Design of Dual Band Microstrip Patch Antenna using Metamaterial

Islam Md Rafiqul, Adel A.A Alsaleh, Mimi Aminah W. N., M. Sarah Yasmin, Norun Farihah A.M.

Department of Electrical & Computer Engineering, Faculty of Engineering
International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur, Malaysia
rafiq@iium.edu.my, deul89@yahoo.com, mimie@iium.edu.my, norun@iium.edu.my
smohamad@iium.edu.my

Abstract. Metamaterial has received great attention due to their novel electromagnetic properties. It consists of artificial metallic structures with negative permittivity (\(\varepsilon\)) and permeability (\(\mu\)). The average cell size of metamaterial must be less than a quarter of wavelength, hence, size reduction for the metamaterial antenna is possible. In addition, metamaterial can be used to enhance the low gain and efficiency in conventional patch antenna, which is important in wireless communication. In this paper, dual band microstrip patch antenna design using metamaterial for mobile GSM and WiMax application is introduced. The antenna structure consists of microstrip feed line connected to a rectangular patch. An array of five split ring resonators (SRRs) unit cells is inserted under the patch. The presented antenna resonates at 1.8 GHz for mobile GSM and 2.4 GHz for WiMAX applications. The return loss in the FR4 antenna at 1.8 GHz is -22.5 dB. Using metamaterial the return loss has improved to -25 dB at 2.4 GHz and -23.5 dB at 1.8 GHz. A conventional microstrip patch antenna using pair of slots is also designed which resonates at 1.8 GHz and 2.4 GHz. The return loss at 1.8 GHz and 2.4 GHz were -12.1 dB and -21.8 dB respectively. The metamaterial antenna achieved results with major size reduction of 45%, better bandwidth and better returns loss if it is compared to the pair of slots antenna. The software used to design, simulate and optimize is CST microwave studio.

1. Introduction

The prefix Meta is an ancient Greek means beyond which is used to refer to materials that do not exist in nature [1]. A metamaterial is an artificial compound material that has a precise structure, which offers properties not found in nature [2]. In other words, metamaterial is designed to obtain special electromagnetic properties such as negative permittivity or permeability, enormous handedness and zero refractive index [3]. The same like naturals materials deciding the properties of metamaterials can be done by their arrangement and components. Hence, the component must be designed with precise pattern to achieve particular properties and produce resonant structures. Sometimes Metamolecules or meta-atoms are the name given to these kinds of components. They are arranged in a periodic way in one, two, or three dimensions. Back in history, the first idea of metamaterial consist of double negative materials and negative refraction and it was proposed by Veselago in 1967 and Mandelstam in 1945[4][5]. However, in 2000, Smith and Pendry were the first to do an experiment to verify the feasibility of negative refraction [6]. Even though a major progress was seen in the new century. Nevertheless, clear and precise description to metamaterial is still debatable. However, the most important concept which...
is clear and essential in metamaterial is that the dimensions of unit cells and periodicity must be much less than the operating wavelength. This is to obtain quasi-homogeneous material [2] [3].

The usage of metamaterial is wide in antennas and microwave devices. An enormous number of antennas and microwave devices have been designed and fabricated with unique properties. In addition, flexible portable devices like laptops, mobile phones, wearable device, antennas with tuneable functions based on variable structures are still crucially important and demanded.

In this paper, dual band microstrip patch antenna design using metamaterial for mobile GSM and WiMax application is introduced. The antenna structure consists of microstrip feed line connected to a rectangular patch. An array of five split ring resonators (SRRs) unit cells is inserted under the patch. The presented antenna resonates at 1.8 GHz for mobile GSM and 2.4 GHz for WIMAX applications. The performance and size of metamaterial dual band antenna are compared with that of conventional dual band antenna.

2. Metamaterial Design

The metamaterial unit cell is designed and simulated by using the Eigenmode solver in CST. The result investigates the dispersion characteristics. For the boundary conditions, they are set to be in state of perfect magnetic boundary condition (PMC) and this in Z-direction while in Y and X-direction they are set to be in periodic condition. The LHM unit cell structure consists of two rectangular split ring resonator (SRR) and thin wire (TW). The rings are printed on the substrate. The substrate is a FR4 substrate. The length of the outer ring is \( L1 = 7.4 \text{mm} \), and the inner ring is \( L2 = 5.4 \text{mm} \). The gap between the rings \( W1 = W2 = 0.5 \text{mm} \) and a small brick is inserted in the centre of the inner ring. The cut in both rings is \( G1 = 1.6 \text{mm} \). The permittivity of the substrate is 4.4. The unit cell with it dispersion diagram are shown in Figures 1 and 2.

To prove that this unit cell is useful for wireless application, calculation to get the resonant points must be done. Four cells will be considered. Number of resonant points are given by [5]

\[
\text{Resonant points} = 2N - 1
\]  

These frequencies can be found by sampling the dispersion diagram as [5]:

\[
\beta l = m\pi
\]
Where:
\[ m = \text{resonance index: } 0, \pm 1, \pm 2, \ldots \]
\[ l = \text{physical length of the unit cell} \]
\[ \beta = \text{phase shift in degrees} \]

By increasing the number of unit cells, resonance points can be further sampled from the dispersion diagram of the unit cell, which results additional resonance frequencies.

