

## A T-shaped partial ground microstrip patch antenna based UHF sensor for partial discharge detection

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### Article Info

#### Article history:

Received Feb 10, 2020

Revised Apr 19, 2020

Accepted May 4, 2020

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#### Keywords:

Microstrip patch antenna

Partial discharge

Return loss

UHF

VSWR

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### ABSTRACT

Continuous partial discharge (PD) monitoring and early PD detection is important in making sure the necessary preventative measures can be taken accordingly. This paper proposed a T-shaped partial ground microstrip patch antenna that is able to detect PD signal within the UHF range. The antenna was designed and simulated using CST Microwave Studio. The antenna was then fabricated using FR4 substrate material and tested for reception test. The simulation results and the analysis from the fabricated antenna confirmed that the proposed antenna able to detect PD signal at UHF range (specifically at about 500 MHz) and fulfilled the design requirements in terms of the return loss, VSWR, bandwidth and gain. Reception test had confirmed that the proposed antenna was able to detect PD signals that are located at maximum distance, ranges from 37 cm to 70 cm (depending on the PD signal strength). The proposed antenna also had successfully detected PD occurrences at 300 MHz to 700 MHz. In conclusion, the proposed T-shaped partial ground microstrip patch antenna had been successfully designed and able to detect PD signal emitted in the UHF range.

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## 1. INTRODUCTION

Partial discharge (PD) occurrences in high voltage equipments is one of major concerns in power utility industry, as it may lead to inconvenient power outage and involves cost intensive repairs. PD is an electrical discharge that do not completely or partially bridge the insulation between conductors and which can or cannot occur adjacent to a conductor [1]. The physical symptom appears such as visible burn marks at the solid insulation. Particularly in high voltage cable, PD can be the result of improper installation or poor cable with weak spots such as void and cracks. Therefore, PD measurement is critical process during on-site cable commissioning. PD monitoring and early detection is also crucial in routine maintenance to prevent unexpected equipment failure.

There are several conventional PD detection methods that are popularly deployed in industries such as electrical detection, acoustic detection, optical detection, and dissolved gas presence method [2-5]. They are known as conventional methods. In [6], it was reported that PD signal also emits electromagnetic waves within 300 MHz to 1.5 GHz, which falls within the ultra high frequency (UHF) range. Recently, there is a growing interest in investigating UHF based PD signal in gas insulated substation (GIS) transformer, power transformer and cable [7-9]. The UHF based PD detection is a promising alternative to the conventional PD detection methods due to its robustness to interference, high sensitivity, detection accuracy and detection localization. In substation, noise is usually prevalent at lower frequency range (less than 200 MHz), which can be easily eliminated by the UHF based PD detection [9]. In [10], Judd et. al stated that

interference from communication systems that coexist in the UHF range is not a serious concern because PD event is an impulse signal, which is possible to discriminate and extracted from the polluted signal. Additionally, the author mentioned that with appropriate positioning of the UHF sensors, locating the PD sources can be achieved by comparing the signals captured from different sensor positions. UHF based PD detection in high voltage equipment is very much dependent to the UHF sensor performances. In designing a good UHF sensor for PD detection, the following requirements need to be carefully addressed:

- a) Operating frequency band  
The frequency band of the UHF antenna should be within the PD signal, which ranges from 300 MHz to 1500 MHz.
- b) Radiation pattern  
Various UHF antennas have been proposed in literature, namely monopole antenna [6, 11-13], fractal antenna [14, 15], Hilbert antenna [16, 17], Archimedean antenna [18] and microstrip patch antenna [19-21]. However, most of these antennas are directional antenna. Using directional antenna, the maximum gain is towards where the PD signal frequently occurs. However, the location of PD source is typically unknown. Hence, omnidirectional antenna pattern, which receives signal from all direction would be more advantageous and offer higher accuracy in detecting the PD signal.
- c) Maximum distance of UHF antenna placement within the high voltage equipments.  
This is to ensure that the antenna can be placed at location within its detection range from the PD source.

