IOP Conf. Series: Materials Science and Engineering **318** (2018) 012052 doi:10.1088/1757-899X/318/1/012052

Design of UHF Antenna Sensor for Partial Discharge Detection in High Voltage Substation

Sharulnizam Mohd Mukhtar[1,*], Muzamir Isa[2,] and Azremi Abdullah Al-Hadi[3,***]**

[1] Faculty of Engineering Technology, Universiti Malaysia Perlis, Malaysia,
[2] School of Electrical System Engineering, Universiti Malaysia Perlis, Malaysia,
[3] School of Computer & Communication Engineering, Universiti Malaysia Perlis, Malaysia

E-mail: sharul@unimap.edu.my, *muzamir@unimap.edu.my, azremi@unimap.edu.my

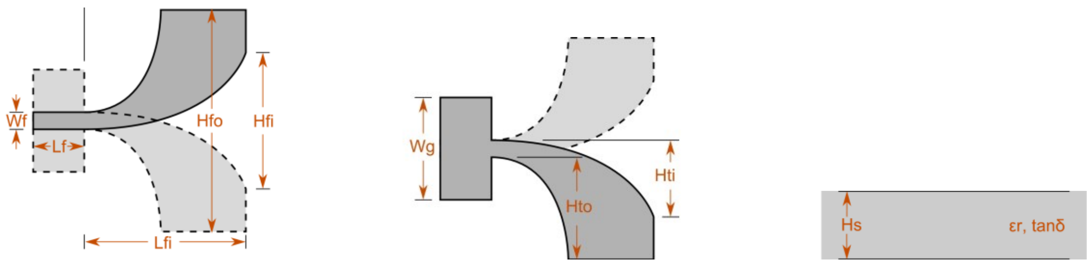
Abstract. Partial discharge early detection is a major issue in preventative maintenance. This condition is necessary to prevent greater damage in the high voltage system. The PD detection method using UHF sensors has become an attractive method because of its high sensitivity and the ability to detect the PD location. The objective of this study was to investigate the performance of an antipodal Vivaldi antenna (AVA) as the UHF sensor for the partial discharge detection. The simulation was carried out using CST Design Studio™ to analyze the optimal parameters of the antenna before it was manufactured. The result revealed that the AVA has the good capability to be used as UHF sensor for PD detection with the high sensitivity and good directivity.

1. Introduction

Partial discharge (PD) is a localized dielectric breakdown of a small portion of an electrical insulation. PD could occur in the gaseous, liquid or solid form in the insulating medium. It often starts with a small gas voids, such as voids in solid epoxy insulation or bubbles in the liquid insulation medium such as transformer oils [1]. Voids also could occur in the insulation by two factors either manufacturing defects or by the aging of the equipment. Premature failure of an asset also could occur at the manufacturing stages that caused by poor workmanship. A high percentage of insulation failure of the asset can be observed in the first 3 years of its working life [2].

Early PD detection is very important and can prevent more serious damage to high voltage equipment. Once the PD is detected, faults can be expected and preventive maintenance can be done earlier. There are various methods that can be used to detect PD such as electrical methods, chemicals, acoustics, optics and electromagnetic. Among these, the ultra-high-frequency (UHF) method is widely used to detect PD on power transformers, gas-isolated substation (GIS) and air-insulated substation (AIS) [3][4].

In the early studies, increased time of the PD pulses generated in the high voltage equipment is very short, the pulse width was shown to be a nanosecond [5]. Therefore, an electromagnetic signal caused by the PD pulses may include a UHF band and lies in the range of 300 MHz to 3 GHz. UHF signal is extracted to reduce the effects of noise on the PD signal. Frequency band of common electromagnetic interference is not in the range of UHF band. Therefore, the interference is eliminated by UHF detection.



(a) (b) (c)

Figure 1. (a) Geometry of a top view of the AVA (b) Geometry of a bottom view of the AVA (c) Geometry of a side view of the AVA

Liu proposed a miniaturized equiangular spiral antenna (ESA) to overcome the disadvantage of most frequency independence antenna like the Archimedean spiral antenna and log-periodic dipole antenna [6]. In [7] it has been using a single-arm Archimedean spiral antenna to detect the UHF partial discharge signal emitted from the power transformer. While [8] has applied the use of the meander antenna for the same purpose.

2. Design of the UHF Antenna Sensor

The important factor that influence detection's efficiency of the sub-station UHF PD, is the performance of the sensor. Since the frequency component of the PD's signal can be as high as GHz, and there is attenuation during the transmission. The sensor must have enough wide band range and has a high sensitivity [9].

