1. Hussam Keriee[1,2], 2. Mohamad Kamal A. Rahim[1], 3. Osman Ayop[1], 4. Nawres Abbas Nayyef[4], 5. Ahmed Jamal Abdullah Al-Gburi[3], 6. B.A.F Esmail[1], 7. Syed Muzahir Abbas[5]

[1]Advance RF and Microwave Research Group (ARFMRG), School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, UTM Johor Bahru, Johor, 81310, Malaysia
[2]Department of Medical Equipment Techniques, Al-Hadi University Collage, 10022, Baghdad, Iraq
[3]Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka, Malaysia (UTeM)
[4]Ministry of Interior Affairs, Baghdad, Iraq
[5]School of Engineering, Faculty of Science and Engineering, Macquarie University, Sydney, NSW 2109, Australia
ORCID: 1. 0000-0002-1445-6637; 2. 0000-0002-5488-9277; 3. 0000-0001-8162-739; 5. 0000-0002-5305-3937

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Wideband Planar Microstrip Antenna Based on Split Ring Resonator For 5G Mobile Applications

Abstract*. This paper presents a wideband planar microstrip antenna based on split ring resonator left-handed metamaterial (SRR-LHM) type at 3.5 GHz frequency for mid-band 5G mobile applications. The need to design a wideband antenna with good gain realising the proposed lower band spectrum for 5G technology is urgently demanded. To meet the requirements, microstrip technology and metamaterial are proposed. Firstly, the microstrip antenna is designed with a square patch and two longitude slots at 3.5 GHz. The metamaterial unit cell is designed individually based on the split ring resonator (left-handed metamaterial) SRR LHM type and then integrated with the developed antenna at the same band. The metamaterial is placed on the ground plane of the microstrip antenna. That will increase the bandwidth accordingly. The proposed metamaterial antenna is simulated and optimised using CST software. A good return loss of greater than 10 dB and impedance bandwidth of 1.04 GHz is obtained. This metamaterial antenna is a good candidate for mid-band 5G applications.*

Streszczenie. *W artykule przedstawiono szerokopasmową planarną antenę mikropaskową opartą na lewoskrętnym metamateriale z rezonatorem pierścieniowym (SRR-LHM) o częstotliwości 3,5 GHz do zastosowań mobilnych 5G w średnim paśmie. Pilnie potrzebna jest potrzeba zaprojektowania anteny szerokopasmowej z dobrym wzmocnieniem, realizującej proponowane dolne pasmo widma dla technologii 5G. Aby sprostać wymaganiom, proponuje się technologię mikropaskową i metamateriał. Po pierwsze, antena mikropaskowa została zaprojektowana z kwadratową łatą i dwoma szczelinami długości geograficznej o częstotliwości 3,5 GHz. Komórka elementarna metamateriału jest projektowana indywidualnie w oparciu o dzielony rezonator pierścieniowy (metamateriał lewoskrętny) typu SRR LHM, a następnie integrowana z opracowaną anteną w tym samym paśmie. Metamateriał umieszcza się na płaszczyźnie uziemienia anteny mikropaskowej. To odpowiednio zwiększy przepustowość. Proponowana antena metamateriałowa jest symulowana i optymalizowana za pomocą oprogramowania CST. Uzyskuje się dobrą tłumienność odbiciową większą niż 10 dB i szerokość pasma impedancji 1,04 GHz. Ta antena metamateriałowa jest dobrym kandydatem do zastosowań 5G w średnim* paśmie. (***Szerokopasmowa planarna antena mikropaskowa oparta na rezonatorze z dzielonym pierścieniem do zastosowań mobilnych 5G***)

Keywords: Metamaterials, SRR LHM, Wideband planar, Mid band 5G.
Słowa kluczowe: antena szerokopasmowa, antena planarna, 5G.

Introduction

5G technology is proposed to provide huge communications and capacity. In order to accommodate such communications, the cellular network has to dramatically increase its capacity. In this regard, in order to accommodate such massive communications, it is forecasted that 5G network has to provide 1000 times higher capacity than the current system [1]. The increasing need for high gain antenna and compact size for industrial [2-7], In the same time, 5G technology should also provide the smallest size of devices and reduces the losses from the path loss and components as well [8-11]. At lower frequency (5G lower frequency), two important issues are raised. The first one is the antenna should provide a higher bandwidth of more than 1 GHz to achieve the required 5G bands [1]. The second issue is the size of the whole antenna integrated into other arrays [12-15]. Since 5G technology needs to have compact size devices. Microstrip technology was proposed for the implementation of the antenna array since it's a low loss transmission line and can provide wideband bandwidth [16-18]. At the same time, metamaterial structures are proposed for compacting the size of the antenna and devices and increasing the bandwidth and the gain of the whole system [19],[20].

