bandwidth of the miniature printed antenna for 5G applications [3.4-3.8] GHz, it reaches the value of 774 MHz which is very satisfactory. A comparison between the slot miniaturisation technique of the same initial antenna [1] and metamaterial miniaturisation technique was carried out to more evaluate the performance of the proposed method. The miniaturisation rate obtained with the slit miniaturisation is 42%, while that with the metamaterials is 48% with a measured reflection coefficient of –28dB.**

Keywords – **Patch antenna, Miniaturisation, Slot, CSRR, 5G, Metamaterials, S11, Radiation pattern.**

I. Introduction

The growing demand for mobile communications requires the development of new generation mobile communications systems including 5G which will meet this need by increasing the spectral efficiency of the system, which will be tripled compared to the long term evolution (LTE) as well as the maximum data rate reaching 20 Gbps and the energy efficiency of the network will be multiplied by 100 [2]. Currently, 5G mobile systems are expanding their coverage to accommodate higher data rates. In 2015, the frequency bands below 6 GHz allocated by the World Radio Communication (WRC) were widely debated [3]. The following frequency bands were proposed: 470-694 MHz, 1427-1518 MHz, 3300-3800 MHz and 4500-4990 MHz [3]. 3.5 GHz is generally considered as the most important frequency part in the countries [3]. Over the last few decades, the need to use miniaturised printed antennas in several application areas, such as communication systems, radio sensors and radar applications is increasing day by day. One of the main challenges is the realization and integration of these miniaturized microstrip antennas, which have characteristics that are not readily available [4]. Microstrip antennas have great advantages and best prospects than conventional antennas, such as lighter weight and better performance [5]. These include lighter weight, small size, low cost, easy manufacturing and compliance. In addition, they can provide frequency agility, wide bandwidth, feed flexibility and an omnidirectional radiation pattern [6]. Patch antennas are used in various application areas such as medical, telecommunications and military. However, the narrow bandwidth and low gain are among the major drawbacks of these antennas [7]. Reducing the size of patch antennas is a challenge. Miniaturisation is the reduction of the overall area occupied in the communication system. To achieve this, various techniques have been introduced such as the introduction of slots, the use of high dielectric materials, short-circuiting and the use of metamaterials[8]. Metamaterials are artificially engineered materials that have a negative permittivity or permeability close to zero, or that have both negative permittivity and permeability [9]. Materials with negative permittivity only are called Ůnegative (ENG) and materials with negative permittivity only are called ε-negative materials (MNG). Finally, a material with negative permittivity and permeability is called double negative (DNG) [10]. The class of metamaterials that is probably best known is that which has a negative real part of both permittivity and permeability called double negative materials (DNG). In 1999, they were experimentally demonstrated for the first time [11]. CSRR metamaterials have received much attention because of the flexibility to generate negative dielectric constants (permittivity) in planar configurations. CSRR also offers promising candidates for miniaturisation and gain enhancement [12].

In this paper, we present a new metamaterial miniature patch antenna structure based on 8 Cell CSRR etched in the ground plane. This antenna resonates at 3.5 GHz for 5G mobile applications. A comparison with [1] in terms of performance; antenna dimensions, reflection coefficient, VSWR, bandwidth, radiation pattern was performed. The Miniature patch antenna was designed and measured using the network analyser to validate the simulation results.

II. Initial Antenna Structure

The proposed rectangular patch antenna is designed with the CST Microwave studio software [13]. An FR4 dielectric substrate with permittivity Ůr = 4.3 is used, with a thickness of h=1.5mm; fed by a quarter wave line. The overall size of the proposed antenna is (35.32 x 50.89 mm). Fig. 1 shows the

Article history: Received April 19, 2022; Accepted December 01, 2022

[1]Moussa Fatima Zahra is a member of the SLL Laboratory, Department of Electronic and Telecommunications, Faculty of Science and Technology, University of Ain Temouchent, Algeria, E-mail: fatima.moussa@univ-temouchent.edu.dz

[2]Souheyla Ferouani is a member of the LTT Telecom Laboratory of Tlemcen University, Electronic and Telecommunications Department, Faculty of Science and Technology, University of Ain Temouchent, Algeria, E-mail: souheyla.ferouani@univ-temouchent.edu.dz

[3]Yamina Belhadef is a member of the LTT Telecom Laboratory of Tlemcen University, Telecommunications Department, University of Tlemcen, Algeria, E-mail: yamina.belhadef@univ-tlemcen.dz

initial antenna geometry and Table 1 the optimal dimensions obtained. Then, Fig. 2 gives a reflection coefficient of –17.22 dB at 3.5 GHz. And Fig. 3 shows a quasi-omnidirectional radiation pattern.

