Design and Optimization of Discone Antenna for Medical Device Electromagnetic Interference Measurement

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Abstract— The wide spread of the Internet of Things creates the possibility of electromagnetic interference in medical devices. Therefore, it is necessary to perform risk mitigation by finding the value of electromagnetic interference through measurements using wideband and omnidirectional antennas, e.g., the discone antenna. In this research, the optimization of the S_{11} value of a designed discone antenna was obtained using simulation from the effect of dimensional variations in discone parameters like disc diameter, cone bottom diameter, gap, and cone height on S_{11} characteristics. The parameters were combined for optimization. The design was fabricated, and the S_{11}, radiation pattern, gain value and antenna factor, and the ability to measure interference through modeling were measured. Gain value and antenna factor were obtained using the gain-comparison method, which compared the antenna of interest against another antenna with a standard gain. The optimization was successfully performed with a better S_{11} value. At 5.2 GHz, the value of S_{11} was below -10 dB. The realization of the design showed similar results to the simulation, and it was found to be able to operate in the medical device frequency range (wideband). The ability of the discone antenna improved in terms of S_{11} value, especially at 5.2 GHz, where the value was below -17.443 dB. The radiation pattern of the designed antenna is omnidirectional. Additionally, validation was carried out by providing gain value and antenna factor. It has been proved that the designed discone antenna could measure interference successfully by modeling interference sources as electric field sources from all directions.

Keywords— discone antenna; electromagnetic interference; medical devices; optimization; S_{11}

I. INTRODUCTION

The Internet of Things (IoT) system has become an inseparable part of almost all activities and places in this era. Health facilities such as hospitals implement this system with the aim of making access to health services more efficient [1] in terms of time, place, and cost. IoT is applied to all aspects, including information access and health equipment. Health equipment, wearable or not, uses IoT to assist health workers in diagnosing a health problem in real-time and easily [2], [3], especially during the COVID-19 pandemic [4], [5]. During this period, IoT saw increased applications in several medical devices, including sphygmomanometers, electrocardiogram (ECG), electroencephalography (EEG), blood sugar monitoring devices, and heart rate monitoring devices [6].

In its use, the ECG monitoring system has been reported to experience interference from the Wireless Local Area Network (WLAN) communication system) [7]. The signal shown by the ECG monitoring device is disturbed when the WLAN system is turned on but returns to normal when the WLAN system is turned off. Measurements of the emission from Radio Frequency Identification (RFID) equipment are carried out in the healthcare environment [8], which can generate electromagnetic interference. Signals coming from cell phones can also cause interference with medical devices such as ECG monitors, treadmill examination devices, pulse oximeters, fetal heart detectors [9], and telemetry systems in pacemakers [10]. The hematology analyzer in a clinical laboratory experiences interference on its screen caused by electromagnetic interference originating from the distributed antenna system for communication systems in the 0.7–2.6 GHz frequency range [11]. The oscillator on the ventilator is also disrupted due to Universal Mobile Telecommunications System (UMTS) signals from a short distance [12]. To note, based on the CISPR standard 11:2015 regarding limits and methods for measuring radio frequency interference characteristics for industrial, scientific, and medical equipment, the transmission power limit for this equipment that can interfere with other equipment during measurement at a test site with a distance of 3 m is 47 dBμV/m in the 0.23–1 GHz frequency range and 70.47 dBμV/m in the 1–18 GHz frequency range [13]. Meanwhile, based on IEC 6060-1-2, the power transmission limit is 3 V/m [14].

Risk mitigation is required to prevent disruption of the function of medical devices due to electromagnetic interference, where more and more sources of electromagnetic waves have the potential to cause great interference from the environment and the medical devices themselves [15]. Data on the distribution and amount of emission of electromagnetic waves from all directions and various frequency ranges are required for the mitigation process. Measuring instruments that can measure electromagnetic interference, in general, are antennas

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that have specifications for a wide frequency range (wideband), high gain, compact size, and, where possible, low cost to manufacture [16]. Based on this, the discone antenna has the required specifications because it has a wideband (wide frequency range), compact size, high gain, and omnidirectional property (the ability to capture emission from all directions) needed for this measurement [17], [18].

Discone antennas in several studies have been made with various frequency ranges and applications. A discone antenna design with a disc of FR4 material for television broadcasting system applications is shown in [19]. In its working frequency range, some frequencies have S_{11} values above -10 dB. Then, the discone antenna designed with some modifications to the shapes of the disc and cone for measuring signal characteristics indoors in [20] has a good S_{11} value. Another discone antenna design found in [21] is used for energy harvesting applications. It is a simple design using copper sheets as the material. The resulting S_{11} value is quite good but has yet to reach a maximum level at frequencies around 2.1 and 3.2 GHz.

Studies on electromagnetic interference measurement applications include [22] and [23]. In [22], a discone antenna was designed for use in radio frequency interference measurements, in which case, based on its S_{11} value, it works in the 1.42–2.14 GHz frequency range. In [23], a discone antenna was designed for interference measurements in medical devices with a copper sheet as its material, in which case it works across a wide frequency range, 0.7–6 GHz. Based on previous studies, the discone antenna design, when viewed from its S_{11} value, has a wider working frequency coverage, but at the 5.2 GHz frequency, it does not have an optimal S_{11} value.