In UHF networks, digital radios, televisions, telecommunications signals, and periodic pulses from switching operations can affect the accuracy of PD detection. Hence the need for a UHF sensor that has a wide band and can reduce the band at certain frequency disturbances such as the GSM system that operates at 890 MHz to 960 MHz [10].

Therefore, based on wide band and high-gain antenna, Vivaldi was selected in this study as a detection antenna. The antipodal Vivaldi antenna (AVA), also known as the dual exponentially tapered slot antenna (DETSA), is part of a group of antennas of the end-fire tapered slot antennas (TSAs). End-fire tapered slot antenna includes constant width (CWSA), linear tapered (LTSA) and exponential tapered (ETSA), also known as Vivaldi antenna. Vivaldi antennas are widely used in wireless and radar applications due to their wide bandwidth, low cross- polarization, and highly directive patterns. The geometry of an AVA is shown in Figure 1.

2.1. Design of a Antipodal Vivaldi Antenna

To assess the performance of the AVA, the effects of antenna parameters such as dimensions and thickness of printed circuit boards are carefully investigated using commercially available software CST Design Studio™. With this parametric investigation, the antenna with the desired parameters can be expected for the future, after the necessary changes.

The AVA consists of substrate and copper on both sides of the substrate and is divided into 2 parts, which are part of the balun and radiation area. The AVA is made of metalized dielectric substrate. Both flare, each exponentially tapered to its inner and outer profile on both sides of the substrate. To create an AVA, the equation used to describe the inner and the outer profile should be written as:

$$y = C_1 e^{\alpha x} + C_2 \tag{1}$$

where

$$C_1 = \frac{y_2 - y_1}{e^{\alpha x_2} - e^{\alpha x_1}} \tag{2}$$

Table 1. Design parameters of the AVA

Modeling parameters	Dimensions
Inner flare height, Hfi	106.5mm
Outer flare height, Hfo	245.0mm
Inner flare length, Lfi	210mm
Outer flare length, Lfo	120mm
Ground plane width, Wf	1.338mm
Feed line width , Wg	1.338mm

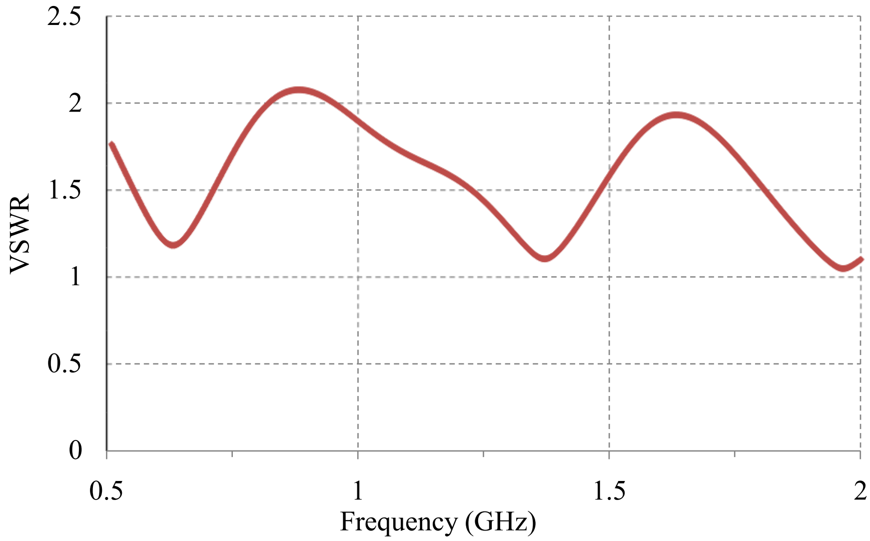


Figure 2. Simulation result of Voltage standing-wave ratio (VSWR) of the AVA

and

$$C_2 = \frac{y_1 e^{\alpha x_2} - y_2 e^{\alpha x_1}}{e^{\alpha x_2} - e^{\alpha x_1}} \quad (3)$$

where x_1, x_2, y_1, y_2 are the start and end x and y coordinates of the taper profiles. Determined parameter for the antenna are listed in Table 1.

3. Preliminary Result

Simulations are conducted using EM simulation software CST Design Studio^{TM}. The results of the designed AVA are shown in Figure 2 through Figure 5. The VSWR is a reflection coefficient function, which illustrates the power reflected by the antenna. An antenna must meet the needs of bandwidth provided in terms of VSWR is less than 2. Simulation result in Figure 2 shows that the VSWR value for whole frequency band is less than 2 except for the range from 825 Mhz to 950 Mhz. For other frequency, the VSWR value was fluctuate between 1 to 1.9.