The designed antenna should also fulfill performance metrics in terms of return loss (S11), voltage standing wave ratio (VSWR), directivity and gain. This paper presents our proposed T-shaped partial ground microstrip patch antenna that can be used as UHF sensor for partial discharge detection. The proposed antenna is designed to resonant at 500 MHz, motivated by the simulation and experiment conducted on high voltage equipments in [11, 19]. The standard microstrip patch antenna, which can be either square, rectangular or circular in shape, are usually exhibited directional radiation pattern [22-24]. Applying complex geometrical shape, the microstrip patch antenna could produce omnidirectional pattern [8, 25] and affects the bandwidth [26]. In [27], our initial microstrip patch antenna was based on a rectangular full ground plane. The work is extended here with the T-shaped partial ground plane, to achieve omnidirectionality. Hence it could detect PD signal from any direction. The antenna's detection range is also studied here. In summary, the contribution of this paper is in twofolds; (i) design of T-shaped microstrip patch antenna that can detect unknown PD signal within UHF range (ii) PD signal detection range.

## 2. RESEARCH METHOD

There are several parameters that need to be carefully considered when designing a microstrip patch antenna, such as the substrate material, physical characteristics of the patch, the feeding technique and the geometrical shapes of the antenna. The proposed antenna is based on FR4 board, having dielectric constant,  $\epsilon_r$  of 4.3. There are 4 common feeding techniques, namely inset coupling, coaxial coupling, proximity coupling and aperture coupling. In this work, inset coupling technique is adopted, with the conducting strip connected directly at the edge of the microstrip patch. This creates a planar structure to the antenna and hence offer better impedance matching compared to other feeding techniques [28, 29]. Figure 1 illustrates the front view of the proposed T-shaped partial ground antenna, showing the inset coupling and a rectangular shape. In order to improve the gain and bandwidth, researchers have proposed several techniques such as slots, notching, parasitic element, partial ground and optimizing the antenna's geometrical shape [30-32]. In this work, the T-shaped partial ground technique as shown in Figure 2 is adopted to improve the bandwidth and gain.

The design parameters of the proposed antenna are tabulated in Table 1. The proposed antenna is designed and simulated using CST Microwave Studio software. The antenna is then fabricated using FR4 with double copper cladding and the performance is tested using vector network analyzer. Figure 3 and Figure 4 shows the fabricated antenna. The fabricated antenna is also validated for reception test, to observe its' ability in detecting the PD signal and to determine the maximum distance for antenna placement. Prior to the reception test, m-dB method is used to determine the noise threshold. The m-dB method allows a margin of m-dB above the measured average noise value. The m-dB margin is set to clearly differentiate the PD signal from the noise. It is also to avoid unnecessary false alarm, which assumes noise as a PD signal. The m-dB method has been widely used in detecting unused spectrum in wireless communication [33, 34]. In this work 5dB margin is chosen based on our measurement and observation of noise. The measured average noise is -77dBm and thus the noise threshold is set to -72 dBm. It would mean that any signal that is above -72 dBm is considered as PD signal.

The reception test is carried out in the laboratory. Block diagram of the experimental setup for the reception test is illustrated in Figure 5. The PD source is generated by a signal generator (GWINSTEK USG-LF44), connected to the T-shaped partial ground antenna that acts as transmitter. Another similar T-shaped partial ground antenna that acts as receiver is connected to ADVANTEST U3571 spectrum analyzer. Parameters of PD source are configured using USG software, while the detected PD signals are monitored using spectrum analyzer and UV37000s software. Referring to [35], the PD signal can be as low as -10dBm or 100mV. In the reception test, the PD signal source is set from -10 dBm (min) to 0 dBm (max). The spectrum analyzer is set to monitor the received PD signal from 300 MHz to 700 MHz, with centre frequency of 500MHz.

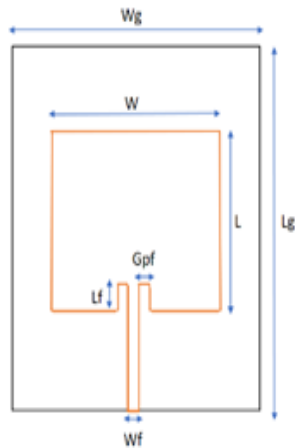


Figure 1. Front structure

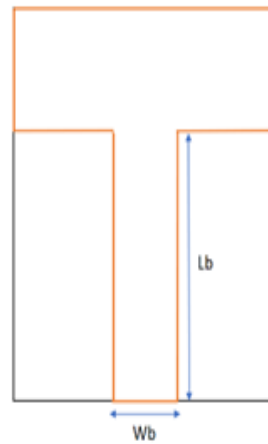


Figure 2. T-shaped partial ground plane

Table 1. Design parameters of the T-shaped partial ground microstrip patch antenna

