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PUBLIC HEALTH SUSTAINABILITY: PERFORMANCE ANALYSIS OF CIRCULAR PATCH ANTENNA FOR NON-IONIZING RADIATION (NIR) LEVEL MEASUREMENT

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Abstract: Past studies show that non-ionizing radiation (NIR) exposure may affect living things. Thus, this kind of exposure needs to be monitored to provide sustainable public health. The proper measurement technique and the high gain antenna are required to obtain an optimum reading. The main purpose of this paper is to provide the performance analysis results of a circular patch (CP) antenna which operates up to 4 GHz. The antenna is designed and simulated using CST Studio Suite® software which has a simple circular radiation patch structure with half grounded plane with defected ground structure (DGS) design. The comparison between the performance of the proposed CP antenna characteristics and the simulation results were presented in terms of the radiation pattern, bandwidth, S-parameter, gain and efficiency for validation. Based on the actual measurement results, the CP antenna performance is acceptable since it successfully operates within the targeted frequency band (S-parameter: 0.89 GHz to 4 GHz) with the percentage of frequency bandwidth (FBW) that is equal to 127.2%. Besides, the highest gain of simulated and measured obtain are 2.099 dBi and 5.17 dBi respectively with the omnidirectional radiation patterns for both measurements. The developed antenna is suggested to be used in the ambient reading of frequency signals for NIR exposure measurement purpose.

Keywords: Non-ionizing radiation, receiving antenna, circular patch, omnidirectional, public health sustainability.

Introduction

Due to high demand in human technology, the effect of NIR produced on human health is questioned. Studies have been conducted to measure the exposure which originated from the technology usage (Dianah *et al*., 2017) and various clinical studies have been done to investigate the effect on living things (Syaza *et al*.,2017). From the findings, NIR is proven to affect living things and human health. Several countries have developed their own policy on NIR exposure limit while others have used recommendation limit set by an independent organization, the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Therefore, it is crucial to develop Malaysia's own NIR policy on safety for public health sustainability.

The ambient measurement of exposure level around Malaysia had been conducted before by Sabri *et al*. (2015), Umar *et al*. (2015a), Umar *et al*. (2015b), Syafiqah *et al*. (2018), Islam *et al*. (2006) and Sufiah *et al*. (2010). The proper measurement technique should be done in order to reach an optimum reading. Thus, a specific antenna should be designed for the best measurement result. The specific antenna is one that it is appropriate for the assessment of NIR exposure level that is specifically used to capture frequency up to 4 GHz. These frequencies are in

UHF and VHF band region of the RF spectrum which is allocated for communication signals coming from all directions.

Unfortunately, the construction of antennas specifically for radiation exposure assessment was not considered a necessity by previous researchers. This is because most of the studies, especially on measuring the NIR exposure level conducted either in or outside Malaysia, were using the commercialized antenna or Electric Field (EF) probe as receivers which do not meet the research priorities (Dawoud, 2003; Voudouris & Grammatikakis, 2005; Al-Akhras *et al*., 2015). This is because wider bandwidth and omnidirectional receiver usually performed with low efficiency. Generally, an antenna which is good in terms of efficiency can radiate in between 50% to 60% of the energy fed to it. The high-efficiency antenna is essential to capture exposure signals as high as possible to represent the actual value of exposure received by residents in the vicinity. However, up till now, there is no researcher who has developed antenna that meets the required specifications specifically for NIR exposure level measurement application. Therefore, an antenna that meets the specifications of the measurement application will be developed for exposure measurement. The exposure data could be used for future studies to identify the biological effects due to NIR exposure.

The main antenna characteristics that need to be emphasized are the operating frequency range, the radiation pattern, and the antenna gain. Besides, the size and type of the antenna that is compatible with the applications also would need to be considered because most of the antenna characteristics are related to the antenna dimension. It is because the wavelength is different at different frequencies, so the antennas must be different in size to radiate signals at the correct wavelength.

