Design of Vivaldi Microstrip Antenna for Ultra-Wideband Radar Applications

M Y Perdana¹, T Hariyadi¹, Y Wahyu²

¹Department of Electrical Engineering Education, Universitas Pendidikan Indonesia
²Research Center for Electronics and Telecommunications, Indonesian Institutes of Sciences

*m.yoga@student.upi.edu

Abstract. The development of radar technology has an important role in several fields such as aviation, civil engineering, geology, and medicine. One of the essential components of the radar system is the antenna. The bandwidth can specify the resolution of the radar. The wider the bandwidth, the higher the resolution of radar. For Ground penetrating radar (GPR) or medical applications need with a high-resolution radar so it needs an antenna with a wide bandwidth. In addition, for the radar application is required antenna with directional radiation pattern. So, we need an antenna with wide bandwidth and directional radiation pattern. One of antenna that has meet with these characteristics is vivaldi antenna. In previous research, has designed several vivaldi microstrip antenna for ultra-wideband radar applications which has a working frequency of 3.1 to 10.7 GHz. However, these studies there is still a shortage of one of them is the radiation pattern from lowest to highest frequency radiation pattern is not uniform in the sense that not all directional. Besides the antenna material used is also not easily available and the price is not cheap. This paper will discuss the design of a vivaldi microstrip antenna which has a wide bandwidth with directional radiation pattern works on 3.1 to 10.7 GHz and using cheaper substrate. Substrates used for vivaldi microstrip antenna vivaldi is FR4 with a dielectric constant of 4.3 and a thickness of 1.6 mm. Based on the simulation results we obtained that the antenna design has frequency range 3.1-10.7 GHz for return loss less than -10 dB with a directional radiation pattern. This antenna gain is 4.8 to 8 dBi with the largest dimension is 50 mm x 40 mm.

1. Introduction
The development in radar technology plays an important role as an application that is widely used for a variety of applications including flight, civil, and medical. Radar technology has the potential and the ability to detect the location and distance of an object, for instance is a cancer cell detection system in medical facilities [1] and Ground penetrating radar (GPR) in civil engineering. One of important component in a radar is antenna. In designing an antenna, specification of the antenna will determine the performance of a radar. Some specifications that must be met in a radar antenna are high gain and wide bandwidth [2]. Antenna that can meet these specifications is an ultra-wideband antenna. Ultra-wideband antenna design types can be in the form of Vivaldi antenna.
Some types of Vivaldi antenna design are Linear Tapered Slot Antenna (TSA) however this maximum antenna gain is around 5dBi [3] and the radiation pattern is not stable from lower frequency to higher frequency [4]. In other research, has been studied how to increase the antenna gain [5] and Vivaldi antenna application for breast cancer imaging using antipodal Vivaldi antenna [6]. The antenna that is going to be designed by the author is expected to maximize the performance of ultra-wideband radar. In this paper, will be designed a Vivaldi microstrip antenna that has a stable radiation pattern from 3.1 GHz to 10.7 GHz. Vivaldi antenna is a kind of antenna with tapered slots that provide great bandwidth, and directional radiation pattern. Vivaldi antenna designed using FR4 substrate with 1.6 mm thickness and permittivity (\(\varepsilon_r\)) of 4.35.

2. Literature Study

2.1. Radar
Radio Detecting and Ranging (Radar) is used to detect an object position expressed by the direction or azimuth that refers to the North and at a certain distance (range) of the antenna. Radar works by using radio waves that is reflected from the surface of the object. Radar generating electromagnetic energy signal that is focused by the antenna and transmitted into the space [7].

2.2. Ultrawideband (UWB)
Ultra-wide band (UWB) is a wireless technology for transmitting large digital data through a wide spectrum of frequency bands with low power and a short distance [8]. UWB radio not only can carry large amounts of data through distances up to 70 meters with very low power (< 0.5 milliwatts) but also can carry signals through walls and other obstacles that tend to reflect signals at limited bandwidth. UWB can be compared to the short-range wireless technology, Bluetooth, which is a standard to connect a handheld wireless device (mobile phones) with another similar device, or by a computer [9].