Parameters	Dimensions (mm)
Antenna Width, W	76
Antenna Length, L	140
Substrate Width, Wg	84
Substrate Length, Lg	226
Feedline Length, Lf	15
Feedline Width, Wf	3
Feedline Gap, Gpf	1
Partial Ground Length, Lb	192
Partial Ground Width, Wb	20
Substrate Height, Hs	1.6
Copper Height, Ht	0.035



Figure 3. Front view of the fabricated antenna



Figure 4. T-shaped partial ground

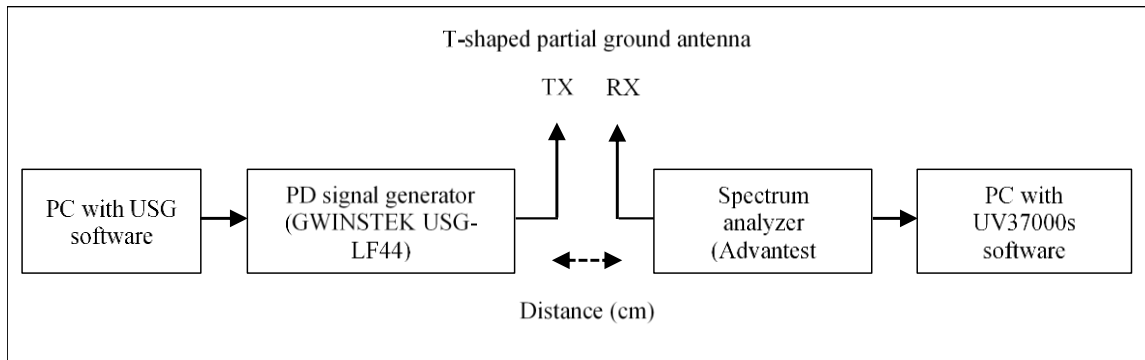


Figure 5. Setup for the reception test

The performances are evaluated in terms of return loss (S11), VSWR, directivity and gain. The requirement for S11 should be less than -10 dB, which means that only 10% of power signal is reflected back and the remaining 90% shall be received by the antenna [36]. The VSWR is defined as reflection coefficient which describes the power reflected from the antenna. The ideal case of VSWR is 1 (unity) which indicates perfect match and there is no reflected power from the antenna [37]. However, VSWR of less than 2 is expected in this work. Antenna directivity is used to evaluate the concentration of the antenna radiation pattern in a particular direction. An antenna that radiated equally well in all directions would be omnidirectional. The antenna gain is defined as radiation efficiency multiply with the directivity.

### 3. RESULTS AND ANALYSIS

This section presents the results from the CST simulation, measurements from fabricated antenna and also the reception test. Figure 6 depicts that the simulated antenna attained return loss of -48 dB, while the fabricated antenna obtained -28.83 dB. Although the S11 of the fabricated antenna is largely different than the simulation, it fulfills the S11 requirement of less than -10 dB. The graph also shows that the simulation result attained resonant frequency of 500 MHz with bandwidth of 68 MHz (474 MHz to 542 MHz). On the other hand, the fabricated antenna achieved resonant frequency of 504 MHz with bandwidth of 58 MHz (468 MHz to 526 MHz). Figure 7 depicts closer look of the VSWR performance at around 500 MHz. It is observed that the VSWR from simulation is 1.008, while the fabricated antenna achieved slightly higher VSWR of 1.26. Both VSWR values achieved the target of less than 2. Simulation result also shows that the maximum gain is 1.951 dB.