According to Balanis, (2005) the IEEE has interpreted an antenna as a means for radiating or receiving radio waves, whereby, the antenna that received signals from a transmitter through the transmission line before being propagated to the free-space is called transmitting antenna. Meanwhile, the antenna that received signals from free-space is called receiving antenna. There are numerous types of antennas such as a monopole, dipole, helical, aperture, microstrip antenna, and many others for various applications by depending on the operational frequency band as shown in Figure 2.14 (Nakar, 2004). The conventional antennas are often bulky and costly, thus microstrip antenna or also to be known as patch antenna has become a popular choice among antenna designers due to their simple structure and low-cost development.

Generally, a microstrip patch antenna is made up of three basic layers which include a radiating element layer (patch), a dielectric layer, and a ground plane layer.

The radiating element, also called the radiating patch is the upper part that is generally made of conductive material such as copper, gold, aluminium and other potential material (Molaei *et al*., 2018) of various possible configurations like rectangular, circular, square, and elliptical or any other shape. Meanwhile, the ground plane layer can be printed on the other side of the dielectric layer made up of

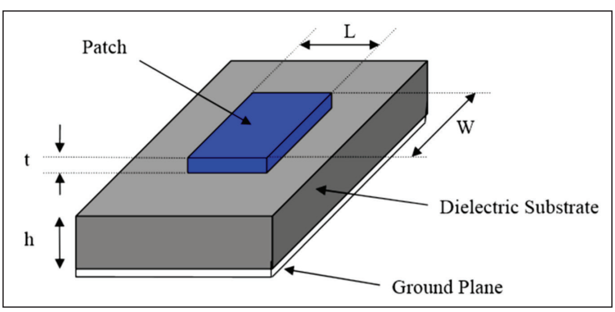


Figure 1: The basic structure of a microstrip patch antenna (Mehta, 2015)

conductive material. The ground layer should usually separated from the radiating element. Moreover, this kind of antennas is broadly used in numerous of microwave frequency band applications as it would not be practical to used in the low-frequency band as the size of the antenna would be too large (Kamarudin *et al*., 2018).

However, the performance of the whole system mainly depends on the efficiency of the receiving antenna used to have high accuracy (Ja'afar *et al*., 2014). Hence, a modification of the antenna configuration needs to be optimized to achieve the desired antenna performance. Moreover, the selection of the appropriate antenna characteristics is necessary because the applicability of the antenna to be used is different depending on its application or study. Therefore, the selection of antennas that conforms to the features of its application with a better performance has been constructed with support from previous studies (Miswadi *et al*., 2015). An omnidirectional CP antenna has been designed and fabricated for priority in NIR field strength detection specifically for communication signals measurement application.

Thus, the main purpose of this study is to demonstrate results of the analysis CP antenna performance in terms of the radiation pattern, impedance bandwidth, reflection coefficient (S11-parameter), gain and efficiency. Ultimately, the operating frequency range was determined specifically for communication band to monitor the public ambient NIR exposure around base station tower (BST) sites and compared with the reference levels for human exposure limit by ICNIRP. The determined range was 0.89 GHz to 4.00 GHz where the allowed transmission frequency allocated by MCMC are used in broadcasting stations for either radio or television, mobile base stations (GSM – Global System for Mobile Communications, UMTS – Universal Mobile Telecommunications System, and LTE – Long-Term Evolution), Digital Enhanced Cordless Telecommunications (DECT) base stations, radiofrequency tagging systems and wireless communication applications (WLAN – wireless local area networks, WiFi – wireless fidelity and WiMax – worldwide interoperability for microwave access).

Materials and Methods

For NIR exposure assessment, the receiver system commonly comprises of a receiver antenna that function as the receiver of the desired radiation signal sources, a low noise amplifier – to amplify the received signal by increasing the power of the desired signal and reducing the internal noise and a spectrum analyser – to measure and display the strength of the received signal. The receiver antenna is the crucial component where its efficiency represents the whole detection system performance. In the development of antenna, there are several important processes that need to be carried out, that is structural analysis, simulation test and measurement test. The block diagram of the overall instrument setup is shown in Figure 2.

