Design and simulation of a rectangular microstrip patch antenna with single stub for GPR applications at 500 MHz

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Abstract. GPR (ground penetrating radar) is an equipment that makes it possible to detect objects below the ground surface. The antenna is one of the components needed in GPR. In this paper, the microstrip antenna design was discussed and proposed for GPR applications that work at a frequency of 500 MHz. This antenna design has a size of $29 \times 22 \text{ cm}^2$ using the FR4 substrate with a thickness of 1.6 mm. The optimal design was carried out by using a single stub. Based on the simulation results, the minimum VSWR was achieved at 1.009 with a bandwidth of 12 MHz (493.2 - 505.2 MHz). The minimum return loss value obtained is $-47.21$ dB and 5.695 dB of the gain.

1. Introduction

Ground-penetrating radar (GPR) is a system that uses electromagnetic waves (EM) to map conditions below ground level. GPR is a very broad of applications, detecting objects buried around and explorations of space planets. The choice of working frequency, modulation type, kind of the antenna, and polarization is highly dependent on some number of factors such as the size and shape of the target, transmission properties, and earth characteristics [1]. One type of antenna that can be proposed is a microstrip antenna. Several studies have discussed microstrip antennas for radar applications seen in [2-4]. Microstrip antenna is an antenna that a simple profile and planar. It is quite suitable to be applied to GPR systems.

This paper discusses the rectangular patch microstrip antenna (RPMA). The rectangular patch shape is low profile and easy to get the expected working frequency [5]. The use of a single stub on a rectangular patch microstrip antenna can also improve its performance [6]. This design is carried out with the theoretical equation approach as described in [7] and the assistance of the AWR simulator. The substrate material used in the design is the FR4 substrate with a thickness of 1.6 mm and a dielectric constant value of 4.4. The parameters to be observed from this design are VSWR, bandwidth, return loss, radiation pattern, and gain.

2. The antenna design

The design of RMMA in the form of width ($W$) and length ($L$) of the rectangular shape can be done by approaching the following equations [7]:

$$W = \frac{c}{2f_s}, \quad L = W \cdot \tan \theta$$
\[ W = \frac{1}{2 f r (\varepsilon_r \varepsilon_0)^{1/2}} \left( \frac{2}{\varepsilon_r + 1} \right)^{1/2} \]  

(1)

\[ L = \frac{1}{2 f r (\varepsilon_{\text{reff}} \mu_0 \varepsilon_0)^{1/2}} - 2 \Delta L \]  

(2)

with:

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

(3)

\[ \Delta L = 0.412 h \left( \frac{\varepsilon_{\text{reff}} + 0.3}{\varepsilon_{\text{reff}} + 0.264} \right) \left( \frac{W}{\pi} \right)^{1/2} \]  

(4)

where:  
\[ W = \text{width of the rectangular patch} \]  
\[ L = \text{length of the rectangular patch} \]  
\[ \varepsilon_r = \text{dielectric constant of the substrate} \]  
\[ f_r = \text{resonant frequency} \]  
\[ h = \text{thickness of the substrate} \]  
\[ \varepsilon_0 = \text{dielectric constant of free space} = 8.85419 \times 10^{-12} \text{ F/m} \]  
\[ \mu_0 = \text{permeability of free space} = 4\pi \times 10^{-7} \text{ H/m} \]  
\[ c = \text{light speed in free space} = 3 \times 10^8 \text{ m/s} \]

With the equations (1) and (2) approach, the initial steps to design a rectangular patch microstrip antenna are simple. In the next stage, carry out several iterations using a simulator so that it gets optimal results. The iterations were done by changing several parameter values, namely the length and width of the patch, the position of the feeder, and the length of the feeding channel. The use of a single stub has also been done so that optimal results can finally be obtained. The design geometry proposed in this paper is shown in Figure 1.

![Figure 1. Geometry of the antenna design](image-url)
3. Discusses and analysis
Based on the simulation results, the antenna design has performed well enough to be used at a frequency of 500 MHz. It's seen from the achievement of the antenna design parameters. Figure 2 shows the VSWR graph based on the simulation results.

![Figure 2. The VSWR](image)

In Figure 2, it can be seen that the minimum VSWR achieved is very close to the perfect value, namely 1.009. The design bandwidth based on the VSWR ≤ 2 value is 12 MHz, starting from 493.2 MHz to 505.2 MHz. Figure 3 shows the return loss graph of the antenna design.

![Figure 3. The return loss](image)

In Figure 3, it can be seen that the minimum return loss value is -47.21 dB at the frequency of 499 MHz. As for the frequency of 500 MHz, the resulting return loss value reaches -25.83 dB. Figure 4 shows a graph of the radiation pattern of the antenna design.
Figure 4. The radiation pattern

Figure 4 shows the radiation pattern of the antenna design, which is directional. The maximum beam is right at an angle of 0°. The antenna gain at this peak point reaches 5.696 dB. The beamwidth, which is the angle between the half-power points of the main lobe, is 83.45°.

Figure 5 shows the variation of stub length. The use of a stub with a length of 15 cm is very significant to improve the return loss value. Based on these changes, it can be seen that the return loss value is improved along with a slight shift in the minimum frequency.

Figure 5. The variation of stub length

The resulted design still has wide dimension (22×29 cm²). This dimension will expect to reduce using a special technique such as complementary split ring resonator in [8] and the ground plane reduction combine slots in [9,10].

4. Conclusion
The rectangular microstrip patch antenna with the use of a single stub has been discussed in this paper. Based on the obtained simulation results, the antenna design can operate well at a frequency of 500MHz, which is one of the work frequencies of the GPR system. Even though it has a bandwidth of only 13 MHz, this design can provide a very good VSWR value of 1.009 and a return loss value of -47.21 dB.
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