TABLE 1
PROPOSED INITIAL ANTENNA PARAMETERS [1]

Parameters	Values [mm]
wp	26.32
Lp	20.25
L1	10.82
L2	10.82
Wg	35.32
Lg	50.89

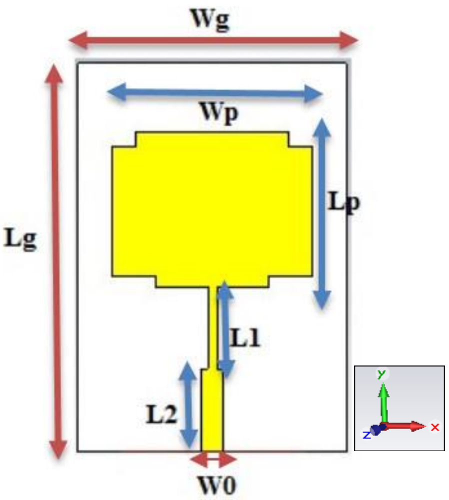


Fig. 1. Initial patch antenna [1].

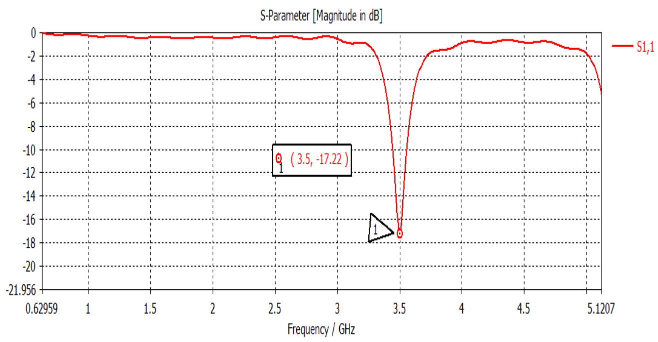


Fig. 2. A reflection coefficient of the proposed initial antenna [1].

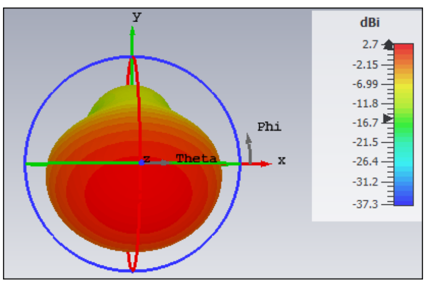


Fig. 3. 3D radiation pattern of the proposed initial antenna [1].

III. MINIATURISATION OF THE PATCH ANTENNA WITH METAMATERIALS

A. CSRR Cell Design for 5G

In our work, we are interested in the study of a complementary split ring resonator (CSRR). This resonator is made of copper placed on a FR-4 lossy dielectric substrate characterised by a permittivity ⍰⍰ of 4.3 and a thickness of 1.5 mm. The two rings of the square CSRR are concentric and spaced with 0.9 mm. The outer ring is 5.2 mm on the outer side while the inner ring is 4 mm on the outer side. The track width for each ring is 0.3 mm with a cut in one of its sides having a gap of 0.59 mm. The CSRR cell is alimented by two port in left and right as shown in Fig. 4. Fig. 5 shows the transmission coefficient S_{21} and the reflection coefficient S_{11} of the CSRR cell in dB. For metamaterial CSRR cells, the permittivity and permeability must have negative values witch is presented in section bellow.

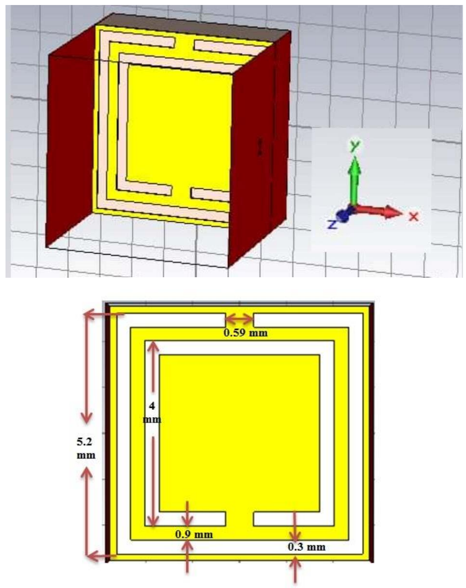


Fig. 4. CSRR cell at 3.5 GHz resonant frequency.