S11 represents how much power is reflected from an antenna, therefore it's known as a reflection coefficient or return loss. S11 = 0 dB indicates that all the power is reflected from the antenna and nothing is transmitted. And if S11 = -10 dB, this indicates that if the 3 dB power is transmitted to the antenna, -7 dB is the reflected power. Figure 3 shows the S11 parameter for the designed AVA. As can see, the value of S11 parameter is less than -10 dB except for the frequency of 825 Mhz to 950 Mhz portion.

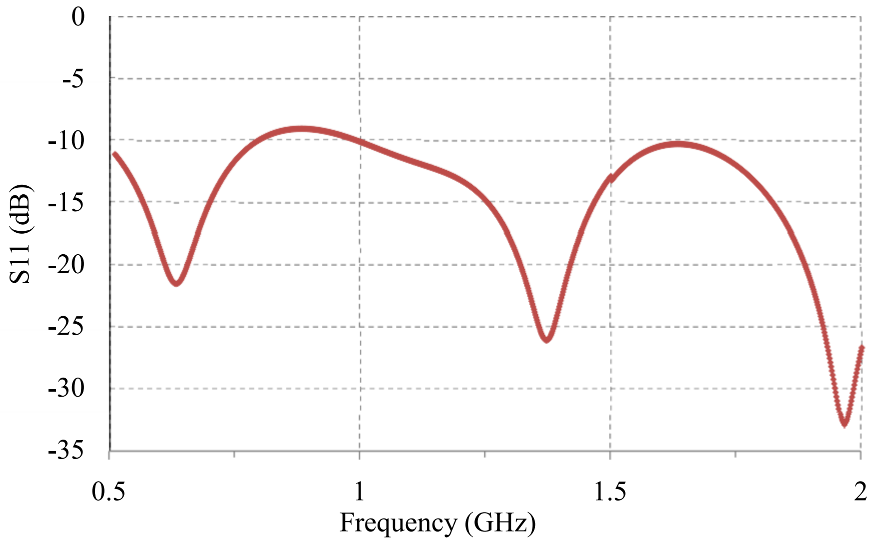


Figure 3. S11 parameter simulation result of the AVA

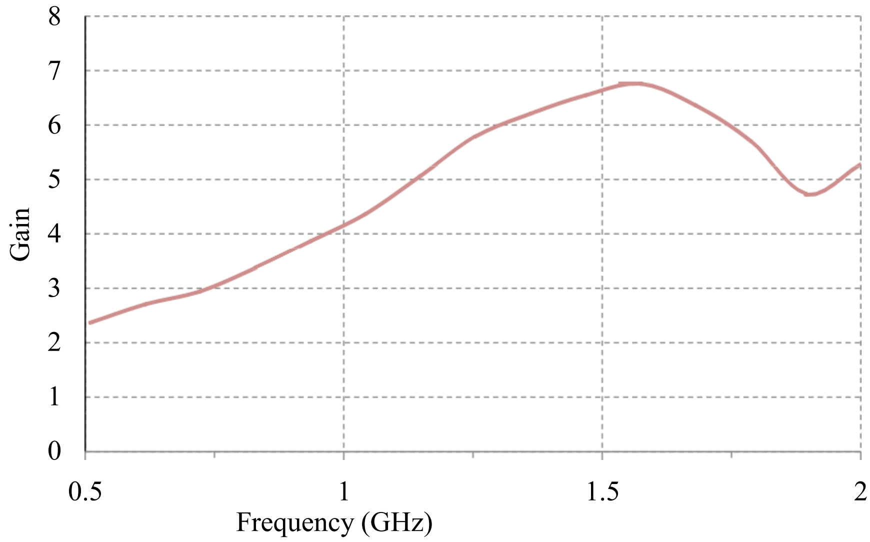


Figure 4. Simulation result of Gain versus frequency

Gain over frequency for this antipodal Vivaldi antenna is shown in Figure 4. As can be seen, gain increased with increasing frequency until it reached a maximum value at 1.575 GHz and thereafter decreased at a higher frequency. Although the gain at the lower frequency is low, about 2.3 dB it's indicates that this antenna is still able to radiate.

Antenna radiation patterns or antenna patterns are defined as "mathematical functions or graphical representations of antenna radiation characteristics as spatial coordinate functions" [11]. Figure 5 show the radiation pattern of the antipodal Vivaldi antenna for the different frequencies. H plane is marked with a solid line while E plane is marked with a dotted line. The result shows that these antenna has a good directivity at the radiation frequency of 2 GHz, 1.66 GHz, and 1.255 GHz. However, the radiation pattern shows it to be omnidirectional antenna when at a frequency of 0.5 GHz.

