

Hexagon Shaped Metamaterial-Loaded Antenna for K_u Band Applications

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Abstract

This study presents the comparison results of a single patch K_u-band antenna with hexagon-shaped metamaterial loaded-antenna. The proposed double negative material loaded-antenna achieved to have better efficiency with a percentage of approximately 10%, besides the directivity increased 0.04 and the gain increased 0.27dB.

1. Introduction

Due to the progress in wireless communication, engineers aim to increase the efficiency of systems. Increasing the efficiency of the each single component has a crucial impact on increasing the overall performance. Accordingly, antenna efficiency has a significant effect on the overall systems [1].

Metamaterials are the periodic designed-materials, which assess extraordinary electromagnetic properties by having ϵ -negative and μ -negative values simultaneously at the same frequency. They were first theoretically proposed by Vesalago who claimed that those materials could achieve backward propagation, reverse Doppler Effect, reverse Vavilov-Cerenkov effect and negative index of refraction [2].

Researchers tried to take advantage of using metamaterials for increasing the efficiency of the wireless communication systems and start to use those materials for increase the antenna efficiency, gain and directivity. They either combine the metamaterial structure with antennas or they designed metamaterial inspired antennas [3]-[9]. Especially the designs that requires the installation of μ -negative or $\epsilon\mu$ -negative metamaterials in order to increase the antenna efficiency is one common method for achieving the aim [6]-[9].

In this study, a hexagon shaped split ring resonator [10] is used to increase the efficiency of a K_u band antenna by proper loading next to the feed point. In section 2 a K_u band patch antenna proposed with its features including the operating frequency, gain and efficiency. In section 3, the unit cell geometry and its properties are demonstrated. Double negative (DNG) frequency region is presented. In section 4 the metamaterial structure with array size of 1x4 and 2x4 loaded to the antenna proposed in section 2 and the impact of the metamaterials evaluated in section 5.

2. Single Patch Antenna

2.1. The geometry of the proposed design

The single patch, which the hexagon SRR will be loaded, has been designed to have an operating frequency for K_u band application is presented in Fig. 1.

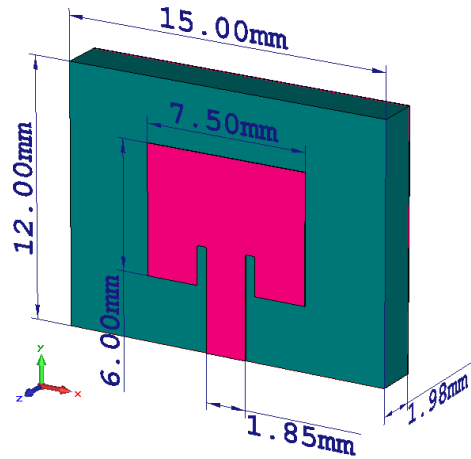


Fig. 1. Geometry of a single patch antenna

The length and the width of the proposed antenna is 15mm and 12mm, respectively. The length and the width of the patch is denoted as 7.5mm and 6mm having a transmission line width of 1.85mm and length of 4.73mm. The thickness of the Rogers RT5880 is 1.575mm and the substrate has a permittivity value of 2.2. Dent size of the strip line is defined as 0.31mm.

For determining the width, effective permittivity, and the length of a single rectangular patch; equation (1), equation (2) and equation (3), respectively.

$$\text{Width}(W) = \frac{c}{2f_o \sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + 12 \left(\frac{h}{W} \right)}} \right] \quad (2)$$

$$\begin{aligned} \text{Length}(L) \\ = \frac{c}{2f_o \sqrt{\epsilon_{eff}}} - 0.824h \left(\frac{(\epsilon_{eff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{eff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \right) \end{aligned} \quad (3)$$

Where c is the speed of electromagnetic wave, ϵ_r denotes the relative permittivity. W , h and f_o denotes the width of the patch, height of the patch and operating frequency, respectively.

The corresponding calculation yields a width value and a length value of 8.465mm and 6.120mm with an input impedance of 144 Ω . However the impedance matching is required so that a dent is created to achieve this having the values presented before.

2.2. Single Patch antenna results regarding S-parameters, Gain and efficiency

The proposed design is evaluated in terms of operating frequency and reflection characteristics besides gain and efficiency. The reflection characteristic is shown in Fig. 2.