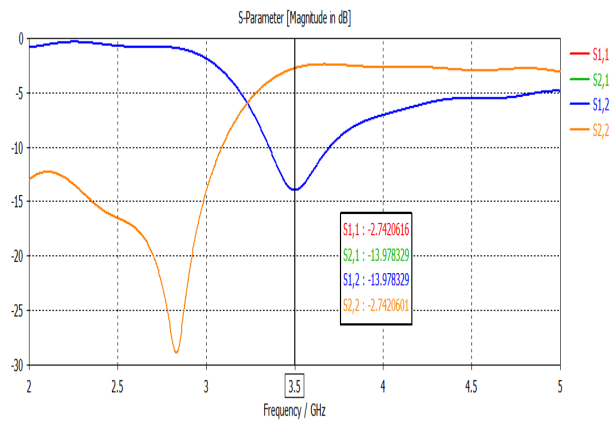


Fig. 5. Reflection and transmission coefficients of the CSRR cell.

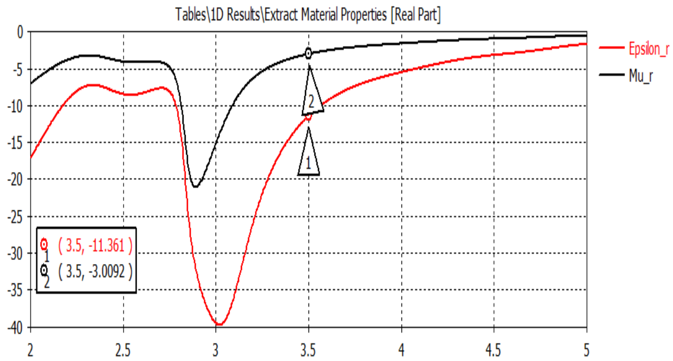
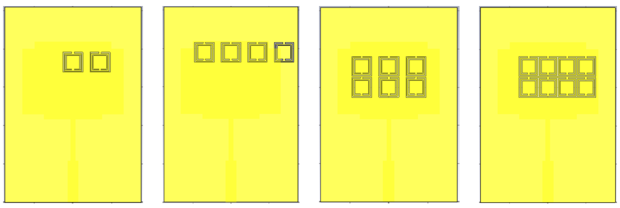


Fig. 6. Permittivity and permeability of the CSRR cell.

The results obtained shown by the Fig. 5 are satisfactory in terms of the reflection coefficient S_{11} which gives a value less than –2.74 dB at the 3.5 GHz resonance frequency and the transmission coefficient which is around –13.97 dB at the same 3.5 GHz resonance frequency. The permittivity and permeability of the CSRR cell simulated under the CST MWS software are shown in Fig. 6. It is noticeable that they have negative values at the desired frequency of 3.5 GHz, which shows that the cell is designed to be a metamaterial technology.

B. Miniaturisation of the Initial Patch Antenna

Figs. 7 and 8 show the steps for inserting the paired CSRR cells on the ground plane in order to have a frequency as low as possible than 3.5 GHz, this allows to have a high miniaturisation rate by returning to the 3.5 GHz frequency. The 8 CSRR cells insertion leads to a frequency around 2 GHz, which is very satisfactory for our case.



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

Fig.7. Insertion of CSRR cells on the ground plan, (a) 2-cells, (b) 4-cells, (c) 6-cells and (d) 8-cells.

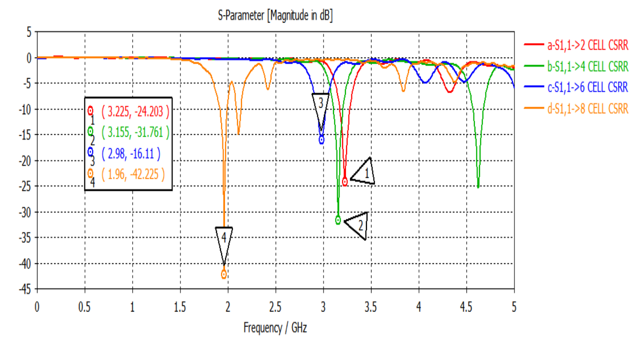
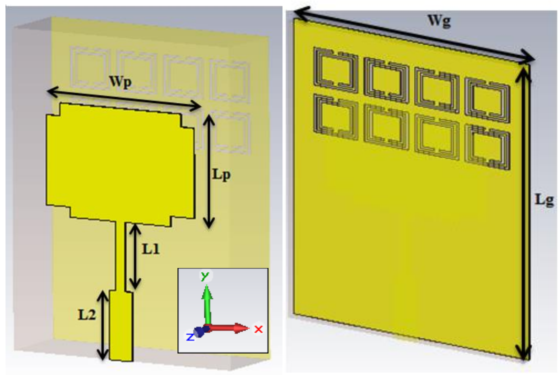


Fig. 8. Reflection coefficients of the four proposed antennas.



(a) (b)

Fig. 9. Geometry of the miniaturised antenna with an array of 8 CSRRs (a) front view: patch, (b) rear view: ground plane.