Microstrip technology is lower millimetre-wave bands has low gain and power handling capabilities. Therefore, metamaterials technologies have been proposed as a promising solution to realise the lower millimetre-wave antenna. Several works on microstrip metamaterials antenna at millimetre-wave bands have been presented in [21-25]. Microstrip with metamaterial antennas with high gain is introduced in [21], [22]. However, the size of the antennas is quite bulky, with a narrow bandwidth of 400 MHz. An omnidirectional microstrip metamaterial antenna is introduced in [23]. The measured gain is relatively meagre, 4 dB, besides the bulky size and narrower bandwidth. Another type of metamaterial antenna is proposed in [24]. The design is realised by implementing two radiation slots on the cavity surface of the microstrip at 5 GHz. However, high side lobes are reported. Additionally, to the wildly CRLH structure mushroom structure implementation in [25]. Despite the excellent size reduction of up to 50%, these designs exploit a fractional bandwidth of 1.75%, which is not preferred at lower millimetre-wave bands

Therefore, this paper aims to design and simulate a planar wideband microstrip antenna with CRLH metamaterial at 3.5 GHz. Firstly, the design procedures are discussed in section 2, including planar microstrip antenna design, metamaterial unit design, and planar microstrip antenna integrated with metamaterial. Secondly, the simulated and measured performance of the proposed metamaterial antenna is demonstrated in section 3. Finally, the outcomes of this paper are concluded in section 4.

Planar microstrip antenna with metamaterial design method

The proposed planar microstrip antenna structure is illustrated in Figure.1. The parameters of the microstrip antenna should be taken into consideration. The parameters can be found by [4], [9]:

$$W = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

where w is the patch width, fr is the resonant frequency, and ε_r is the substrate dielectric constant. The effective dielectric constant can be calculated using [24].

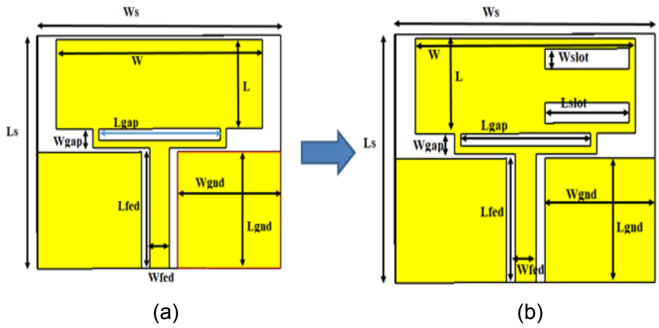

Fig.1. The proposed planar microstrip antenna. (a) available patch, (b) modified patch with two slots.

The simulated return loss of the proposed modified microstrip antenna is illustrated in Figure. 2. A parametric study is done by investigating the effect of adding two slots to the original patch in figure 1 (a). It can be noticed from the simulated response that increases the slot number leads to an increase in the return loss and shifts the frequency to the desired 3.5 GHz.

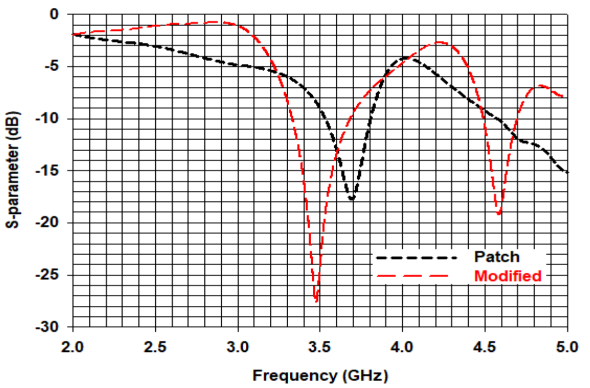

Fig. 2. The initial response of the modified antenna with respect to the general structure.