The proposed CP antenna used covers the frequency band from 0.89 GHz - 4 GHz and has been designed and simulated through CST software which is a simulation tool that uses electromagnetic field solver in order to design NIR level measurement application. The CP antenna design which had meets the specification requirement by operating at L band region was then fabricated. It had undergone three types of measurement tests which were conducted in the laboratory (in anechoic chamber and vector network analyzer) and also in the fieldwork. The simulation and measurement test results of the antenna were compared to verify its performance before it could be utilized.

Designation and Optimization of Antenna Structure

The studies on the criteria of an appropriate antenna need to be done before the designation process by setting the target frequency range, radiation pattern and the dimension of antenna. Generally, the antenna size is related to the operating frequencies whereby the smaller antenna operated at high-frequency meanwhile

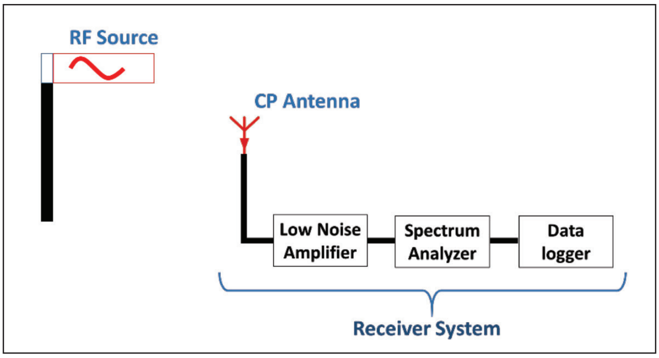


Figure 2: Block diagram of the receiver system in NIR exposure assessment

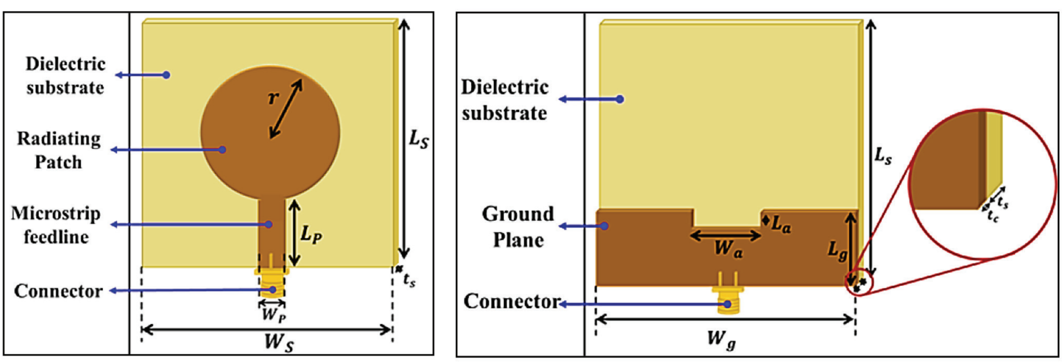
the antenna with larger size operated at low-frequency (Roslee *et al*., 2011).

All the designation works were simulated using the CST simulator to ensure that all the targeted antenna specification targets had been achieved. Therefore, the structure of the CP antenna was analyzed to get the optimized dimension and the most effective signal receiver as well for better efficiency. This would enable the receiving system to haves the best performance for NIR level measurement.

The design of the antenna is optimized by changing the radiating patch radius and DGS adjustment of the CP antenna in order to reach the bandwidth required to cover certain regions of the NIR spectrum. For a patch antenna, usually, the bandwidth is very narrow. The modification done was to make the bandwidth larger.

The final configuration of the proposed CP antenna based on the parameter that has been optimized is shown in Figure 3 and has been detailed in Table 1. The radiating patch, microstrip feedline and ground plane which are made up of full copper material with a thickness of 0.035 mm were printed on low-cost FR-4 substrate with a thickness of 1.6 mm and dielectric constant of 4.