UWB is a short-range communication system that has a very wide bandwidth, to be categorized as UWB communication, the fractional bandwidth requirements at 25% of the center frequency. UWB emit so much RF bursts (Radio Frequency), wherein the radiation emitted by a wide band, transmits through so many frequencies simultaneously. This is what allows a very high data transfer speeds [9]

2.3. Microstrip Antenna
Microstrip antenna is an antenna that is quite popular today. That is because the shape, size, and weight are perfectly suited to the demands of today's telecommunications technology that prioritizes these things so that the antenna is easy to apply [10]. The simplest form of microstrip equipment is in the form of inserts of two mutually parallel conductive layers separated by a dielectric substrate. The top conductor is a thin piece of metal (usually copper) which is a small fraction of a wavelength. The bottom conductor is a grounding field that theoretically worth infinite. Both are separated by a non-magnetic dielectric substrate [10].

![Figure 1. Basic Structure of Microstrip Antenna](image-url)
2.4. Tapered Slot Antenna (TSA)
Tapered Slot Antenna (TSA) model was first discovered and studied by Gibson in 1970 [11]. Typical shape of TSA antenna consists of a tapered-shaped slot etching on the dielectric substrate metal. TSA is an end-fire antenna radiator, which is not like the other antennas that just radiates to the printed substrate [8]. TSA antenna has several models with variations on the tapered-shaped slot model. Among them are Linear TSA, Exponentially TSA, and Constant Width TSA. Tapered Type Slot antenna designed is Exponentially TSA which also called Vivaldi antenna with tapered slot shape that changes exponentially with the length of antenna [12].

3. Antenna Design
Early stage of designing an antenna is determining the characteristics or parameters of the desired antenna. In designing the characteristics expected to yield:

The text of your paper should be formatted as follows:

| Parameters of the desired antenna. |
|-------------------------------------|
| Frequency Range : 3 – 11 GHz       |
| VSWR : ≤ 2                          |
| Gain : > 6 dBi                      |
| Bandwidth : ± 9 GHz                 |
| Radiation Pattern : Directional     |
| Impedance : 50 ohms                 |
| Return Loss : ≤ -10dB               |

Antenna dimensions are shown in Figure 2 with the substrate size of 60 mm x 60 mm. The size is obtained from (1). The designed antenna is the slot microstrip antenna. Slot microstrip antenna is the development of the patch antenna concept which is excited by the stripline channel by releasing the patches and supply channel will radiate directly into the earth field through the slot. The main advantage of microstrip antenna slot is a wider resulting bandwidth. Microstrip antenna slot also allows the performance of the antenna in circular polarization.

![Vivaldi Antenna Dimensions](image)

**Figure 2.** Vivaldi antenna dimensions (a) top view of the antenna, (b) bottom view of the antenna.
Table 1. Parameters used in designing Vivaldi antenna.

| Parameter | Dimension | Note                  |
|-----------|-----------|-----------------------|
| L         | 60 mm     | Substrate length      |
| La        | 43.5 mm   | Curve length          |
| W         | 60 mm     | Substrate width       |
| Wa        | 60 mm     | Curve width           |
| d1        | 5 mm      | Circle’s diameter     |
| d2        | 5 mm      | Circle Feed diameter  |
| s         | 0.4 mm    | Gap Width             |
| Ls        | 5 mm      | Gap Length            |
| fp        | 11.2 mm   | Distance to the Feed line |
| W1        | 3.065 mm  | Feed line 1 width     |
| W2        | 1 mm      | Feed line 2 width     |
| W3        | 1.3 mm    | Feed line 3 width     |
| W4        | 6 mm      | Feed line 4 width     |
| L1        | 8 mm      | Feed line 1 length    |
| L2        | 3.2 mm    | Feed line 2 length    |
| L3        | 1 mm      | Feed line 3 length    |
| L4        | 0.75 mm   | Feed line 4 length    |