Metamaterial Unit Cell Design

The proposed design of the metamaterial CRLH unit cell is shown in Figure 3. The desired goal of the unit cell is to resonance at the frequency of 3.5 GHz for 5G mobile applications as the first case. The unit cell consists of four square metal strip square ring with a thickness of t1. The length and width of each strip square are defined as Lm × Wm. The design parameters of the proposed unit cell are found in Table 1. The unit cell structure is implemented on FR4 substrate, with a dielectric constant of 4.6 and 0.002 loss tangent as implemented in [26-29].

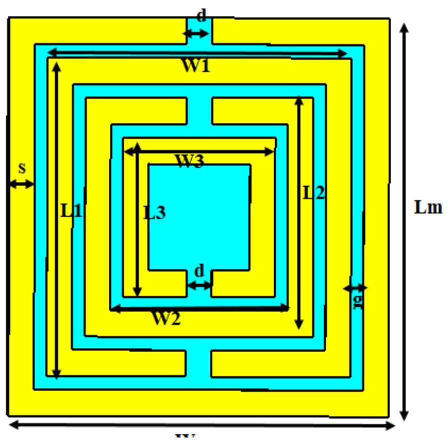

Fig..3. The proposed CRLH metamaterial design. The variables of the proposed CRLH metamaterial (All dimensions in mm)

Table 1. Geometries of the proposed antenna

Variable	Definition	value
Lm	Length of outer square	6.5
Wm	Width of outer square	6.5
g	Gap between each square	0.25
s	Width of all squares	0.5
d	Split width of cut	0.5
L1	Length of second square	6
L2	Length of third square	4.5
W1	Width of second square	6
W2	Width of third square	4.5
L3	Length of fourth square	3
W3	Width of fourth square	3

The S-parameters (S11, S21) of the proposed CRLH metamaterial is illustrated in Figure. 4(a). The simulated responses show a 3 dB transmission peak at 3.5 GHz with an impedance bandwidth up to 4 GHz, denoting a left-handed band. Figure. 4 (b) shows both permeability (μ) and negative permittivity (ε) as negative values, which covers a bandwidth from 2 GHz to 4 GHz.

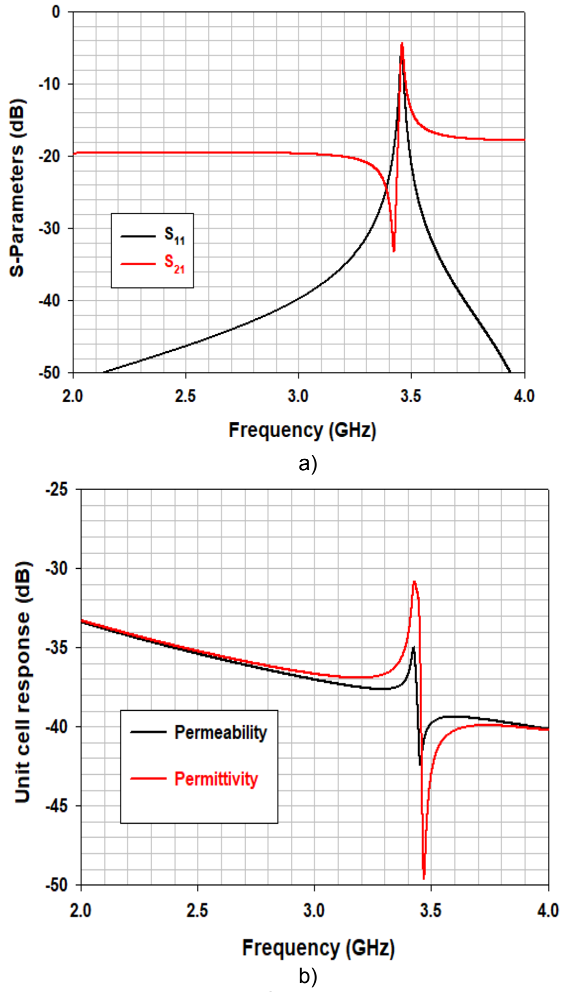

Fig.4. Unit cell response. (a) S-parameters, (b) Permeability and Permittivity.

Integrated Antenna with Metamaterial Unit

The geometric structure of the proposed antenna based on previously-designed, zero-index with metamaterial unit cell is shown in Figure 5 CRLH is placed on the back of substrate with two units behind the feed line and four units behind the patch.

