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Design of Vivaldi Antenna at 0.9 – 6 GHz for Mobile Cognitive Radio Base Station (MCRBS)

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Abstract

Mobile Cognitive Radio Base Station (MCRBS) is a system for disaster area. This system provides a network for an area after disaster for evacuation activities. MCRBS system works in 0.9 – 6 GHz frequency range to support the second generation of mobile communication system (2G) up to the fifth generation of mobile communication system (5G) frequency candidate. An antenna is one of MCRBS components with function to transmit and receive electromagnetic signals. To support MCRBS system, an antenna with *Ultra-Wideband* (UWB) characteristic will be needed in communication services that facilitated by MCRBS system. The Vivaldi antenna is one of UWB antennas that has wide bandwidth and high gain for UWB applications. It was invented by P. Gibson in 1979. The antipodal Vivaldi antenna which is one of Vivaldi antenna types has been designed using FR-4 material and copper. The antenna will use quarter wave transformer and array method. Based on the results of simulations conducted, the antenna has a return loss ≤ -10 dB, a VSWR ≤ 2, with 5.1 GHz bandwidth, gain 11.13 dBi, and unidirectional radiation pattern to support MCRBS system.

Keywords: Ultra-Wideband, Vivaldi antenna, Mobile Cognitive Radio Base Station.

1. Introduction

Indonesia's geographical condition which has the potential for natural disasters greater than other regions often requires quick rescue measures[1]. In the process of searching and evacuating victims of disaster, a reliable communication system is needed to be able to support the post-disaster conditions. Mobile Cognitive Radio Base Station (MCRBS) is a technology to recover communication systems after a disaster when the main connection network is unavailable.

MCRBS is a system in the form of a Base Transceiver Station (BTS) that can be mobilized. After disaster occurred, MCRBS will provide a network that will assist the process of evacuation and search for victims by detecting the network on the victim's cell phone. MCRBS provides 2G up to 5G communication services using limited power in its application. MCRBS system requires an antenna component with a very wide bandwidth to provide services that is able to cover long distances with limited power.

In MCRBS, an antenna is needed to fulfill the standards of the system. The antennas must have wide bandwidth specification to support the frequency candidate of the communication services. To cover long distance, high gain also needed to support the MCRBS system. The Vivaldi antenna which is one of the *Ultra-Wideband* (UWB) antennas that was invented by P.J Gibson[2] is used for UWB applications[3] that has wide bandwidth and high gain [4].

This research concentrates on designing an antipodal Vivaldi antenna which is one of the types of Vivaldi antenna[5] with 5.1 GHz bandwidth using FR-4 substrate material and copper as a conductor. The quarter wave transformer method is added to reduce the return loss[6]. Array method is also added to increase the gain [7].

2. System Design

2.1 Mobile Cognitive Radio Base Station (MCRBS)

MCRBS is a device in the form of a Base Transceiver Station (BTS) that can be mobilized. MCRBS is expected to be used in emergencies such as when a natural disaster occurred. In the event of a natural disaster, the MCRBS will function as a network transmitter used to evacuate victims that are affected. This system provides 2G up to 5G communication services. Antenna is one of MCRBS components. To support MCRBS system, an antenna is needed that has wide bandwidth to support 2G up to 5G services. Also high gain is needed to cover large distances. The antipodal Vivaldi antenna is proposed to support the MCRBS system.

2.2 Determination of Antenna Design

The antenna designed is a Vivaldi antenna with the type of antipodal with FR-4 substrate that has a dielectric constant (ε_r) of 4.4 and thickness (h) of 1.6 mm and copper as its conductor. This antenna works at a frequency between 0.9 to 6 GHz following the working frequency of MCRBS that serves 2G up to 5G communication with a bandwidth of 5.1 GHz, unidirectional radiation pattern, and gain ≥ 8 dBi. The dimensions of this antenna can be obtained from the following equation (1) [8]:

$$y\,(x) = s.e^{rx} \tag{1}$$

Where y (x) is a function to form antipodal Vivaldi antenna, s variable is the transformer width of 2 × s, and r is the curvature of the antenna. The dimensions of the antenna's substrate are obtained from the following equation (2) [8]:

$$L_s = W_s = \frac{c}{f}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2}$$

With L_s is the length of the substrate, W_s is the width of the substrate, c is the speed of light, and f is the operating frequency, and ε_r is the dielectric constant.

For the feedline dimensions, the following equation can be used (2) [7]:

$$W_o = \frac{2h}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right] \tag{3}$$

For B variable, the following equation can be used (3) [7]:

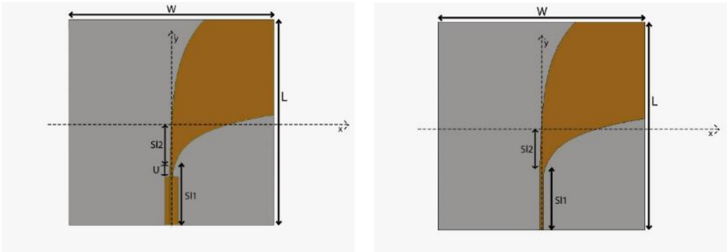
$$B = \frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}} \tag{4}$$

Z_o is a transmission impedance value of 50 Ω.