The feeding technique that used for CP antenna is 50 Ω microstrip feedline with a dimension of $L_P \times W_P$. The feed line can be photo-etched on the dielectric substrate then connected to the edge of the patch by an SMA connector (Balanis, 2005). The CP antenna design structure had been optimized in order to achieve the targeted frequency band. Besides, it was also incorporated with the defected ground structure (DGS) to enhance the reflection coefficient. The proposed CP antenna then was successfully developed and measured with the Vector Network Analyzer (VNA) and the spectrum analyzer used in the anechoic



(a) (b)

Figure 3: Schematic diagram of the CP antenna. (a) Front view. (b) Rearview

Table 1: Optimized parameters of the CP antenna

Parameters	Value *(mm)*
W_s	100
L_s	85
r	30
W_P	4
L_P	21
L_g	21
W_g	100
W_a	20
L_a	2

chamber to measure the radiation pattern and reflection coefficient respectively. For the final process, the comparison between simulation and measurement results were analyzed to validate the performances of the proposed antenna.

Results and Discussion

The different attributes and the type of antenna are needed for a certain application. For NIR measurement, the proposed antenna should be working in a wideband frequency range at the microwave region. At the microwave region, the radiation may be absorbed throughout the body.

In order to have an accurate reading of EF strength on ambient NIR exposure level around BST, a precise receiving antenna is needed with omnidirectional radiation pattern type. Based on the diagram shown in Figure 3(b), CP antenna has half ground plane because it is one of the characteristics that must be considered to obtain omnidirectional radiation pattern antenna (Miswadi *et al*., 2015).

With such an antenna, more research can be done to see the biological effect of such waves. Unfortunately, patch antennas experience narrow bandwidth drawback. However, this weakness can be overcome by implementing DGS to enhance the bandwidth and improve the gain of the antenna (Gajera *et al*., 2011). This technique is more convenient compared with several other several techniques. Therefore, the effect of radiating patch radius and DGS parameters on the antenna bandwidth was optimized until performed at the larger bandwidth and has been presented in this paper. The optimization work has been performed by varying one selected parameter while fixing the other parameters at a time.

Figure 4 shows the effects of various DGS depth, L_a, on the simulated reflection coefficient,

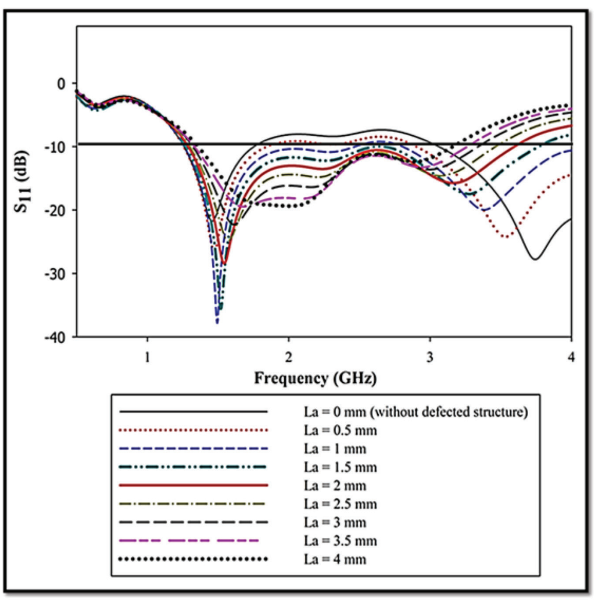


Figure 4: The simulated reflection coefficient of various ground defected depths, L_a

S11, versus frequency in GHz. S11 parameter which is also known as return loss represents the mismatch loss. Hence, getting the lowest value (below than -10 dB) of the S11 is the best. This means that lower S11 value leads to lower power loss and thus will increase the ability of a receiving antenna to capture the signal at certain operating frequency range (Gupta & Sharma, 2013).

Initially, the partial ground plane without defected structure had been designed and was found that the proposed antenna exhibited multiband and narrow bandwidth performance. Then, the DGS was applied and optimized the depth, L_a, on the half grounded plane of the proposed antenna by varying from 0.5 mm to 4 mm in steps of 0.5 mm to enhance the bandwidth.