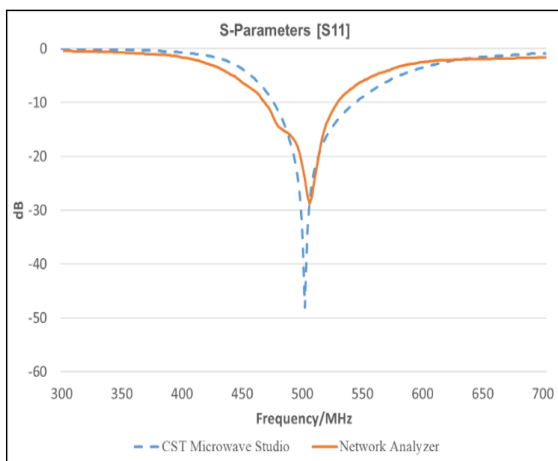


Figure 6. The S11 performance of the T-shaped partial ground antenna

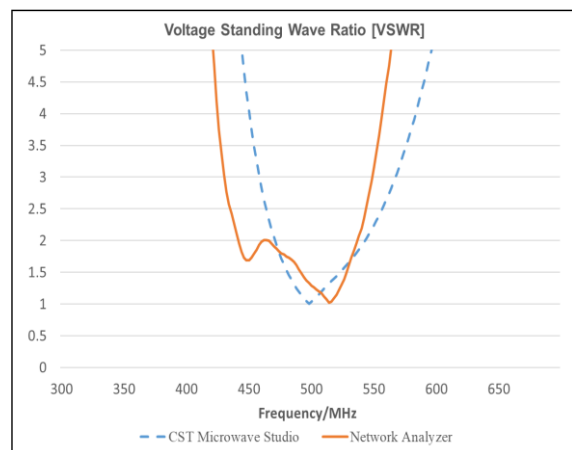


Figure 7. VSWR performance of the T-shaped partial ground antenna

In contrast to the simulated antenna, the overall performance of the fabricated T-shaped partial ground microstrip patch antenna is slightly lower. It might be due several factors such as material oxidation from lengthy exposure, quality of the FR4 substrate and fabrication losses. Whereas the results from simulation are based on ideal conditions. Nevertheless, it can be concluded that the overall performance of the fabricated antenna is in a good agreement with the simulation results. The fabricated T-shaped partial ground microstrip patch antenna is further analyzed in terms of (i) its ability to detect the PD signal and (ii) to determine the maximum distance of the antenna placement from the PD source. In this reception test, the PD signal is observed closely from 450 MHz to 550 MHz, consistent with the optimal bandwidth of the fabricated antenna. The PD source is varied from 0 dBm, -5 dBm and -10 dBm, while the noise threshold is set to -70 dBm. The farthest distance of the antenna placement is then observed accordingly. Figure 8, 9 and 10 show the received PD signal over the distance (in cm). Based on those experimental results, the maximum distance of the antenna placement is recorded in Table 2. As expected, the maximum distance became shorter as the PD signal became weaker. However, since the proposed antenna is omnidirectional, it is able to receive and detects PD signal from any direction which is unknown. This clearly shows that the proposed T-shaped partial ground microstrip antenna is functional well and able to detect the PD signal at up to certain distance.