The dimension of the microstrip antenna can be obtained from (1)

\[
L = W = \frac{c}{f_L} \sqrt{\frac{2}{\varepsilon_r + 1}}
\]

Where \( L \) is antenna length, \( W \) is antenna width, \( c \) is the speed of light, \( f_L \) is the lower frequency, and \( \varepsilon_r \) is dielectric constant. While the Exponentially Tapered Slot Antenna (TSA) can be obtained from (2)

\[
y(x) = C \cdot e^{K_u x}
\]

constant \( C \) and opening rate \( K_u \) is given by

\[
C = \frac{s}{2} \quad (3)
\]

\[
K_u = \frac{1}{L_w} \ln\left(\frac{W}{s}\right) \quad (4)
\]

Table 1 shows the parameters used to perform the microstrip Vivaldi antenna design that have been obtained based on the literature study.

4. Result and Discussion

4.1 Initial Simulation

At this step, the initial simulation of microstrip antenna is done with the dimension which obtained from table 1. The result of initial simulation has a return loss value that is above -10 dB in the
frequency range of 3-11 GHz. Figure 3 shows the return loss of the antenna and Figure 4 shows the gain and radiation pattern of antenna at 7 GHz.

![Figure 3. Antenna return loss based on initial design](image1)

![Figure 4. Antenna gain and radiation pattern at frequency 7 GHz in initial simulation results](image2)

4.2. Optimization of Gain Enhancement

At this step, antenna optimization is done by adding the rectangular slot on the right and left of the curve to improve the antenna gain. Rectangular slot designed with 11 slots with the length of the first slot is 15 mm in and the second slot length is minus 1 mm long and multiples for the next slot. Table 2 shows the addition of parameters of rectangular slot. Figure 5 shows an antenna model after the addition of rectangular slot on the antenna. Figure 6 and Figure 7 shows the return loss value and the antenna gain.

| Parameter | Description       | Dimension |
|-----------|-------------------|-----------|
| Cx        | slot rectangular distance | 1 mm      |
| Cz        | slot rectangular width | 1 mm      |
| Cg        | slot rectangular length | 15 mm     |
Based on Figure 7 we can see that the antenna gain is higher than before we add rectangular slot. Before we add rectangular slot the antenna gain is 5.116 dBi while after we add rectangular slot the antenna gain is 6.368 dBi. However, the antenna bandwidth is narrow so that we need to reoptimize our design.

4.3. Final Simulation Result
At this stage, to obtain final simulation results some antenna optimizations are done such as, optimizing the substrate size, the circle diameter, the distance between the curve, and the Feed line so that final simulation results end in accordance with the prescribed specifications. Table 3 shows the
dimensional change after the optimization and prior to optimization. Figure 8 shows the return loss value above -10dB and bandwidth of 9 GHz while Figure 9 shows the value of a gain of 7.9 dB and radiation pattern at a frequency of 7 GHz. While antenna gain from 3 to 11 GHz can be seen in Figure 10.

Table 3. Parameters of antenna before and after optimization.

| Parameter | Initial Dimension | Final Dimension |
|-----------|-------------------|-----------------|
| L         | 60 mm             | 50 mm           |
| La        | 43.5 mm           | 28.5 mm         |
| W         | 60 mm             | 40 mm           |
| Wa        | 60 mm             | 30 mm           |
| d1        | 5 mm              | 7 mm            |
| d2        | 5 mm              | 7 mm            |
| s         | 0.4 mm            | 4 mm            |
| Ls        | 5 mm              | 7 mm            |
| fp        | 11.2 mm           | 10 mm           |
| W1        | 3.065 mm          | 3.065 mm        |
| W2        | 1 mm              | 1 mm            |
| W3        | 1.3 mm            | 1.15 mm         |
| W4        | 6 mm              | 8 mm            |
| L1        | 8 mm              | 8.5 mm          |
| L2        | 3.2 mm            | 3.2 mm          |
| L3        | 1 mm              | 1 mm            |
| L4        | 0.75 mm           | 0.75 mm         |
| Cx        | -                 | 1 mm            |
| Cz        | -                 | 1 mm            |
| Cg        | -                 | 15 mm           |

Figure 8. Antenna return loss based on final simulation result
Figure 9. Antenna gain and radiation pattern at frequency 7 GHz

Figure 10. Antenna gain based on final simulation results

The simulation result of VSWR on UWB antenna can be seen in Figure 11. A good antenna is an antenna that has VSWR close to 1 and less than 2. Shown in the Figure 11 that the antenna has been qualified with VSWR less than 2 at the operating frequency covers from 3-11 GHz.