By only looking at the frequency band of each L_a changing that fell below the -10 dB of S11 value, it was realized that the bandwidth was getting larger with the increasing of L_a and exhibited wideband performance when L_a changing was from 2 mm to 4 mm. The optimum L_a with the highest FBW of 94.48% (1.29 GHz – 3.60 GHz) was found at L_a = 2 mm.

Figure 5 shows a comparison of the simulated reflection coefficient, S11, by varying the radius of the radiating patch, *r*, by maintaining L_a = 2 mm, the transmission line and the other part.

It can be observed that the frequency range and resonant frequency had no obvious change with *r* changing from 28 mm to 32 mm. However, the changing of *r* has influenced the S11 value in between the frequency band, especially for the resonant frequency. As can be seen, *r* = 32 mm resulting in the best S11 (-40.0132 dB) at 1.45 GHz however, exhibited multiband performance when revealed S11 less than -10 dB at 2.18 GHz to 2.25 GHz. Thus, the optimum *r* is obtained at 30 mm since it has shown the lowest S11 of wideband performance.

Figure 6 shows a comparison between the simulation and experimental results of the reflection coefficients of the proposed CP antenna.

As can be seen, the simulated and measured frequency range is slightly shifted from each other and where is the simulated curve exhibited the frequency ranges cover from 1.29 GHz to 3.60 GHz producing a 2.31 GHz impedance bandwidth. Meanwhile for the measured curve, the frequency range cover from 0.89 GHz to 4 GHz resulted in the impedance bandwidth of 3.11 GHz. The reason for such discrepancy is due to several factors. One of the factors is that the simulation dimension and the fabricated dimension have a slightly different measurement. Based on the results, it is clearly shows that the antenna fabricated is slight larger compared with

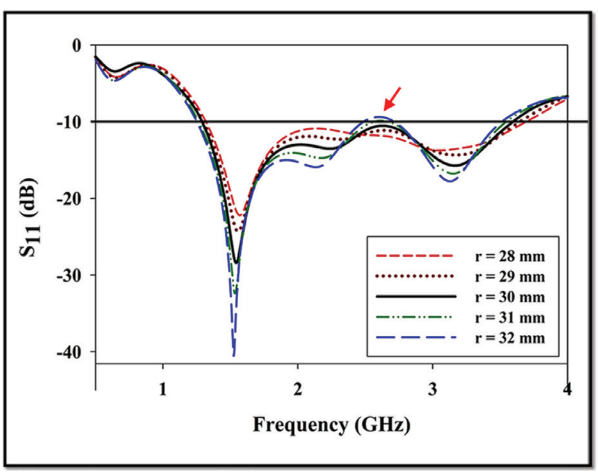


Figure 5: The simulated reflection coefficient of various radiating patch radius, *r*

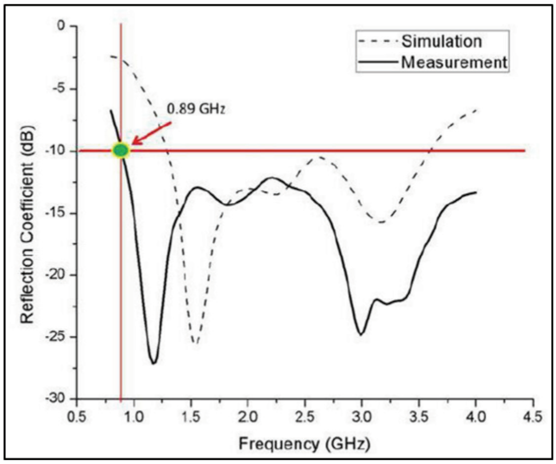
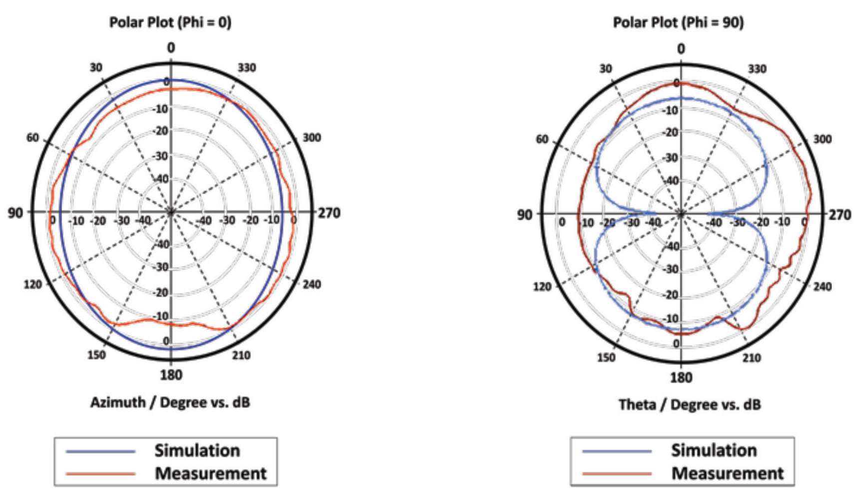