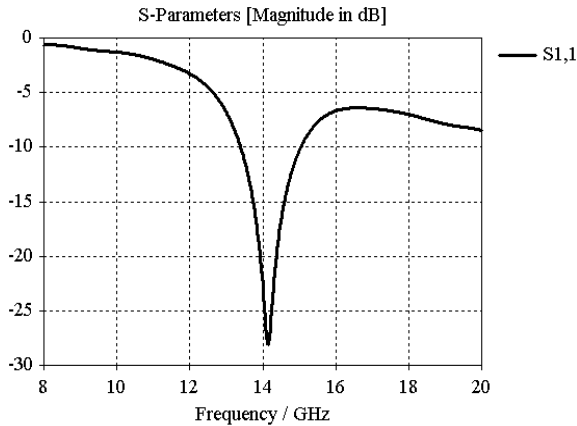


Fig. 2. S₁₁ characteristics of a single patch antenna

As shown in the figure above single patch design has a operating frequency of 14GHz with a bandwidth value of 1.66GHz. The lower frequency and the higher frequency observed at 13.4GHz and 15.1GHz, respectively. Gain of the propose antenna at the operating frequency is denoted as 6.6dB and the farfield pattern is presented in Fig. 3.

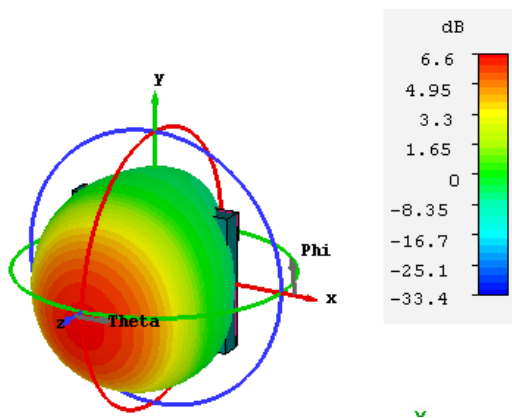


Fig. 3. Gain of a single patch antenna

As a performance criterion, radiation efficiency is considered as well as the total efficiency at the desired operating frequency with a 3GHz bandwidth between 13GHz and 16 GHz.

The corresponding results presented in Fig. 4 showing that the radiation efficiency is approximately 80% at desired frequency and more than 70% for all band. Total efficiency is more than 70% for a bandwidth of 1.2GHz.

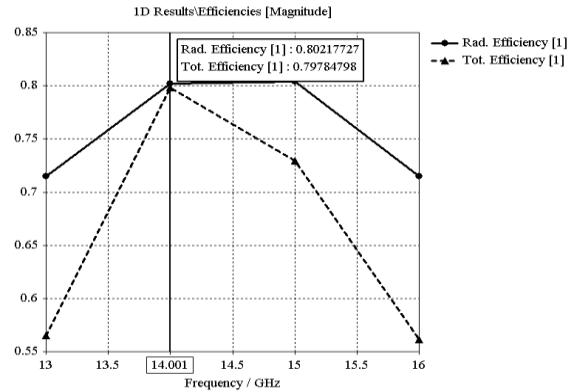


Fig. 4. Radiation and total efficiency of a single patch antenna

3. Unit Cell Design of the Metamaterial

The unit cell design that will be used to increase the antenna performance is presented in Fig. 5 with its dimensions. The substrate for the unit cell is defined as Rogers RT 5880 with a thickness of 1.575mm as single patch design in order to make the manufacturing process easier.

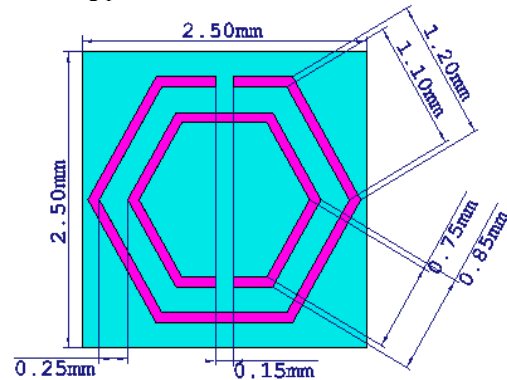


Fig. 5. Structure of a unit cell SRR

The SRR, which has a 0.15mm conductor rod behind the substrate, is magnetically excited.