Figure 11. Antenna VSWR

Vivaldi microstrip antenna radiation pattern from the simulation results can be seen in two-dimensional form in Figure 12 for the H-plane (azimuth) and the E-plane (elevation).
Figure 12. Radiation pattern of $H$-plane (azimuth) and $E$-plane (elevation) in frequency (a) 3GHz, (b) 7GHz, and (c) 11 GHz.
5. Conclusion
In this paper, a design and building of Vivaldi microstrip antenna for ultra-wideband radar applications has been made. Based on the simulation and analysis results which has been carried out can be summarized as follows:
1. Vivaldi microstrip antenna that works at a frequency of 3-11 GHz have a stable directional radiation pattern with a bandwidth of 8 GHz, VSWR ≤ 2 and a gain of 4.8-8.02 dBi in the simulation while in the measurement is 5.53-8.2 dBi.
2. The design of rectangular-shaped slot addition of Vivaldi microstrip antenna affects the amount of gain approximately 7.6 dBi, but in the bandwidth design has not reached the 8 GHz.

References
[1] Jasmine J A and Anita J M T 2014 Design of Vivaldi Antenna for Brain Cancer Detection Int. Conference on Electronics and Communication Systems pp 1-4.
[2] Hidayat T 2013 Microstrip antenna array 4x8 elements for airborne radar applications at frequency 2.95 GHz (Jakarta: Universitas indonesia).
[3] Wu J N, Zhao Z Q, Liu J Z, Nie Z P and Liu Q H 2012 A Compact Linear Tapered Slot Antenna with Integrated Balun for UWB Applications Journal of Progress In Electromagnetics Research Vol. 29 pp 163–176.
[4] Gopikrishna M, Krishna D D, Aanandan C K, Mohanan P and Vasudevan K 2008 Compact Linear Tapered Slot Antenna for UWB Applications IEEE Electronics Letter Vol. 44 Issue 20 pp 1174-1175.
[5] Pandey G K, Singh H S, Bharti P K, Pandey A and Meshram M K 2015 High Gain Vivaldi Antena for Radar and Microwave Imaging Apllications International Journal of signaling System Vol. 3. No. 1 pp 35-39.
[6] Bah M H, Hong J, Jamroo D A, Liang J J and Kponou E A 2014 Vivaldi Antenna and Breast Phantom Design for Breast Cancer Imaging International Conference on BioMedical and Informatic pp 90-93.
[7] Ewell G W 1990 Radar Transmitters (New York: McGraw-Hill Book Company).
[8] Milligan T A 2005 Modern Antenna Design 2nd Edition (New Jersey: Wiley-IEEE Press).
[9] Kumar R, Chaubey P N and Srikan t I 2012 On the Design of CPW- Fed Ultra Wideband Triangular Wheel Shape Fractal Antenna Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 11 No.2 pp 230-241.
[10] Balanis C 2005 Antenna Theory Analysis and Design 3rd Edition (New Jersey: John Wiley & Sons).
[11] Sarkar C 2014 Some Parametric Studies on Vivaldi Antenna International Journal of u-and e-Service, Science and Technology Vol.7 No.4 pp 323-328.
[12] Vignesh N, Kumar G A S and Brindha R 2014 Design and Development of a Tapered Slot Vivaldi Antenna for Ultra-Wide Band Application Int. Journal of Advanced Research in Computer Science and Software Engineering Vol. 4 No. 5 pp 174-178.