Table 2. Maximum distance of the antenna placement

PD signal source (dBm)	Maximum distance (cm)
0	70
-5	56
-10	37

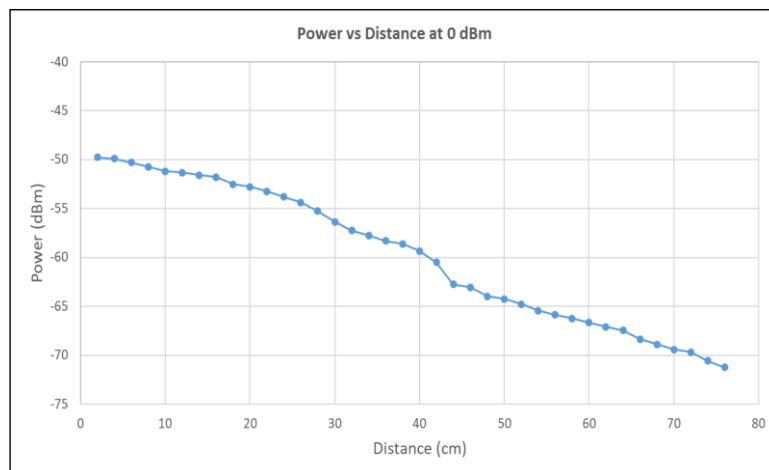


Figure 8. The detected PD vs distance at 0 dBm

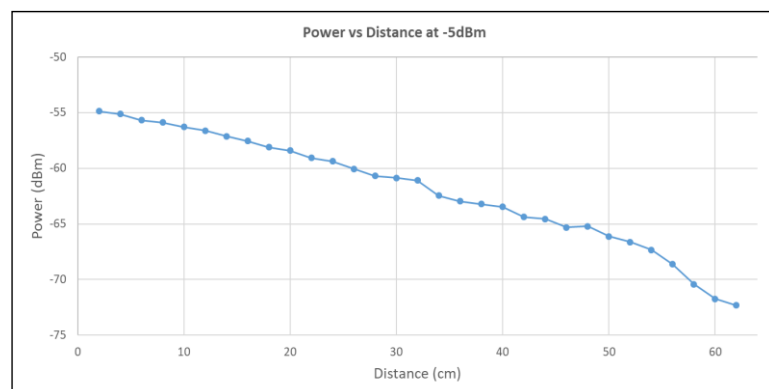


Figure 9. The detected PD vs distance at -5 dBm

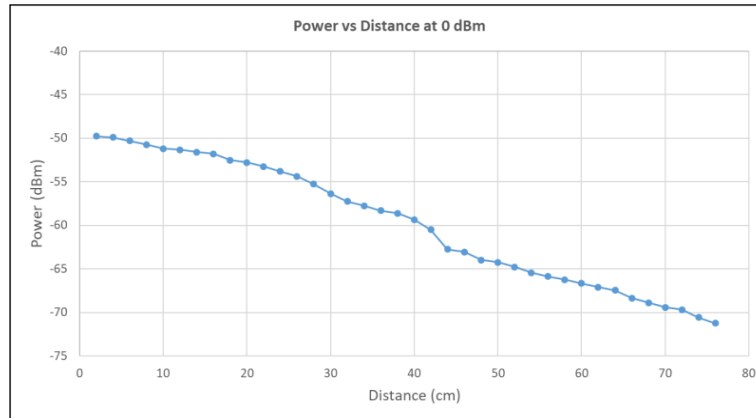


Figure 10. The detected PD vs distance at -10 dBm

The observation window for the reception test is then further expanded from 300 MHz to 700 MHz. The objective is to evaluate the trend of PD signal occurrences within that frequency range. It is observed that the PD signals are consistently present at 312.4 MHz, 398.4 MHz, 595.6 MHz and 679.3 MHz. Table 3 presents the detected PD signal strength, for PD source of 0 dBm. The same trend is also witnessed for PD sources of -5 dBm and -10 dBm. This test confirms that the proposed antenna is able to detect PD signal from 300 to 700 MHz.

Table 3. The detected PD at various frequencies (PD source of 0 dBm)

Distance	5 cm	10 cm	15 cm	20 cm
Frequency (MHz)	Power (dBm)			
312.4	-57.84	-64.02	-64.27	-65.82
398.4	-51.25	-57.72	-61.70	-65.65
595.6	-50.69	-54.40	-56.33	-59.96
679.3	-44.65	-50.91	-54.49	-56.56

**4. CONCLUSION**

This paper presents our proposed T-shaped partial ground microstrip patch antenna that is designed specifically to detect PD signal that emits electromagnetic waves at UHF range. The proposed antenna is designed to resonant at 500 MHz. The design and simulation is carried out using CST Microwave Studio, fabricated on FR4 substrate, analyzed using vector analyzer and validated through reception test. Simulation results confirmed that the proposed antenna fulfills the performance requirements in terms of the return loss, VSWR, bandwidth and gain. Although the results for the fabricated antenna is slightly lower than the simulation results, but it is still within the acceptable range. Results from reception test also verified that the proposed antenna has successfully detecting the PD signal, up to certain maximum distance (37cm to 70 cm). Additionally, the proposed antenna had also successfully detected PD occurrences at 300 MHz to 700 MHz. However, there are still a lot of improvements that can be done and is open for further investigations. For example, PD signal localization will help to improve the detection accuracy. In addition to that, the impact of structure of high voltage equipments to the electromagnetic waves need to be investigated further, especially on the actual high voltage.

**ACKNOWLEDGEMENTS**

A special thanks to the Innovation & Research Management Center (iRMC), Universiti Tenaga Nasional for the research funding under the Uniten Internal Grant 2018 (UNIIG 2018).

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