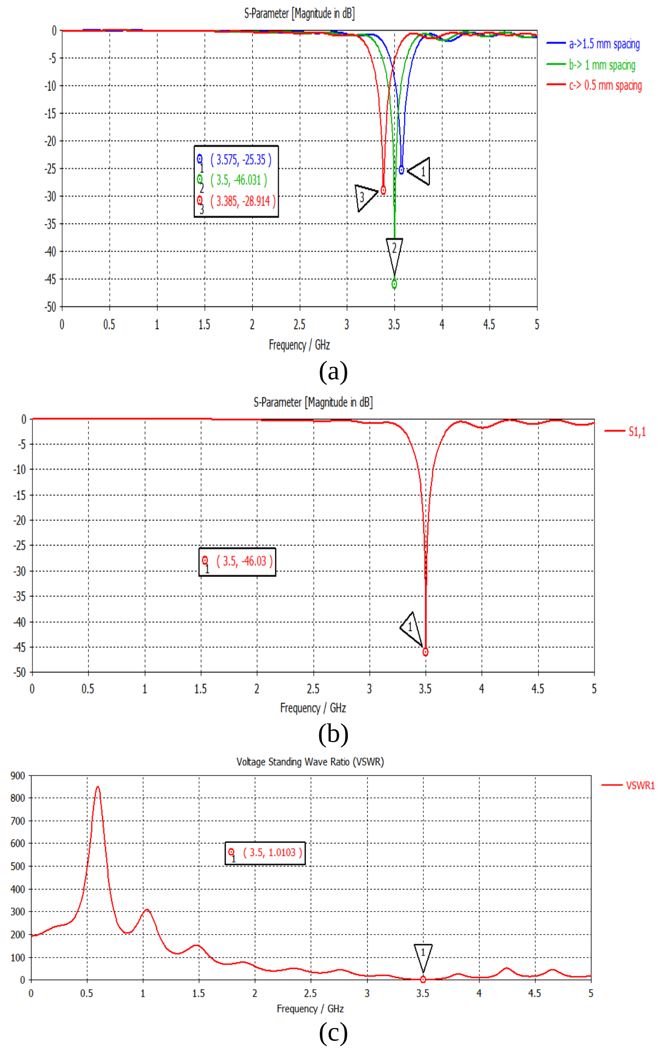


Fig. 10. (a) Return loss of parametric study between 8 CSRR spacing, (b) and (c) reflection coefficient and VSWR of the proposed miniature antenna respectively with 1mm spacing between 8 CSRR.

The dimensions of the proposed miniature antenna (Fig. 9) are given in the Table 2.

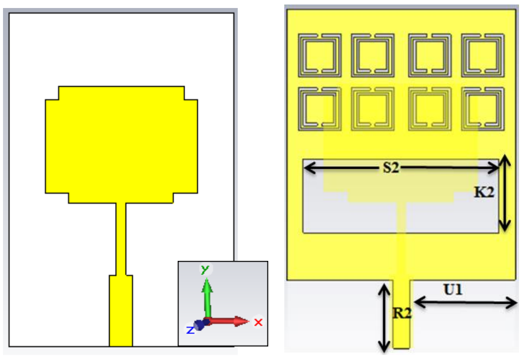
TABLE 2
DIMENSIONS OF THE PROPOSED MINIATURE RECTANGULAR PATCH ANTENNA

Parameters	Dimensions [mm]
wp	19
Lp	14.45
L1	8.85
L2	8.85
Wg	28
Lg	41.15

Fig. 10 shows the results of a parametric study on the spacing between the 8 CSRR cells placed in the ground plane of the antenna designed to improve performance, the final reflection coefficient obtained is –46.03 dB at 3.5 GHz. And the VSWR obtained is 1.0103 at 3.5 GHz. It is <2 which is very satisfactory.

C. Bandwidth Enhancement with the DGS

The proposed antenna is designed for 5G applications between [3.4-3.8] GHz. The bandwidth obtained in Fig. 10 (b) is 135 MHz, in order to further improve the bandwidth, we used DGS as shown in Fig. 11. Fig. 12 shows respectively the results of the different parametric studies carried out to improve the performance of the miniature antenna.