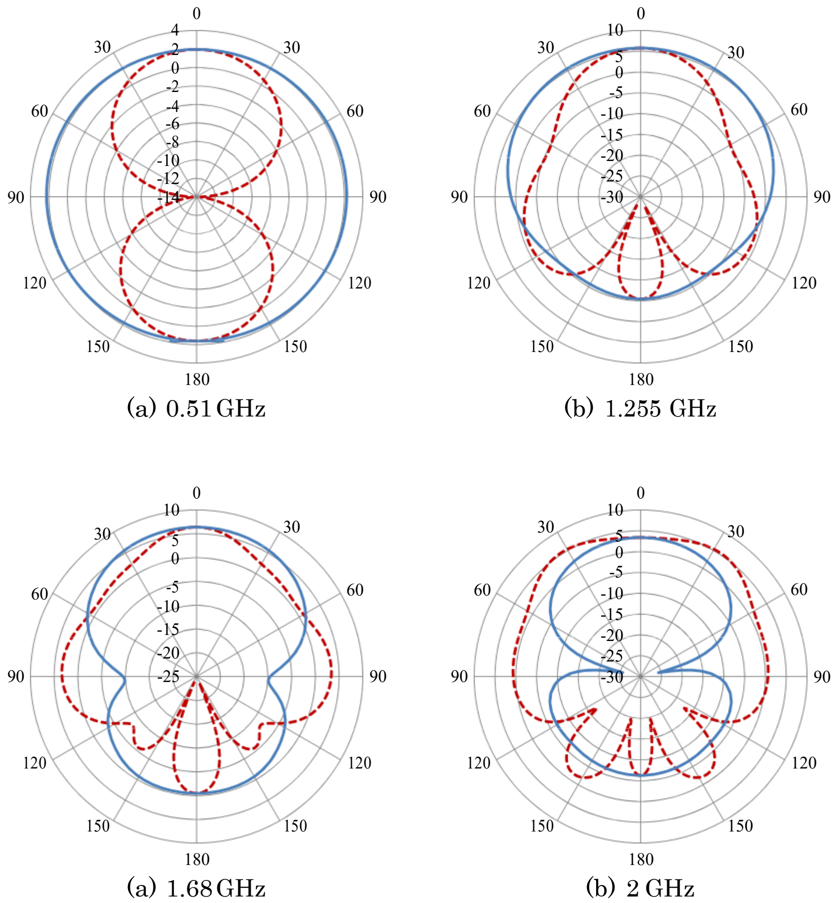


Figure 5. Simulation result of the radiation pattern of the AVA at different frequencies

4. Conclusion

In this work, an AVA antenna has been designed and analyzed using CST Design Studio™in order to assess the capability of antipodal Vivaldi antenna to be used as UHF sensor for partial discharge detection.

It was found the proposed AVA antenna satisfied the requirement for PD detection with the working frequency band of 510 Mhz to 825 Mhz and 950 Mhz to 2 Ghz. The denoised process to remove unnecessary signals before PD analysis is made will be easier with this AVA UHF sensor because the interference on the GSM band has been reduced.

Although the design of this UHF antenna was not completely accurate, it can serve as a foundation before carried out the manufacturing process of the sensor to which improvement can be made in the future.

References

[1] Chudnovsky B H 2013 Electrical power transmission and distribution: aging and life extension techniques (CRC Press)
[2] An introduction to partial discharge (pd) URL http://www.hvpd.co.uk/technical/
[3] Hikita M, Okabe S, Murase H and Okubo H 2008 IEEE Transactions on Dielectrics and Electrical Insulation **15** 505–518 ISSN 1070-9878
[4] Bell R, Charlson C, Halliday S P, Irwin T, Lopez-Roldan J and Nixon J 2003 IEEE Transactions on Power Delivery **18** 1187–1191 ISSN 0885-8977

[5] Li T, Rong M, Zheng C and Wang X 2012 IEEE Transactions on Dielectrics and Electrical Insulation **19** 1421–1430 ISSN 1070-9878
[6] Liu J, Zhang G, Dong J and Wang J 2015 Sensors **15** 29434–29451 ISSN 1424-8220 URL http://www.mdpi.com/1424-8220/15/11/29434
[7] Wang Y, Wu J, Chen W and Wang Y 2014 Journal of Sensors **2014** 8 URL http://dx.doi.org/10.1155/2014/839386
[8] Publishing I, Li M, Guo C and Peng Z 2014 Design of meander antenna for uhf partial discharge detection of transformers
[9] Judd M D, Yang L and Hunter I B B 2005 IEEE Electrical Insulation Magazine **21** 5–14 ISSN 0883-7554
[10] Global system for mobile 900 (gsm900) URL http://sppd.skmm.gov.my/skmmgovmy/files/attachments/GSM900.pdf
[11] Balanis C A 2016 Antenna Theory: Analysis and Design (John Wiley & Sons)