There is a quarter wave transformer in the feedline to increase matching impedance [6], [9]. From the calculation (2), (3), and (4), the dimensions of the antenna can be seen in Table 1 and antenna design as shown below in Figure 1.

Table 1. Dimensions of Antipodal Vivaldi Antenna.

Parameter	Value (mm)
Sl	40
SL2	35
r	0,037
r2	0.08
s	0.44
s2	3



(a) (b)

Fig. 1: Antipodal Vivaldi Antenna, (a) Front View (b) Rear View

Problem that occurred in antennas with single element such as low gain cannot be a solution for the developing process of communication system. To increase the gain of the antenna, array method are used [7]. With four antenna elements and the distance between elements is $\lambda/2$.

The results of the antipodal Vivaldi antenna with array method design can be seen in Figure 2 below.

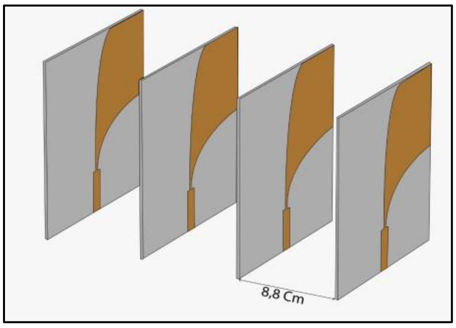


Fig. 2: Final Antenna Design, (a) Front View (b) Rear View

The calculation of dimensions of the antipodal Vivaldi antenna before and after using the array method can be seen in the following Table 2 below.

Table 2. Optimization Dimensions of Antipodal Vivaldi Antenna

Antenna Dimensions	Value before optimation (mm)	Value after optimation (mm)
Wo	20	5
Sl	30	40
SL2	45	35
r	0,05	0,037
r2	0.062	0.08
s	0.5	0.44
s2	5	3
q	16.65	88

3. Result and Analysis

In the simulation results, the parameters that have been determined at the beginning of the antenna specification are reviewed.

3.1 Return Loss, VSWR, and Bandwidth

Based on the dimensions of the antenna that has been designed in simulation software with the equation, the return loss results from the simulation can be seen in Figure 4 below.

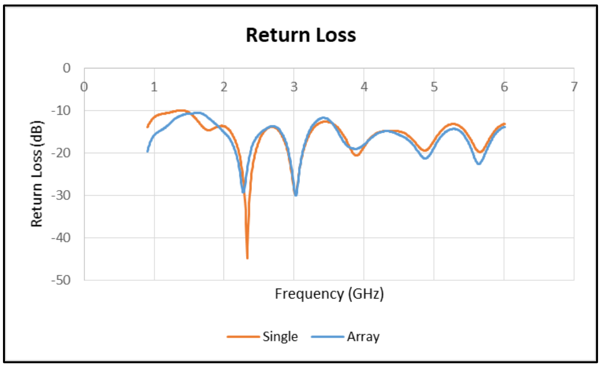


Fig. 3: Return Loss Comparison of Single antenna and Antenna Array

In Figure 4 the return loss value obtained in the simulation results is -10 dB on 0.9 to 6 GHz frequency range. Then the bandwidth obtained is 5.1 GHz on 0.9 - 6 GHz frequency range as seen in Figure 4. It can be concluded that the antenna designed has fulfilled the UWB requirements with a bandwidth of more than 500 MHz.

The VSWR values obtained from the simulation results on the design of antipodal Vivaldi antennas can be seen in Figure 5 below.

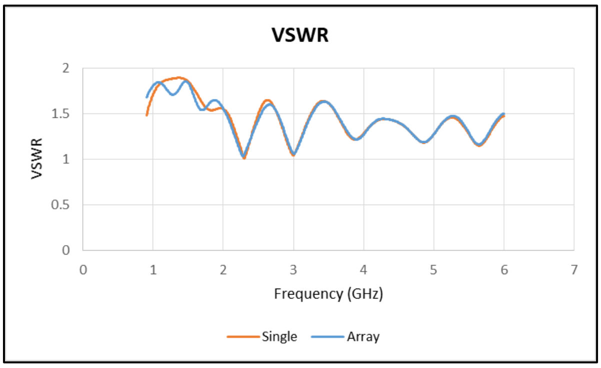


Fig. 4: VSWR Comparison of Single Antenna and Antenna Array

Based on Figure 5, the VSWR value for the results of the antipodal Vivaldi antenna simulation is ≤ 2 dB on 0.9 to 6 GHz frequency range. This means the return loss, VSWR, and bandwidth parameters already fulfilled the MCRBS requirements.

3.2 Gain

Gain is a comparison of how much power is emitted in a particular direction with power emitted in all directions[7]. The antenna simulation results for Gain can be seen from three sample frequencies at the frequency of 0.7 GHz, 4.35 Hz, and 8 GHz which are shown in Table 3 below.