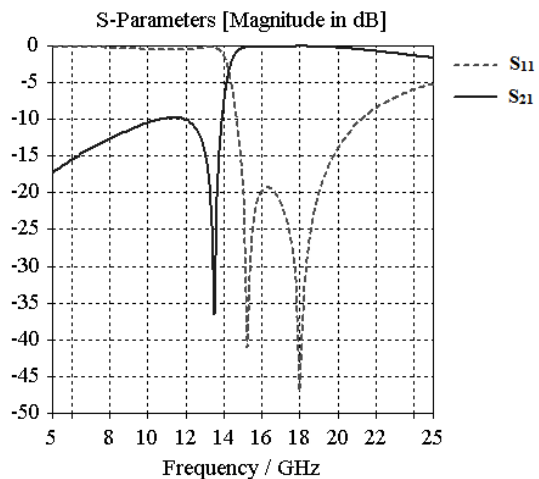


Fig. 6. S₁₁ and S₂₁ characteristics of a unit cell SRR

Reflection and transmission characteristics of the SRR are proposed in Fig. 6. As seen in the figure the S_{21} resonance frequency of the structure is around 14GHz. The boundary conditions are assumed to be unit cell and the results are obtained according to those assumptions. Parameter retrieval for the effective permittivity and permeability is performed using a version of the Nicholson-Ross-Weir (NRW) algorithm that is improved by implementing the Kramers-Kronig relationship. Double negative region is obtained at 14GHz, which is the same with the operating frequency of the proposed single patch antenna. The structure obtained from the study is a scaled version of the structure proposed in [10] in order to use in K_u band operations.

4. Metamaterial Loaded Antenna

The designs proposed in the previous sections are used to form a metamaterial-loaded antenna aiming to increase the antenna performance. In order to obtain the same results with the unit cell boundary conditions, the SRR structures are multiplied to form 1x4 and 2x4 array and the array located downwardly next to the port location. Side and back view of the 1x4 array metamaterial loaded antenna presented in Fig. 7 and Fig. 8.

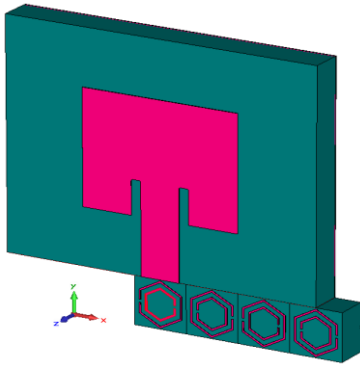


Fig. 7. Side view of a 1x4 array loaded patch antenna

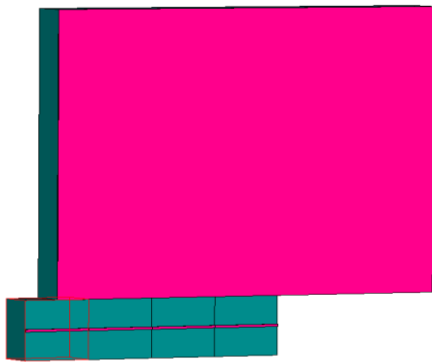


Fig. 8. Back view of a 1x4 array loaded patch antenna

Metamaterial array excited likewise the previous study as shown in Fig. 9.

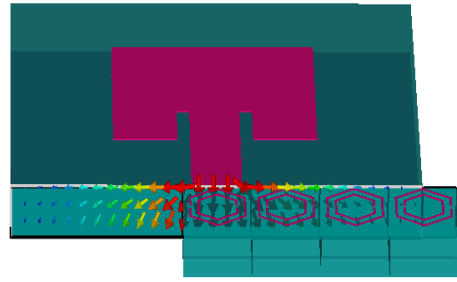


Fig. 9. Excitation of a 1x4 array loaded patch antenna

As aforementioned, the retrieval analyses conducted due to the results of unit cell boundary condition assumptions, which assumes the unit cells are added each other to form an array, which has infinite components. Therefore, the array size increased to be 2x4 for mimic that geometry better and loaded the antenna as in Fig. 10.

