Bandwidth enhancement of rectangular patch microstrip antenna using left handed metamaterial at 2.4 GHz

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Abstract. This paper discusses rectangular patch microstrip antenna design by using left-handed metamaterial (LHM). Designed is on FR4 substrate with dielectric constant of 4.4 and 1.6 mm thickness. LHM structure is intended for bandwidth enhancement. By using the AWR simulator, LHM structure has been designed on 60x50 mm\textsuperscript{2} ground plane for rectangular patch microstrip antenna working on 2.4 GHz. Based on simulation results, the use of LHM structure is able to extend bandwidth up to 175.7 MHz with bandwidth enhancement reaching 213.75\% larger than without LHM. The minimum return loss is about -21.93 dB on 2.4 GHz. The miniaturization ration of the patch dimension achieves 14.6\%.

1. Introduction
Microstrip antenna has many advantages over the conventional antennas, such as thin surface area, easy to fabricate, small size, lightweight, and easy to integrate to existing communication devices. Even dough, innovations and developments are continuously performed in microstrip antenna research. One of the proposed techniques is by using metamaterial \cite{1} \cite{2} \cite{3} \cite{4}. Metamaterial is material structure that has uncommon permittivity and permeability which is hardly found in nature. Metamaterial has a double-negative material ($\varepsilon_r < 0$ and $\mu_r < 0$), a mu-negative material ($\varepsilon_r > 0$ and $\mu_r < 0$) or an epsilon negative material ($\varepsilon_r < 0$ and $\mu_r > 0$) \cite{5}. Metamaterial structure that are applied in microstrip antennas such as a split ring resonator (SRR) \cite{2}, a complementary split ring resonator (CSRR) \cite{3} and the left-handed metamaterial (LHM) \cite{4}.

This paper observes the use of the left-handed metamaterial usage for rectangular patch microstrip antenna working on the wireless local area network (WLAN) spectrum of 2.4 GHz. Impact of LHM to bandwidth enhancement is observed.

2. Antenna design
A rectangular patch microstrip antenna (RPMA) as shown in figure 1 consists of a rectangular patch, feed line, substrate and ground plane.
Basically, RPMA design can be performed by calculating patch size, feed line width and ground plane dimension. The calculation is by using the approximation equations as follows:

a. The wide (W) and length (L) of patch [5] [6]:

\[
W = \frac{c}{2f_r \sqrt{\frac{(\varepsilon_r + 1)}{2}}}
\]

\[
L = L_{eff} - 2 \Delta L
\]

where,

\[
L_{eff} = \frac{c}{2f_r \sqrt{\varepsilon_{reff}}}
\]

\[
\Delta L = 0.412h \left[ (\varepsilon_{reff} + 0.3) \left( \frac{W}{h} + 0.264 \right) - (\varepsilon_{reff} - 0.258) \left( \frac{W}{h} + 0.8 \right) \right]
\]

\[
\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( \frac{1}{\sqrt{1 + 12h/W}} \right)
\]

The c is free-space velocity of light, \(\varepsilon_r\) is the dielectric constant of the substrate, \(f_r\) is resonant frequency, \(h\) is thickness of the substrate, \(L_{eff}\) is the effective patch length, \(\Delta L\) is the length extension and \(\varepsilon_{reff}\) is the effective dielectric constant of the substrate.

b. Feed line width (\(W_0\)):

The size of \(W_0\) is obtained by adjusting the expecting characteristic impedance (\(Z_c\)) [5]:

\[
Z_c = \begin{cases} 
\frac{60}{\sqrt{\varepsilon_{reff}}} \ln \left[ \frac{8h}{W_0} + \frac{W_0}{4h} \right], & \frac{W_0}{h} \leq 1 \\
120\pi \sqrt{\varepsilon_{reff}} \left[ \frac{W_0}{h} + 1.393 + 0.667 \ln \left( \frac{W_0}{h} + 1.444 \right) \right], & \frac{W_0}{h} > 1
\end{cases}
\]

Design on this paper expects the characteristic impedance of 50 Ohm.
c. Ground plane dimension
The physical dimensions of the ground plane are based on the following formulae [7]:

\[ L_g = 6h + L \]  
\[ W_g = 6h + W \]  

By using FR4 substrate characteristics with \( \varepsilon_r = 4.4 \) and \( h = 1.6 \text{ mm} \) and expected resonant frequency of 2.4 GHz, then the designed RPMA can be obtained by using equations from (1) to (5). The slot size is adjustable to match the impedance.

The left-handed metamaterial (LHM) has negative permittivity and permeability. The LHM effect is possible to generate by modifying the ground plane dimension. The RPMA by using LHM structure is shown in Figure 2. The dimension is taken in millimeters (mm) and simulated by the AWR simulator.

![Figure 2](image)

**Figure 2.** The RPMA design with LHM structure (a). Front view  (b). Back view

3. Simulation results
The rectangular patch microstrip antenna with slot 7×1mm² characteristics as results of the AWR 2004 simulation are shown in figure 3 and 4. The optimization is performed by rearranging the patch and the ground plane dimension as LHM applied. The return loss (S11) for both RPMA with and without LHM structure are shown in figure 3, while the voltage standing wave ratio (VSWR) is plotted in figure 4.

The return loss of the designed RPMA on 2.4 GHz is -16.25 dB. After LHM is employed, the return loss downs to -21.93 dB. The minimum VSWR is 1.364 on 2.4 GHz. After LHM is employed, the minimum VSWR decreases to 1.174 on 2.4 GHz. The bandwidth of VSWR ≤ 2 for each design:

\[ \text{Bandwidth without LHM} = (2.4298 - 2.3738) \text{ GHz} = 0.056 \text{ GHz} = 56 \text{ MHz} \]
\[ \text{Bandwidth with LHM} = (2.4923 - 2.3166) \text{ GHz} = 0.1757 \text{ GHz} = 175.7 \text{ MHz} \]
Based on these simulation results, it can be shown that the bandwidth enhancement as the impact of the LHM usage is significant. This enhancement achieves 213.75%. Beside bandwidth enhancement, LHM structure usage in RPMA design is able to reduce patch dimension up to 14.6% as documented in table 1.

**Table 1. Miniaturization of the antenna dimension**

|                        | RPMA without LHM | RPMA with LHM     |
|------------------------|------------------|-------------------|
| **Dimension of patch** | 39×30 mm²        | 37×27 mm²         |
| **Dimension of ground plane** | 61×52 mm² | 60×50 mm²         |
4. Conclusion

This paper has discussed and observed the rectangular patch microstrip antenna (RPMA) design by using left-handed metamaterial (LHM). The employed LHM produces positive impact which is improving the antenna bandwidth up to 213.75% compared to RPMA design without LHM. Furthermore, the LHM results a better antenna miniaturization which reduces up to 14.6%. By these achievements, it is recommended that the LHM is used for RPMA for applications within frequency of 2.4 GHz.

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