Table 3. Gain Comparison of Single Antenna and Antenna Array

Frequency	Results	
	Single	Array
0,7 GHz	1,119 dB	4.017 dB
4.35 GHz	4,858 dB	11,13 dB
8 GHz	4,929 dB	11,03 dB

Based on Table 3, after the array method applied to the simulation, the gain of the antenna is increased.

3.3 Radiation Pattern

The radiation pattern is measured by azimuth direction and elevation. The radiation pattern simulation results are seen in three frequency samples at the frequency of 0.7 GHz, 4.35 GHz, and 8 GHz can be seen in Figure 5 – 7 below.

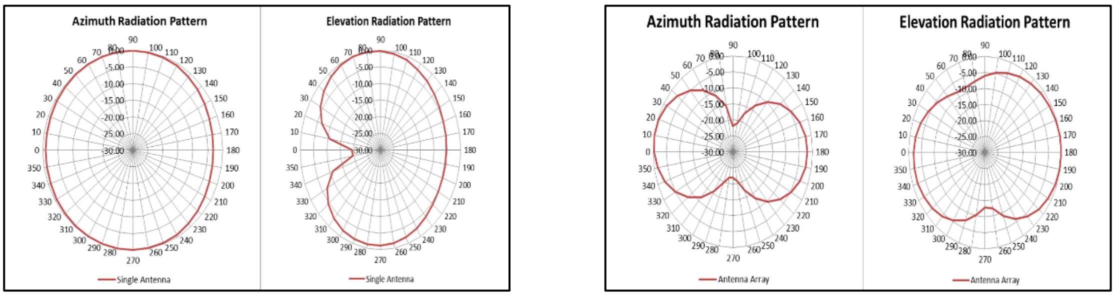


Fig. 5: Radiation Pattern of Single Antenna and Antenna Array at 0.9 GHz

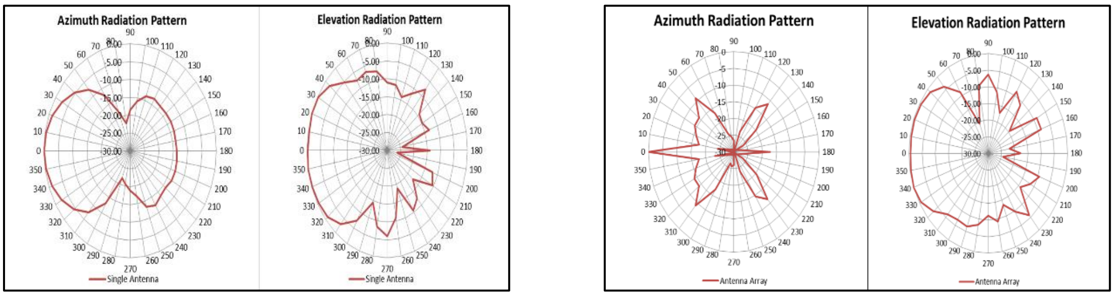


Fig. 6: Radiation Pattern of Single Antenna and Antenna Array at 3.45 GHz

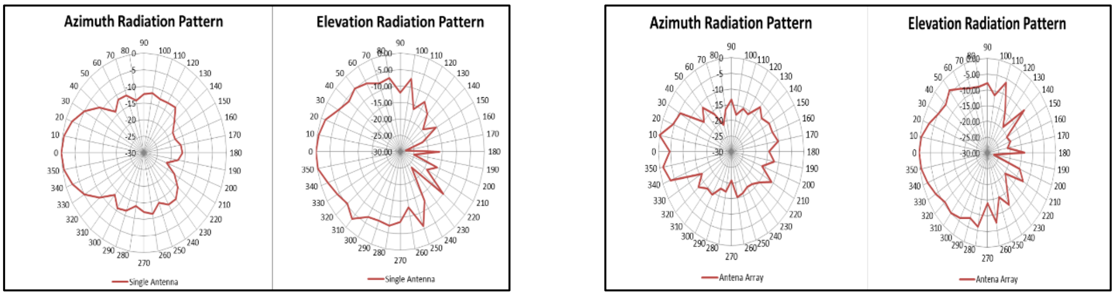


Fig. 7: Radiation Pattern of Single Antenna and Antenna Array at 6 GHz

Based on Figure 5 – 7, the radiation pattern of the simulation of a single antenna and array antenna are unidirectional.

4. Conclusions

The conclusion of this project entitled "Design of Vivaldi antenna at 0.9 – 6 GHz for Mobile Cognitive Radio Base Station (MCRBS)" with FR-4 as the substrate material and copper as the patch on 0.9 – 6 GHz frequency range as follows:

- The antenna simulation can work on 0.9 - 6 GHz frequency range by achieving the return loss specification ≤ - 10 dB, VSWR ≤ 2 dB, 5.1 GHz bandwidth, unidirectional radiation pattern, and gain value 11.03 dBi.
- The wave quarter transformer in antenna design is used for impedance matching.
- The array method in antenna design can increase antenna gain by 3 to 7 dBi. The higher the frequency the increase of the value of the gain will be higher.

From the following conclusions, it can be shown that the antipodal Vivaldi antenna has fulfilled the standards to support the MCRBS system.

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