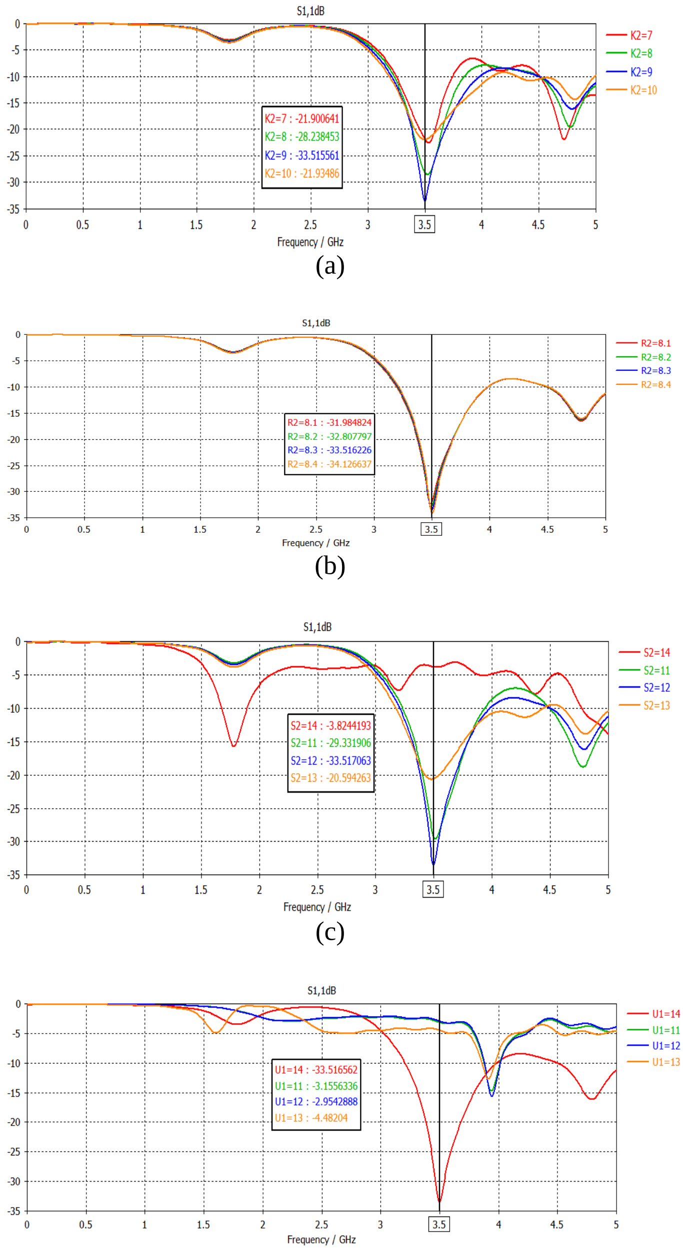
(a) (b)

Fig. 11. Proposed printed antenna with DGS, (a) front view: patch, (b) rear view: ground plan.

The final dimensions obtained are shown in the following Table 3.

TABLE 3
FINAL DIMENSIONS OF DIFFERENT DGS PARAMETERS

Parameters	Dimensions [mm]
K2	9
S2	12
U1	14
R2	8.3

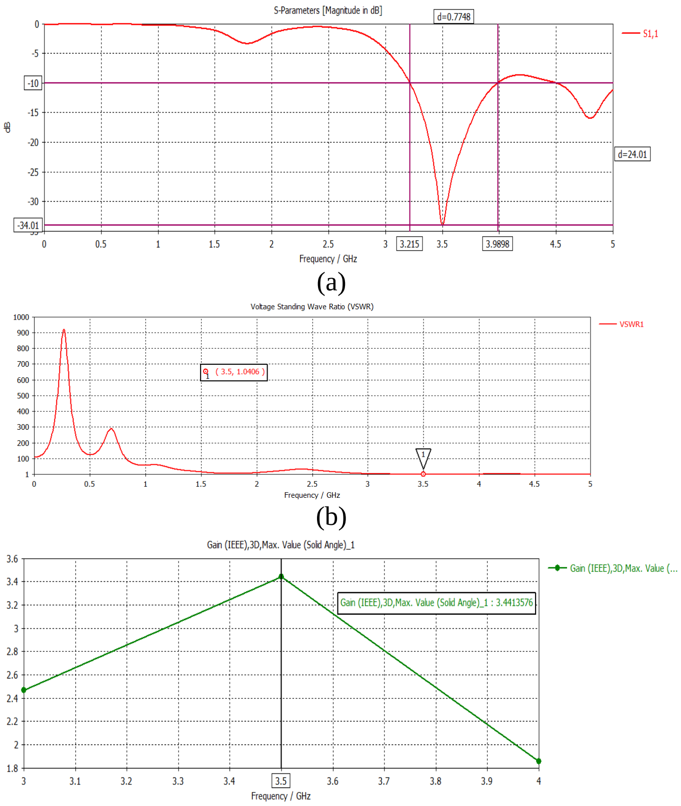


(a) (b) (c) (d)

Fig. 12. Reflection coefficient for different values of the length K2 on (a) and R2 on (b), different values of the width S2 on (c) and U1 on (d).