From the equation (1), the number of resonance points is 7. Moreover, their corresponding mode indices are \( m=0, \pm 1, \pm 2, \pm 3 \) by using \( L=7.4 \) mm. Therefore, the sampled dispersion diagram from equation (2) is as follow, \( m = 0, \beta = 0, m = \pm 1, \beta = \pm 24.3^\circ \) and \( m = \pm 2, \beta = \pm 48.6^\circ \) and \( m = \pm 3, \beta = \pm 72.9^\circ \). The expected resonant frequencies are shown in the Table 1. As it is presented in the table, these frequencies occurred in wireless band. Therefore, this unit cell can be used for wireless application.

### Table 1. Expected resonance frequencies

| Mode of indices | \( M = -3 \) | \( M = -2 \) | \( M = -1 \) | \( M = 0 \) | \( M = +1 \) | \( M = +2 \) | \( M = +3 \) |
|----------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| The Resonant Frequencies (GHz) | 2.79 | 2.59 | 2.4 | 2.31 | 3.03 | 3.03 | 3.05 |

3. **Metamaterial Antenna Design**

Firstly, the microstrip patch antenna has been modelled. The FR4 substrate permittivity used is 4.5 and the thickness of the substrate is 1.6 mm. The patch thickness is 0.1 mm. A microstrip feed line is used to feed the antenna as shown in Figure 3. The Table 2 presented all antenna parameters. The conventional patch antenna resonates at 1.8 GHz. Secondly, the dual band metamaterial antenna is designed. An array of split ring resonators is placed under the patch and in the substrate as shown in Figure 3. The split ring resonators array (SRRs) are located in the near filed of the patch.
The resonance characteristics of the antenna will be affected by the permittivity and permeability of the manufactured substrate. A mutual capacitance will be enlarged between inclusions when the SRRs are placed under the patch. The spacing between SRRs will be optimized to achieve dual band frequency at 1.8 GHz and 2.4 GHz. Table 2 shows the parameters in (mm) of the microstrip patch antenna, the metamaterial patch antenna and the difference between both of them. From Table 2, it is seen that a major miniaturization happened to the microstrip patch antenna when the metamaterial was used. The metamaterial antenna achieves a 40% size reduction in the area of the patch and the substrate if it is compared to the conventional patch antenna where no metamaterial has been used. In addition, a miniaturization occurred in the feed line length and width.

4. Characteristics Comparison Between Conventional and Metamaterial Patch Antenna

Dual band frequency was successfully achieved at 1.8 GHz and 2.4 GHz by metamaterial antenna. The return loss at 1.8 GHz is -25 dB and at 2.4 GHz is -23.5 dB. Figure 5 is showing a comparison between the conventional antenna with single band frequency and metamaterial antenna which is showing dual band frequency.

Table 2. Comparision between microstrip patch antenna and metamaterial antenna parameters.

| Parameter               | Microstrip patch antenna | Metamaterial patch antenna |
|-------------------------|---------------------------|----------------------------|
| Substrate length        | 76                        | 56                         |
| Substrate width         | 102                       | 82                         |
| Patch length            | 38                        | 28                         |
| Patch width             | 51                        | 41                         |
| Feed slot cut, Fi       | 12.5                      | 12.5                       |
| Feed line length        | 31.5                      | 26.5                       |
| Feed line width, Wf     | 8.7                       | 6                          |
| Substrate thickness, h  | 1.6                       | 8.3                        |

Figure 5. Comparision between FR4 antenna and metamaterial antenna.
In addition, the Figure shows improvement in the return loss at 1.8 GHz. In conventional antenna the return loss at 1.8 GHz was -22.5 when at metamaterial it increased to be -25. The Fairfield directivity for both resonant frequencies is shown at Figures 6-9. In Figure 6, the angular width and main lobe direction are shown having the value of 91.8 deg and 8.0 deg respectively. Figure 7 shows that the maximum directivity at 1.8 GHz in metamaterial antenna is 5.459 dBi while the total efficiency is -4.595 dB. In Figure 8, the angular width and main lobe direction are displayed having the value of 76.6 deg and 6.0 deg respectively. The side lobe level is -14.1 dB. In addition, Figure 9 shows that the maximum directivity at 2.4 GHz in metamaterial antenna is 7.501 dBi while the total efficiency is -4.396 dB.

