Circular Patch Microstrip Antenna Design for Wideband Communication

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Abstract

Microstrip antenna is one kind of antenna with small dimensions, light weight and compact. Microstrip and coaxially fed antennas are commonly used in various type of smart antenna. Typically, microstrip patch antennas have problems of low bandwidth. In this research a microstrip patch antenna was designed to have wider bandwidth and work on wideband communication. The patch shape is circular. It is feed by a coaxial probe which is located at the middle of the patch. The result of the simulation showed that the antenna gain of 0.23 dB and VSWR of 1.859 could be achieved, and the frequency centre was at 4.74 GHz with –10.51 return loss. In addition, the bandwidth gained in the simulation was 820 MHz on the working frequency from 3.1 to 7 GHz. Based on the simulation result, an antenna prototype was built. the simulation result above has shown that the designed antenna has a good performance and complied with FCC standard for wideband communication.

Keywords: wideband, microstrip antenna, circular patch.

Introduction

Wireless technology has become a ubiquitous technology in modern society in the information age today. Wireless devices have reached almost all the people not only in developed countries, even the people in the developing countries. Many applications continue to evolve and use a wireless platform as the device model. Therefore, it is not surprising that demand for wireless–based communications equipment that is easy to carry anywhere and supports data transfer rates continuing high anticipated by the user. Wireless devices that are produced must be accepted by users and convenient to use. Therefore, a compact shape and light is an attraction and the miniaturization of the antenna as a component in the communication is important to consider.

As it is progressing, many research on the area of wideband antenna have been conducted to meet the people demand of wireless communication. To make the wireless communication to be low cost and ubiquitous, a low profile and small dimension antenna is needed. Microstrip antenna is one of the most popular types of planar transmission lines that has characteristics that meet these requirements. Microstrip antenna is low profile and has small dimension, easily fabricated and integrated to the electronics devices (such as IC, active and passive device, etc.) and has low fringing effect. The focus of this research was to design and analyze the characteristics of microstrip antenna with circular patch form, working on the frequency of 3.1 to 7 GHz

Microstrip Antenna

Microstrip antenna is an antenna that is designed and fabricated on the printed circuit board and generally works at microwave frequencies. Compare to other antennas model, microstrip antenna which is most widely used in telecommunications equipment. Its accomplishment starts from very well known advantages such as: light weight, low profile, easy and low cost fabrication. In applications, microstrip antenna is one of microwave antenna that is used as an efficient radiator in many modern telecommunication systems such as Global Positioning System (GPS), Personal Communications System (PCS), and Direct Broadcasting System (DBS). This type of antenna is widely chosen in various applications for its simple shape, and other advantages described above. However, on the other hand, it has the limitation in bandwidth,
gain and the power handling capability. Therefore, many techniques have been developed to increase the bandwidth and very wideband microstrip antennas have been introduced (Wong, 2002; Chen, 2006).

**Circular Patch Microstrip Antenna**

Microstrip antenna with circular patch will have the same performance as the square one. For certain application, like array, the circular patch is more beneficial compare to others. The microstrip antenna with circular patch is easy to modify to yield certain impedance value, radiation pattern and working frequency. There are many methods available to analyze this antenna, including: cavity model, matching mode with side admittance, common transmission line mode, integral equation approach, coaxial probe and FDTD.

**Substrate and Patch Radius.**

Substrate used in a circular patch microstrip line is considered by selecting a suitable dielectric material by adjusting the thickness \(h\) and loss tangent \(\delta\). Thicker substrate, which obviously mechanically stronger, may increase radiated power, reduce conductor loss, and improve the bandwidth impedance. However, thicker substrate also increases the weight, dielectric loss, and ground wave loss. Dielectric constant of a substrate \(\varepsilon_r\) has the same function as substrate thickness. Lower \(\varepsilon_r\) value will increase the side area of the patch that will radiated power. For that reason, it is better to choose \(\varepsilon_r\) value < 2.5, unless if the smaller patch is desired. The increasing in substrate thickness has the same impact as the decreasing of \(\varepsilon_r\) value from antenna charateristic. A high loss tangent will increase dielectric loss and in turn will decrease the efficiency of antenna. The materials that are commonly used as substrate include: honeycomb \((\varepsilon_r = 1.07)\), duroid \((\varepsilon_r = 2.32)\), quartz \((\varepsilon_r = 3.8)\), dan alumina \((\varepsilon_r = 10)\). So that, the substrate used has to be the one with low dielectric constant, in order to achieve higher radiation efficiency.