The reflection coefficient, VSWR and gain obtained with the dimensions of the table are given in Fig. 13 (a), (b) and (c), respectively. A reflection coefficient S11 is –34.01 dB at 3.5 GHz, the VSWR obtained is 1.0406 at 3.5 GHz and a gain of 3.44 at 3.5 GHz.

In Fig. 14 ((a) and (b)), the polar and 3D radiation patterns of the proposed final antenna at the 3.5 GHz resonant frequency are shown, respectively.

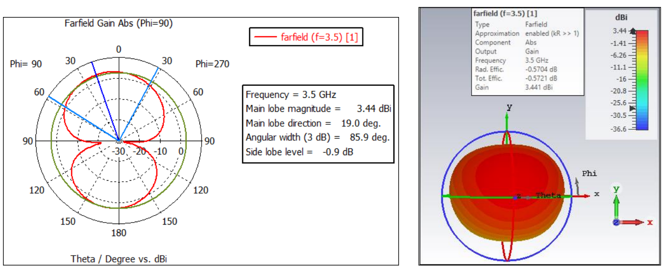


(a)

(b)

(c)

Fig. 13. (a) Reflection coefficient, (b) the standing wave rate and (c) the gain of the proposed miniature antenna.



(a) (b)

Fig. 14. Radiation pattern of the proposed antenna (a) 2D, (b) 3D.

It can be seen that the antenna has omnidirectional radiation in the H-plane (φ=90°).

The Table 4 above summarises the simulation results in terms of the reflection coefficient, gain, bandwidth and efficiency of the proposed final metamaterial-based antenna.

TABLE 4
SIMULATION RESULTS OF THE PROPOSED MINIATURE ANTENNA WITH METAMATERIAL

	Initial antenna	Miniature antenna with 8 CSRR cells
Wp×Lp (patch)	26.32 × 20.25	19 × 14.45
Frequency [GHz]	3.5	3.5
S11 [dB]	–17.22	–33.51
Gain [dB]	2.7	3.44
BP [MHz]	110	774
Efficiency	0.39	0.86

C. Comparison with Other Works

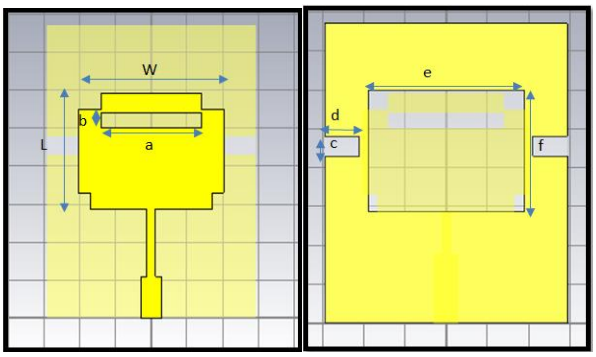
As shown in Table 5, the results of proposed antenna are very satisfactory in terms of S_{11}, gain and bandwidth with the use of 8 CSRR cells in the ground plane.

TABLE 5
SIMULATION RESULTS COMPARISON WITH OTHER WORKS

References	[14]	[15]	Proposed work
Resonance frequency [GHz]	3.5	3.597	3.5
Substrate dimensions (W×L) [mm × mm]	30 × 45	65.68 × 39.4	28 × 41.15
Bandwidth [MHz]	200	101.5	774
Gain [dB]	5.82	2.93	3.44

E. Measurement Results of Initial Patch Antenna, Miniature Patch Antennas with Slots and Miniature Patch Antennas with Metamaterial

We compared the results of the metamaterials miniaturised patch antenna of this paper with slots miniaturised antenna of our paper [1] in which we miniaturise the same initial antenna with slots. The results of metamaterial miniaturization are very satisfying compared to slot miniaturization. Fig. 15 shows antenna geometry and Table 6 gives parameters values.



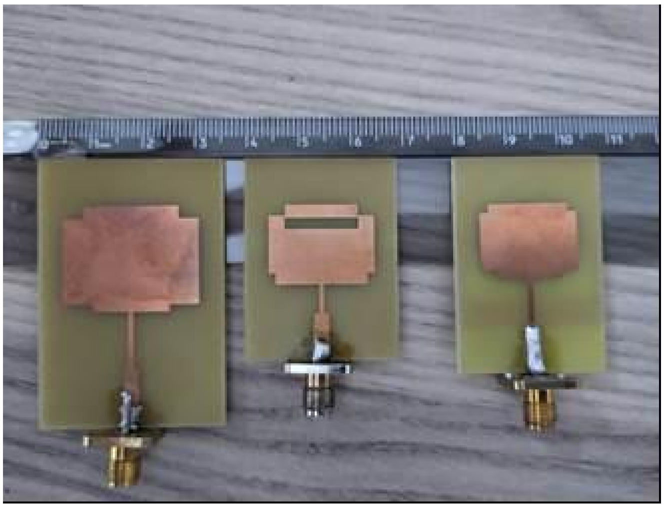
(a) (b)

Fig. 15. Proposed miniature rectangular patch antenna with DGS: (a) Front view (patch), (b) side view (ground plan) [1].