5. Comparison between Pair of Slots Antenna and Metamaterial Antenna

In a previous work [7-8], microstrip patch antenna with pair of slots was designed. In this section, a comparison is done between microstrip patch antenna with pair of slots and metamaterial antenna. Figure 10 shows that the metamaterial antenna is superior to slotted antenna. By using pair of slots, it was possible to obtain 2.4 GHz resonant frequency accurately when the resonant frequency is nearest for 1.8 GHz. However, by using metamaterial, dual band resonant frequencies are found accurate at 1.8 GHz and 2.4 GHz.
In term of the return loss, the metamaterial shows it is superiority again. In the antenna with pair of slots, the return loss at 1.8 GHz and 2.4 GHz were -12.1 dB and -21.8 dB respectively, yet in when the metamaterial is used the return loss at 1.8 GHz and 2.4 GHz were -25 dB and -23.5 dB respectively. Hence, the return loss improved significantly at 1.8 GHz and fairly at 2.4 GHz. In addition, it is noticed that the bandwidth is improved at 2.4 GHz and a better directivity is received at the same resonant frequency with 7.501 dBi. Moreover, by using metamaterial, size miniaturization is achieved. Table 3 displays dimensions difference between pair of slots antenna and metamaterial antenna.

![S-Parameter (Magnitude in dB)](image)

**Figure 10.** Comparision between pair of slots antenna and metamaterial antenna.

**Table 3.** Comparision between pair of slots antenna and metamaterial antenna parameters.

| Parameter            | Pair of slots antenna | Metamaterial patch antenna |
|----------------------|------------------------|----------------------------|
| Patch length         | 40                     | 28                         |
| Patch width          | 53                     | 41                         |
| Feed slot cut, \(F_i\) | 12.5                  | 12.5                       |
| Feed line length     | 31.5                   | 26.5                       |
| Feed line width, \(W_f\) | 8.7                  | 6                          |
| Substrate thickness, \(h\) | 1.6                  | 8.3                        |

Table 3 shows clearly size reduction in the patch length and width in metamaterial antenna compared to pair of slots antenna. This reduction corresponds with total area reduction of 45%. A noticeable size reduction is also seen in the feed line length and width while the substrate thickness is increased to form the magneto dielectric substrate.

**6. Conclusions**

A dual band microstrip patch antenna using metamaterial for mobile GSM and WiMax application is introduced. The antenna structure consists of microstrip feed line connected to a rectangular patch. An array of five split ring resonators (SRRs) unit cells is inserted under the patch. The designed antenna
resonates at 1.8 GHz for mobile GSM and 2.4 GHz for WIMAX applications. The return loss at 1.8 GHz is -25 dB and at 2.4 GHz is -23.5 dB. A conventional microstrip patch antenna using pair of slots is also designed. The pair of slots antenna also resonates at 1.8 GHz and 2.4 GHz. The return loss at 1.8 GHz and 2.4 GHz were -12.1 dB and -21.8 dB respectively. By comparing pair of slots antenna with metamaterial antenna, it is found that the return loss at 1.8 GHz improved significantly while it is slightly improved at 2.4 GHz. Bandwidth has improved and maximum directivity increased at 2.4 GHz. Moreover, a major miniaturization occurs to the microstrip patch antenna when the metamaterial was used. The metamaterial antenna achieves a 45% size reduction in the area of the patch if it is compared to the pair of slots antenna. In addition, a miniaturization occurred in the feed line length and width.

Acknowledgement
Authors are grateful to Research Management Centre, International Islamic University Malaysia to support this research through research grant RIGS16-065-0229.

Reference
[1] Rahmat-Samii, Y. (2006). Metamaterials in Antenna Applications : 2006 IEEE International Workshop, 2(c), 1–4.
[2] Christophe Caloz. (2005). Electromagnetic Metamaterials : Transmission Line Theory And Microwave The Engineering Approach.
[3] Sihvola, A. (2007). Metamaterials in electromagnetics. Metamaterials, 1(1), 2–11. https://doi.org/10.1016/j.metmat.2007.02.003
[4] Veselago, V. G., & P. (1968). The Electrodynamics Of Substances With Simultaneously Negative Values Of E And µ, 10(4).
[5] Nur, Abdirashid Mohamed and Wan Nordin, Mimi Aminah and Islam, Md Rafiqul and Habaebi, Mohamed Hadi (2015). Investigation of metamaterial unit cells based on dispersion characteristics, ARPN Journal of Engineering and Applied Sciences, 10 (23). pp. 17380-17385. ISSN 1819-6608.
[6] Shelby, R. A., Smith, D. R., & Schultz, S. (2001). Experimental verification of a negative index of refraction. Science (New York, N.Y.), 292(5514), 77–79. https://doi.org/10.1126/science.1058847
[7] Adel A.A Alsaleh , Md. Rafiqul Islam , Mimi Aminah Wan Nordin , Shadi Al-Askari (2016). Design and Optimization of Dual Band Microstrip Patch Antenna Using Slots Pair, Proceedings of 6th International Conference on Computer and Communication Engineering, DOI 10.1109/ICCCCE.2016.98, pp. 439-442, July 25-27, 2016.
[8] Mohammad Shawkat Habib, Islam Md Rafiqul, Khairuzran Abdullah and M Jamil Jakpar (2014). U-Slot Rectangular Patch Antenna for Dual Band Application, Proceedings of the 1st International Conference on Communication and Computer Engineering ICOCOE, pp 111-120, DOI: 10.1007/978-3-319-07674-4_12, May 20-21, 2014.