A High Gain Rectangular Microstrip Patch Antenna Using “Different C Patterns” Metamaterial Design in L-Band

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ABSTRACT

Design of rectangular microstrip patch antenna loaded with “different C patterns” left-handed metamaterial structure has been proposed. The proposed metamaterial structure is designed at a height of 3.2 mm from the ground plane for L-band (1 GHz-2 GHz) applications. The most interesting feature of the design is the ability of enhancing the gain and total efficiency of the antenna without affecting the other important parameters like bandwidth and directivity. The double negative (DNG) properties of metamaterial (−µ and −ε) have been proved by simulated S parameters. By using the “different C patterns” metamaterial structure, the return loss of the rectangular microstrip patch antenna is significantly reduced by 24 dB at a resonating frequency of 2 GHz. The proposed antenna is most suitable for wireless local area network (WLAN) application operating at 2 GHz.

Keywords: Rectangular microstrip patch antenna; Double negative; Left-handed metamaterial; Different C patterns.

1. Introduction

A patch antenna [1–3] is a low-profile antenna consisting of a metal layer over a dielectric substrate and ground plane. Typically, a patch antenna is fed by a microstrip transmission line, but other feed lines such as coaxial can be used. The advantages of patch antennas are that they radiate with moderately high gain in a direction perpendicular to the substrate and can be fabricated in a low cost PCB. The basic operating principle of a patch antenna is that the space between the patch and ground plane acts like a section of parallel plate waveguide. Neglecting radiation loss, the edge of the patch is an open circuit, so that energy reflects and remains below the patch. One disadvantage of a high-Q system is narrow bandwidth, so patch antennas have limited bandwidth, meaning that the input impedance of the antenna only remains near the desired value for a small range around the designed center frequency.

Metamaterials [4, 5] were first introduced by Victor Veselago in 1967. Metamaterials are periodic materials that derive their properties from their structures rather than their components. In principle, metamaterials can be synthesized by embedding various constituents with novel geometric shapes and forms. For metamaterials with negative permittivity (ε) and permeability (μ) [6, 7] several names and terminologies have been suggested, such as “left-handed” media with negative refractive index, “backward wave media”, and “double negative (DNG)” [8, 9] metamaterials.

Some of the applications of the metamaterial antennas are wireless communication, mobile communication, space communications, global positioning system (GPS), satellites, space vehicle navigation, and airplanes.

The simulation is done using CST-MWS (computer simulation technology) software.

2. Design methodology and simulation of proposed antenna structure

The designing parameters [10, 11] of rectangular microstrip patch antenna are \( L=34.30 \) mm, \( W=44.20 \) mm, cut width=5 mm, cut depth=10 mm, length of transmission line feed=32.82175 mm, with width of the feed=3.009 mm; shown in Fig. 1. The rectangular microstrip patch antenna is designed on FR-4 (Lossy) substrate with \( \varepsilon_r = 4.3 \) and height from the ground plane \( d=1.6 \) mm.

Several metamaterial structures like SRR, Spiral, Rod, Omega, S, Symmetric Rings etc. has already been introduced by previous researchers. This paper introduces a new and distinct metamaterial structure named “different C patterns” as shown in Fig. 2.

Two waveguide ports [12] were defined at the left and right of the \( x \)-axis in order to calculate the \( S_{11} \) and \( S_{21} \) parameters.
as shown in Fig. 3. The obtained $S$ parameters are exported to MathCAD-15 software for finding the value of the permittivity and permeability of the proposed metamaterial structure, using the Nicolson-Ross-Weir (NRW) approach [13, 14].

Equations used for calculating permittivity and permeability using NRW approach [15, 16] are

$$\mu_r = \frac{2c(v_2)}{\omega d} \left(1 + \frac{v_2}{c}\right)^2,$$  \hspace{1cm} (1)

and

$$\varepsilon_r = \frac{\mu_r + \frac{2S_{11}}{\omega d}}{2}.$$

(2)

where

$v_2 = S_{21} - S_{11},$

$\omega = \text{frequency in Radian},$

$d = \text{thickness of the substrate},$

$c = \text{velocity of light},$

$v_2 = \text{voltage minima}.$

### RMPA Parametric Analysis

Calculation of width ($W$) [1]

$$W = \frac{1}{2f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{C}{2f_r \sqrt{2}} \sqrt{\varepsilon_r + 1},$$

where

$c = \text{free space velocity of light},$

$\varepsilon_r = \text{dielectric constant of substrate}.$

The effective dielectric constant of the microstrip antenna to account for fringing field is calculated from [1]

$$\varepsilon_{eff} = \varepsilon_r = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(\frac{1}{1 + \frac{12h}{w}}\right).$$

(4)

The actual length of the patch ($L$) [1]

$$L = L_{eff} - 2\Delta L,$$

where $L_{eff} = \frac{C}{\varepsilon_{eff}}.$

Calculation of length extension

$$\frac{\Delta L}{h} = 0.412 \left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right) \left(\frac{W}{h} + 0.264\right).$$

(6)

### 3. Outcomes and Discussions

Fig. 4 shows that the return loss [17,18] of “different C patterns” metamaterial structure is reduced by 24 dB in comparison with rectangular microstrip patch antenna at a frequency of 2 GHz. The directivity and bandwidth are unaffected when the metamaterial structure is loaded with rectangular microstrip patch antenna. In Fig. 5, smith chart [19] shows that the antenna is matched with 50 $\Omega$ impedance at the resonating frequency. Radiation pattern of both antennas is shown in Figs. 6 and 7. The graph in Figs. 8 and 9 shows the negative values of permittivity and permeability which proves that the proposed structure is a metamaterial.
Figure 4: Rectangular microstrip patch antenna loaded with “different C patterns” metamaterial structure showing return loss of $-36.33$ dB.

Figure 5: Smith chart of rectangular microstrip patch antenna loaded with “different C patterns” metamaterial structure.

Figure 6: Radiation pattern of rectangular microstrip patch antenna.

Figure 7: Radiation pattern of rectangular microstrip patch antenna with “different C patterns” metamaterial structure.

Figure 8: Permeability of proposed metamaterial structure.

Figure 9: Permittivity of proposed metamaterial structure.

Figure 10: Rectangular microstrip patch antenna showing return loss of $-12.7624$ dB.

Figure 11: $S_{11}$ parameter of metamaterial structure.
4. Conclusion

The “different C patterns” metamaterial structure with rectangular microstrip patch antenna has been proposed in this paper. The simulated results provided the improvement in gain i.e. reduction in magnitude of return loss by 24 dB and directivity is also good. On making different structures by double negative left-handed metamaterials, antenna parameters like gain, directivity, and bandwidth can be improved up to a desired limit but practical limitations should be taken care of while fabricating the structure with CST-MWS software.

References


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