In the antenna design, the value of \(a_e\) on working frequency \(fr\) is calculated using equation (Balanis, 2016):

\[
a_e = \frac{1.841}{h_{o} \sqrt{\varepsilon_r}} = \frac{0.794}{f_{r} \sqrt{\varepsilon_r}}
\]

**Feeding Technique**

Microstrip antenna can be fed with several methods that are classified into two categories, contacting and non–contacting method. In contacting method, RF power is fed directly to patch radiator using connecting element. While in no contacting method, RF power is fed by electromagnetic coupling from microstrip line to the patch. Some feeding techniques that are commonly used are microstrip line technique, coaxial probe, aperture coupling and proximity coupling, see Garg (2000).

There are many previous researches on circular patch microstrip line have been conducted. One of those is the research conducted by Nagalingam, in which he investigated and designed a circular patch microstrip line for Ultra–Wideband application (UWB) and analyzed it in time domain (Nagalingam, 2010). He was successfully found the antenna parameters required, using leveling microstrip line mode, in which the feeding line was directly connected to patch radiator.

Another research was conducted by Zani, *et al.* (2010), who investigated the effect of dielectric material on bandwidth. The microstrip line design was directly connected to patch radiator. Some other researchers also used microstrip line feeding technique by changing the shape and location of the feeding line. In this research, coaxial probe was used as the feeding technique. This technique was selected for it was the best method that can be used to increase the antenna bandwidth. The coaxial probe in this feeding technique was connected directly to the patch, so it may increase the effectivity of the antenna designed.

**Method**

Parameters of an antenna should be the main factors to be considered in designing an antenna, including the circular patch microstrip line antenna. Bandwidth and efficiency of microstrip depend on its dimension, shape, substrate thickness, substrate dielectric constant, type and location of feeding point. A thick substrate with low dielectric constant is suitable for a higher bandwidth, larger antenna with a better efficiency and radiation. Designing a small antenna, needs a big dielectric constant that may result in smaller bandwidth and efficiency, along with higher loss tangent (dissipation factor). This phenomenon can be avoided by modifying the feeding technique, see Balanis (2016). The design procedure of this circular patch microstrip was commenced by determining the material used, FR4 Epoxy (substrate) and calculating effective radius of the antenna. The model then simulated using the software chosen to find out the suitable parameters to build the antenna. The antenna specifications are tabulated on Table 1.
Table 1. Designed antenna specification.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Size/Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric constant ($\varepsilon_r$)</td>
<td>4.4</td>
</tr>
<tr>
<td>$\tan \delta$</td>
<td>0.02</td>
</tr>
<tr>
<td>Thickness (y axis)</td>
<td>1.6 mm</td>
</tr>
<tr>
<td>Effective radius ($a_e$)</td>
<td>8.9 mm</td>
</tr>
<tr>
<td>Feeding point to substrate distance ($D$)</td>
<td>17.8 mm</td>
</tr>
<tr>
<td>Antenna width ($W$)</td>
<td>35.6 mm</td>
</tr>
</tbody>
</table>

Antenna Simulation Result And Discussion

**Antenna Model Design**

The antenna model was designed using a simulator, following the procedures and calculations explained above. The model resulted from the simulation is illustrated in Figure 1 (a) and (b).

![Antenna Model](image)

(a)

(b)

Figure 1. Circular patch microstrip antenna designed (a) side view; (b) top view.

**Antenna Radiation Pattern.**

Radiation pattern is strongly related to energy distribution (gain) of the antenna. The simulation shows that the radiation pattern obtained was omnidirectional, as depicted on Figure 2. In order to get a wide coverage area, gain of omnidirectional antenna should focus its power on horizontal phase and ignore the radiation pattern at top and bottom direction. Having such radiation pattern, allowing the antenna to be put in the middle of the base station. This type of antenna has advantage in term of the number of user it may serve. However, it is difficult to allocate frequency for each cell to avoid interference.