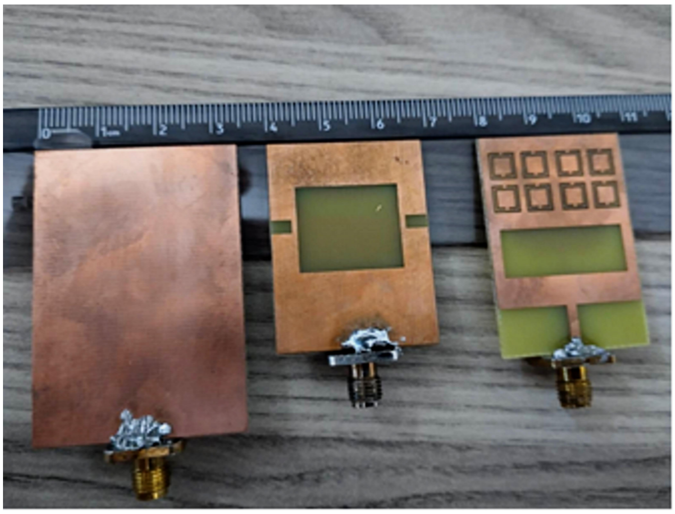
TABLE 6
MINIATURE PATCH ANTENNA FINALE PARAMETERS

Parameters	Dimensions [mm]
L	15.25
W	20.32
a	14
b	2
C	2.5
d	4.5
E	18.94
F	15.75

Figs. 16 and 17 show the prototype comparison between initial antenna, miniature antenna with slots and miniature antenna with metamaterial and antennas measurements with network analyser.

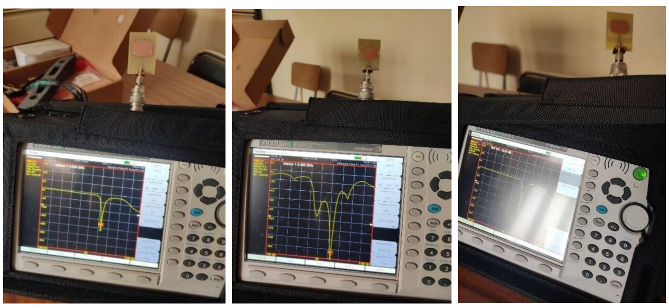


(a)



(b)

Fig. 16. Prototype comparison between initial antenna, miniature antenna with slots and miniature antenna with metamaterial (a) front view: patch, (b) rear view: grounds plan.



(a) (b) (c)

Fig. 17. Prototype of the realized antenna, (a) initial antenna, (b) miniature antenna with slots and (c) miniature antenna with metamaterial.

Figs. 18, 19 and 20 show comparison between simulated and measured return loss of initial, miniature with slots and miniature with metamaterial antennas.

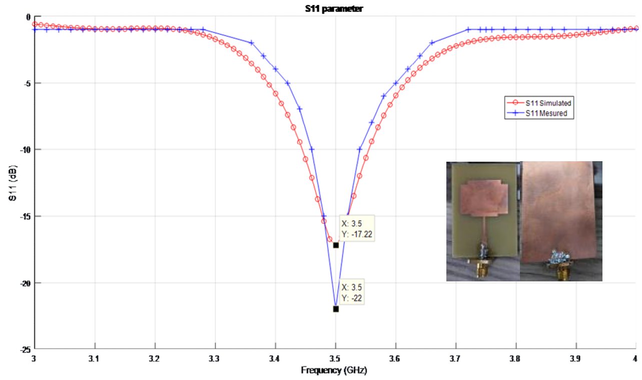


Fig. 18. Simulated and measured S11 of the initial patch antenna.

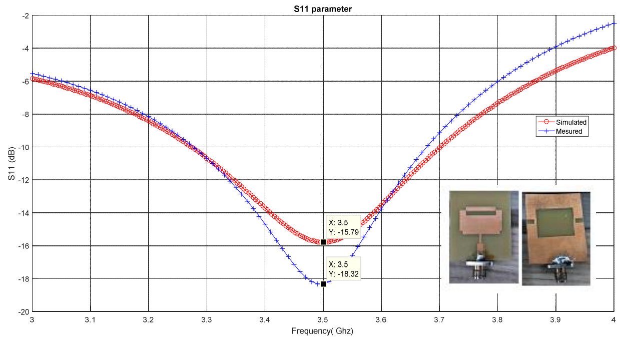


Fig. 19.Simulated and measured S11 of the miniature patch antenna with slots.