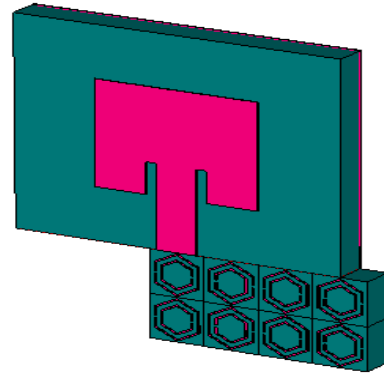


Fig. 10. Side view of a 2x4 array loaded patch antenna

The proposed antennas are compared and the results are presented in the following section.

5. Comparison of Metamaterial Array Loaded and Single Patch Antenna

The results regarding the comparison of single patch, 1x4 metamaterial array-loaded and 2x4 metamaterial array-loaded antennas and corresponding far field analysis of the proposed antennas presented in Fig. 11 by which it can be concluded that there is a negligible effect to load metamaterials for farfield radiation pattern.

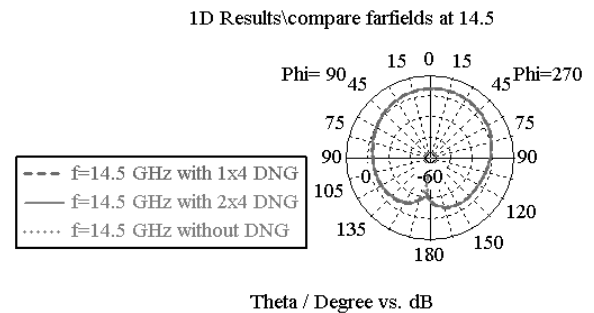


Fig. 11. Farfield comparison of the proposed antennas

Radiation and total efficiency comparison is performed and the results presented in Fig. 12.

As shown in the figure, the efficiency of the proposed single patch antenna increased almost 10% with metamaterial loading.

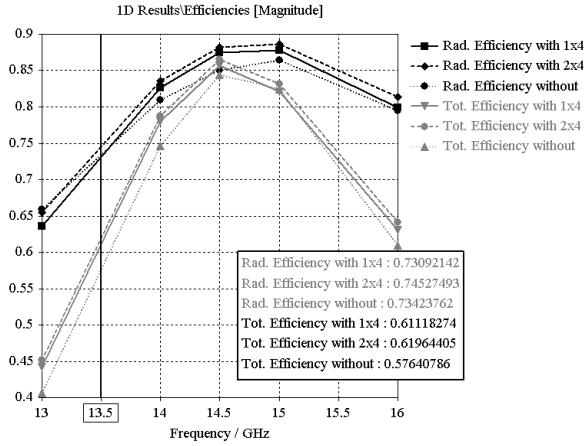


Fig. 12. Comparison of the total and radiation efficiencies

Directivity, realized gain and gain (IEEE) of the metamaterial loaded antennas are evaluated and compared with the single patch design, and the results presented in Table 1.

Table 1. Comparison of proposed antennas in terms of Directivity, Realized gain and Gain (IEEE)

	Single patch antenna		
	f=14 GHz	f=14.5 GHz	f=15 GHz
Directivity	7,59	7,77	7,88
Realized Gain	6,32	7,04	7,04
Gain (IEEE)	6,68	7,07	7,24
	1x4 metamaterial array-loaded		
	f=14 GHz	f=14.5 GHz	f=15 GHz
Directivity	7,63	7,81	7,94
Realized Gain	6,55	7,14	7,08
Gain (IEEE)	6,8	7,23	7,38
	2x4 metamaterial array-loaded		
	f=14 GHz	f=14.5 GHz	f=15 GHz
Directivity	7,63	7,81	7,94
Realized Gain	6,59	7,18	7,14
Gain (IEEE)	6,85	7,27	7,42

Directivity value increased when the metamaterial array loaded from 7.59 to 7.63. Increasing the array size did not change the directivity value but increase the gain. The efficiency is increased correspondingly as well.

6. Conclusions

To conclude up, due to the results obtained from the study, metamaterial loaded patch antennas can be more efficient than the versions that the metamaterials has not been loaded. The directivity increases due to the loading but increasing the size of the array has a negligible effect on the gain of the antenna. In view of the fact that the size increment by loading metamaterial, such

designs can be preferred for the applications that do not have space requirements. The patch designs can be more efficient by using metamaterials.

7. References

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