![Antenna Gain](image)

Figure 2. Antenna radiation pattern

**Antenna Gain**

Other parameter that describe the performance of an antenna is antenna gain. Even though gain of antenna is closely related to directivity, its calculation is needed to measure the antenna efficiency and its directional capability. However, directivity calculation only describes the directionality of the antenna, so that directivity is mainly controlled by its pattern.
The antenna gain graph is shown on Figure 3 below. Total gain of the antenna designed is 0.23 dB. This total gain came only from the antenna designed without comparing it to any gain from another reference antenna. It is the absolute gain produced by the antenna.

![Figure 3. Antenna Gain](image)

**Antenna Input Impedance**

The antenna port is normalized with 50 Ohm characteristic impedance \(Z_0\) on specified frequency. The input impedance obtained from the simulation was 49.533 + j 0.462 Ohm.

**VSWR of the Antenna**

Prior to calculate the VSWR value, the voltage reflection coefficient \(\Gamma\) shall be known, to understand the antenna feeding line condition. Mathematically, coefficient reflection is calculated by substituting 49.533 + j 0.462 Ohm to \(Z_L\) and 50 Ohm to \(Z_0\) into the expression (2).

![Figure 4. Antenna VSWR graph](image)

The coefficient reflection of designed antenna is:

\[
\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{49.533 - 50}{49.533 + 50} \approx -0.0047
\]  

Based on this calculation, it is found that the voltage reflection coefficient is −0.0047 or approximate zero. With this condition, it is said that in the designed antenna, the feeding line is in match condition (no reflection). The graph of VSWR of the antenna is plotted in Figure 4, and its value was calculated using below expression:
As shown on the graph, the VSWR on center frequency $f_c$ is 1.859. The discrepancy is observed between simulated and measured result that is due to design tolerance. However, these results are still within acceptable value.

**Antena Bandwidth**

To conform to FCC standard, the antenna was designed on frequency range 3.1 – 7 GHz. Bandwidth of the antenna was expected to be 500 MHz or greater, with fractional bandwidth characteristic was bigger or equal to 20%. The simulation outcome is shown in Figure 5. In the graph shown that the measurement values obtained at the center frequency is –10.51 dB for return loss.

$$\text{Figure 5. } \text{Return Loss antenna graph}$$

It is shown on the graph above that the antenna highest frequency is 5.23 GHz, the lowest frequency is 4.41 GHz, and centre frequency is 4.74 GHz. These parameters were substituted into the equation (5) and (6) to calculate the antenna bandwidth:

$$\text{BW} = \frac{f_h - f_l}{f_c} \times 100\% = \frac{5.23 - 4.41}{4.74} \times 100\% = 17.29\% (5)$$

And

$$\text{BW} = f_h - f_l = 5.23 \text{ GHz} - 4.41 \text{ GHz} = 0.82 \text{ GHz} \approx 820 \text{ MHz} (6)$$

Based on calculation above, bandwidth of the antenna was 820 MHz with 17.29% fractional bandwidth. These calculation results showed that the antenna designed was capable of working on ultra-wideband frequency on the frequency range from 3.1 to 7 GHz.

$$\text{Figure 6. The prototype of microstrip antenna.}$$
The antenna prototype

The prototype of the microstrip circular patch antenna designed was built using FR4 epoxy PCB. The model was drawn using Microsoft Visio, printed on the film paper and copied to the PCB. The feeder used on the antenna model is coaxial probe located right on the center of the patch as shown on Figure 6.

Conclusions

This research shows that the circular patch microstrip antenna designed using FR4 material with following dimension: \( a = 8.9 \) mm, \( h = 1.6 \) mm, \( e_r = 4.4 \), \( f_r = 4.74 \) GHz, \( \delta = 0.02 \), has complied to FCC regulation for ultra wideband communication. It can operate on the frequency range from 3.1 to 7 GHz with 820 MHz bandwidth. The gain, VSWR and radiation pattern resulted from the research proved that the antenna designed has a good performance. To validate the experiment results, the patch design has to be tested using proper equipment in the future.

References