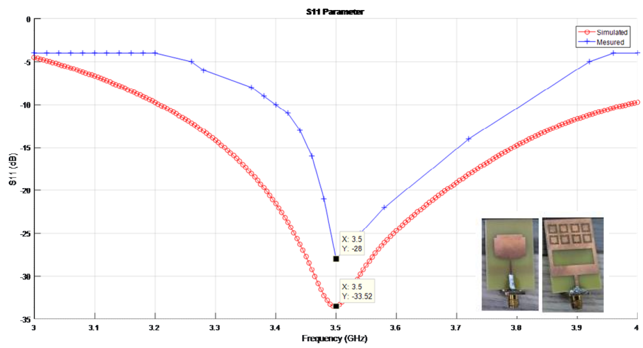


Fig. 20. Simulated and measured S11 of the miniature antenna with metamaterial.

F. Comparison Between Metamaterial and Slot Miniaturisation

Figs. 21 and 22 show the comparison results between simulated and measured results of metamaterials and slots antenna.

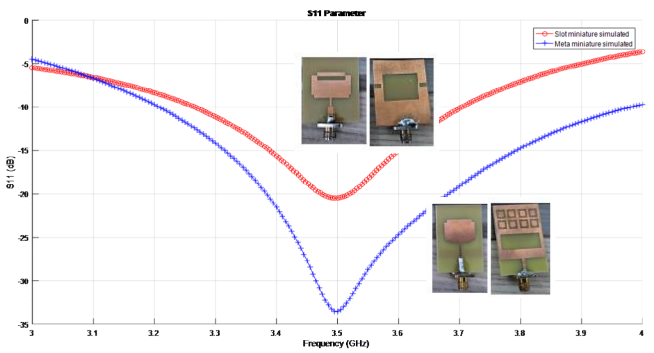


Fig. 21. Simulated S11 of miniature antennas with metamaterials and with slot.

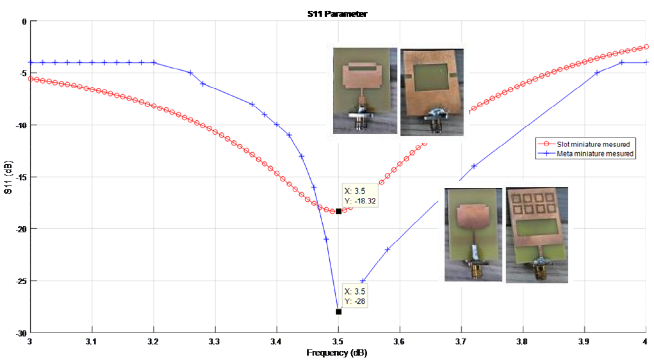


Fig. 22. Measured S11 of miniature antennas with metamaterials and with slot.

Table 7 summarizes the results of the comparison between the two types of miniaturization.

TABLE 7
COMPARISON RESULTS

Miniature antenna	with slot [1]	with metamaterials
Frequency [GHz]	3.5	3.5
Wp×Lp (patch) [mm×mm]	20.32 × 15.25	19 × 14.45
Reflection coefficient S_{11} simulated [dB]	–20.46	–33.51
Measured reflection coefficient S_{11} [dB]	–18.32	–28.94
Simulated bandwidth [GHz]	3.4 - 3.8	3.21 - 3.98
Measured bandwidth [GHz]	3.28 - 3.67	3.38 - 3.72
Gain [dB]	1.78	3.44
Miniaturisation rate [%]	42	48

Miniaturisation with metamaterials gives better performance in terms of S_{11}, gain and bandwidth as shown in the Table 7.

IV. CONCLUSION

Miniaturization by inserting Meta material on the ground plane has been presented in this paper. The proposed miniature antenna is designed for 5G mobile applications. The final dimensions of the proposed antenna are 19 mm x 14.45 mm x 1.5 mm. The simulation results are very satisfactory in terms of reflection coefficient, gain, radiation pattern and bandwidth. The use of CSRR on the ground plane with DGS has the advantage of giving a good miniaturisation rate and a wide bandwidth between [3.4-3.8] GHz compared to the slot miniaturisation technique. The patch antenna is ready to be used in 5G mobile communication systems.

ACKNOWLEDGEMENT

We would like to thank Professor Fehham, director of the STIC laboratory of Technology, the Faculty of Tlemcen University for his collaboration in the measurements of the realized patch antennas.

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