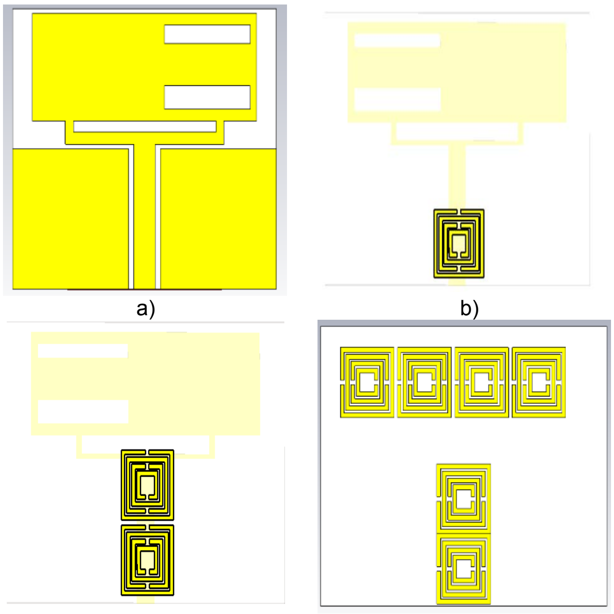

Fig. 5. The proposed geometry of the antenna with metamaterial unit cell. (a) front view, (b) back view with one unit cell, (b) with two unit cells, (c) final configuration.

The comparison graph of the simulated reflection coefficient of the proposed antenna is shown in Figure.6. The antenna with six units MTT has a bandwidth of 1.04 GHz compared to the proposed antenna with 1 and 2 unit cells of 600 MHz and 800 MHz, respectively. The reflection of -23.5 dB is obtained when six units MTT at 3.5 GHz.

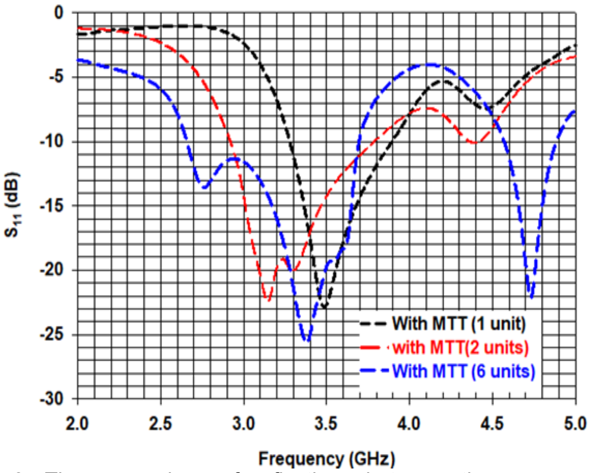

Fig. .6. The comparison of reflections between the proposed antennas MTM at 3.5 GHz.

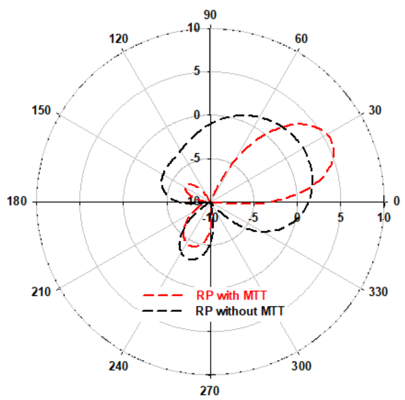

Fig.7. 2D radiation pattern with and without MTT at 3.5 GHz.

As a result, the comparison radiation pattern between the antennas with and without MTT is shown in Figure.7. It can clearly notice that when adding the MTT to the antenna, the gain and directivity increase. The gain is increased to be 5.24 dB, and the directivity is about 5.3 dB compared to the antenna without MTT OF 2.85 dB.

Hence, from the above parametric study, the final design parameters for microstrip antenna and metamaterial unit cell can be found in Table 2. The structure in

Table 2. The final parameters values of the proposed microstrip metamaterial antenna at 3.5 GHz (All dimensions in mm) (obtained from Figure 1 (b)).

Variable	Value
Ls	30
Ws	40
L	33
W	11
LSlot	17
WSlot	2
WSlot2	1
Lfeed	15
Wfeed	2.6
Lgap	10.4
Wgap	2.5

Results and discussion

The prototype of the printed metamaterial antenna is shown in Figure.8. A comparison graph of the simulated and measured return loss of the proposed metamaterial antenna is plotted in Figure 9. A measured return loss of -15 dB with impedance bandwidth of 900 MHz has been obtained compared to the simulated return loss of -23 dB and bandwidth of 1.04 GHz at 3.5 GHz.