Figure 6: Reflection Coefficient of measurement and simulation of the CP antenna

the simulated antenna because the frequency of the fabricated antenna is lower compared to the simulated one. The fractional bandwidth (FBW) for both simulated and measured antennas is 94.48 % and 127.2 % respectively. Therefore, this proposed antenna can contribute to UWB applications due to its FBW which is greater than 50 % (Balanis, 2005). Moreover, the proposed antenna is quite promising with the maximum reflection coefficient value which is -34.69 dB at 1.15 GHz.

Figure 7 demonstrates the two-dimensional (2D) radiation pattern polar plot between simulation and measurement results of the proposed antenna in the azimuth plane (phi 0˚) and elevation plane (phi 90˚) of the spherical coordinate system.

It can be seen that the shape of the radiation pattern at azimuth plane for the simulated and measured as shown in Figure 7(a) and were in a good agreement which is covered 360°. Whereas, the elevation polar plot between the simulated and measured as shown in Figure 7(b) was found to have no similarity to each other. However, it was observed that the radiation patterns for both results were similar in terms



(a) (b)

Figure 7: The radiation pattern of the proposed antenna at (a) azimuth plane and (b) elevation plane

Table 2: The specifications of the proposed CP antenna

Specification	Simulation	Measurement
Operating Frequency Range (S11-parameter)	1.29 GHz – 3.60 GHz	0.89 GHz – 4 GHz
Fractional Bandwidth, % (FBW)	94.48 %	127.2 %
Radiation Pattern Type	Omnidirectional	
Gain, dBi	2.099	5.17
Directivity, dBi	2.348	5.67
Efficiency, %	89.40	91.18

of the main lobe directivity. The reason for the difference might be due to the SMA connectors which were not simulated during the simulation design. The effect of SMA will cause some changes in the radiation pattern cause as it acts as a reflector. Moreover, the high gain of the antenna is acceptable for high-performance antenna development. Finally, the comparison for all the specifications between the simulated and measured antenna performances have been summarized in Table 2.

As stated before, the SMA connectors not only affected the radiation pattern of the antenna, but also the gain. The SMA connector, in this case, performed as a reflector which increased the gain of the antenna which in turn increased the directivity as well.

Conclusion

It can be concluded that the differences between the simulation and measurement results were in large disagreement probably due to the imperfection during the fabrication process or at the antenna connection. In order to reduce the disagreement in measurement and simulation, several improvements can be made. First, the fabrication of the antenna should be measured in order to see the accuracy of the fabrication techniques. Second, in the simulation, the SMA should be simulated to see the overall performance. However, the antenna performance is still acceptable since it meets the targeted requirement. Besides that, the DGS on the ground plane anables the CP antenna to enhance the impedance bandwidth. Based on the overall analysis, it is confirmed that this antenna exhibits stable omnidirectional radiation pattern and is found to be suitable for UHF/VHF and UWB applications with high efficiency. Therefore, this antenna is appropriate for the NIR level assessment especially in the communication band (Genç *et al*., 2010).

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