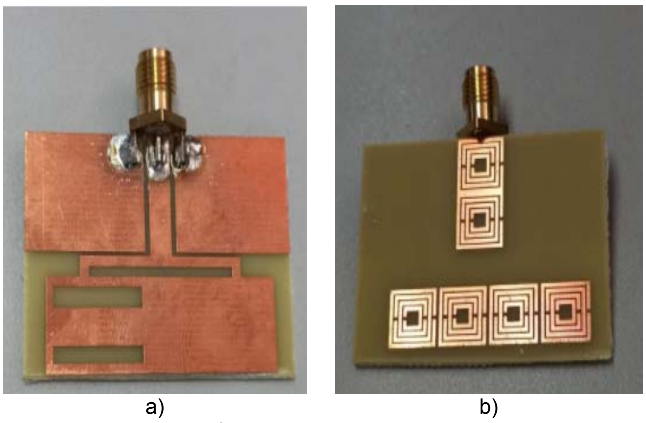

Fig.8. The prototype of a metamaterial antenna. (a) Front view, (b) back view.

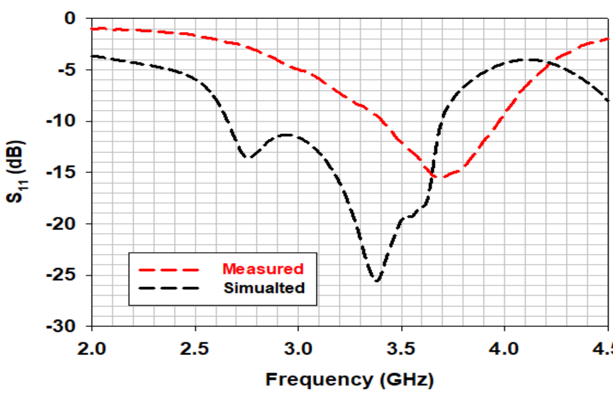

Fig. 9. Simulated return loss of the proposed metamaterial antenna.

The comparison of measured and simulated radiation patterns is shown in Figure. 10. It can be clearly noticed that when adding the MTT to the antenna, the directivity slightly increased. However, two beams are observed. This could be related to the two slots in the structure which produces a second beam. It is also observed that the back lobe is about 0 dB. This mainly comes from the back radiation of the unit cell of the antenna. Therefore, further investigations should be done in the future on the metamaterial array as an absorber on the back of the antenna structure to reduce this unwanted radiation.

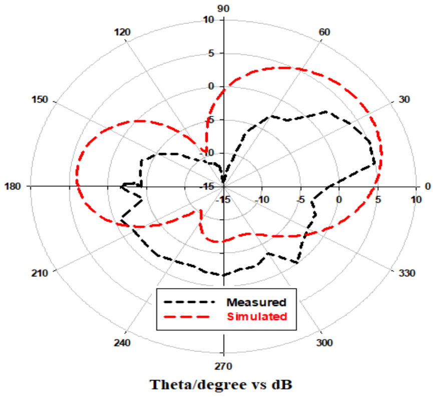

Fig. 10. Measured and simulated radiation pattern at 3.5 GHz.

Conclusion

A wideband metamaterial antenna at 3.5 GHz is presented for lower 5G bands applications. The metamaterial cell is designed based on CRLH SRR types at 3.5 GHz with negative permeability and permittivity values. The CRLH SRR cell is integrated on the bottom metal layer of the microstrip patch and placed behind the feed line. The performance of the metamaterial antenna showed a good response with a return loss greater than 10 dB and a bandwidth of 1.02 GHz. The obtained gain is about 4.8 dB. These results indicate a promising way to further work on designing an antenna array based on metamaterials for the 5G applications.

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***Authors** Hussam Keriee, UTM university, sam22.utm@gmail.com. Prof. Dr. Mohamad Kamal A. Rahim, UTM university, mkamal@fke.utm.my. Dr. Osman Ayop, UTM university, osmanayop@utm.my. Nawres Abbas Nayyef, Nawrasabbas1@gmail.com. Dr. Ahmed Jamal Abdullah Al-Gburi, UTeM university, engahmed_jamall@yahoo.com. Bashar Ali Farea Esmail, UTM university, afbashar@utm.my. Syed Muzahir Abbas, Macquarie University, syed.abbas @mq.edu.au.*
Corresponding author: Ahmed Jamal Abdullah Al-Gburi

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