It requires optimization [23] so that the designed discone antenna can be used for wireless electromagnetic interference measurements in all medical device frequency ranges. If the discone antenna can operate well in these frequency ranges, then measurements of electromagnetic field radiation emissions can be carried out and the results of these measurements can later be used to mitigate potential interference. In order to optimize the performance of the discone antenna for it to be able to operate in all target frequency ranges, this research was conducted. The research carried out a simple optimization, i.e., dimensional optimization, on each parameter of the discone antenna of the same material through simulation. Optimization was carried out by analyzing the S_{11} values for each antenna discone parameter, i.e., the width of the cone bottom diameter, cone height, gap, and disc diameter. The S_{11} values were used as the main optimization factor because they have the ability to indicate whether the discone antenna can work or not. It was also used for measurements in the required frequency range.

The optimized design was expected to have different dimensions in the cone or disc sections and better S_{11} values than those in previous studies. It was then translated into a physical form using the same material. The S_{11} values, radiation pattern, and antenna were measured. In order to measure the electric field from the electromagnetic interference and the required measurement power, antenna validation was performed by measuring the gain and antenna factor. Modeling of electromagnetic interference measurements using the discone antenna was carried out to prove that the antenna could be used for measurements in the electromagnetic interference frequency range of medical devices.

II. METHOD

The discone antenna was designed according to [23] in the 0.7–6 GHz frequency range following the wireless frequency range of medical equipment: 0.915 GHz for RFID, 2.4 GHz for WLAN/Bluetooth, and 5.2 and 5.8 GHz for WLAN. Using minimum frequency (f_{min}), the wavelength (λ) was found to be 428.6 mm through a calculation using (2).

$$\lambda = \frac{c}{f_{min}} \quad (1)$$

Where c is the value of the speed of light in a vacuum (3 x 10^8 m/s). Meanwhile, the length of the slanted side of the cone (L) was found using (2), which was rounded up to 108 mm.

$$L = \frac{1}{4}\lambda \quad (2)$$

Then the height (t) of the antenna and the bottom diameter (D_{bottom}) were obtained using the Pythagorean formula with θ = 30°. As for the top diameter (D_{top}), the discone was adjusted to the size of the cable diameter to be used. The coaxial cable used was with an outer diameter of 3.6 mm. In this case, diameter variation was not applied because the adjustment was made to the size of the existing cable. Meanwhile, the disc diameter (a) was determined using (3).

$$a = 0.7\ L \quad (3)$$

The value of the gap between the disc and the cone (g) was obtained based on the ability of the RG-402 inner copper to support the disc. Hence, in this study, a gap of 1 mm was chosen. The structure of the discone antenna can be seen in Figure 1, while the full dimensions of the discone antenna can be seen in Table I.

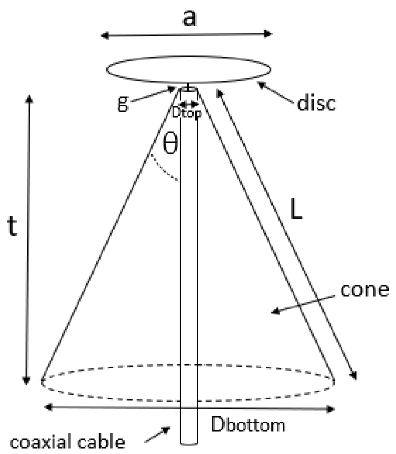

Figure 1. Structure of the discone antenna

TABLE I. DIMENSION OF EACH PARAMETER OF THE DISCONE ANTENNA

Parameter	Dimension (mm)
D_{bottom}	112.0
D_{top}	4.0
a	75.6
t	94.0
θ	30.0
g	1.0

This designed discone antenna was made of copper material. For the cone section, for easy shaping into a cone, the thickness of the copper sheet used was 0.2 mm. Meanwhile, the thickness of the disc used was 0.5 mm to give it sturdiness. After all the parameters were met, a simulation using the high-frequency simulation software, CST Studio suite was carried out. Optimization of S_{11} values was carried out by varying the dimensions of each discone antenna parameter. The parameters included the bottom diameter of the cone, cone height, gap, and disc diameter. In each variation, the characteristics of S_{11} were analyzed, and how they were affected was observed. Then the analysis of each antenna variation was combined with each parameter to obtain the optimal discone antenna design at the desired S_{11} values. The optimal values of S_{11} were seen from its magnitude at -10 dB or below because it reflects that the power on the antenna was only slightly reflected back. Additionally, the S_{11} values must be measured in the required frequency range.

After the optimized discone antenna design was obtained from the simulation, it was then constructed in a physical form using the same material used during the simulation. The discone antenna that was created was then measured for its S_{11} values using a Vector Network Analyzer by connecting the RG-402 coaxial cable port on the discone antenna (as shown in Figure 1) to the Vector Network Analyzer port. The radiation pattern was measured in a semi-anechoic chamber at the wireless health equipment frequencies 0.915 GHz, 2.4 GHz, 5.2 GHz, and 5.8 GHz. In addition, the antenna gain was calculated at each of these frequencies. The constructed discone antenna was expected to have S_{11} values below -10 dB and an omnidirectional radiation pattern at each frequency [24].

A. Variation of Cone Bottom Diameter

Based on Figure 2, the larger the bottom diameter of the cone, the greater the cut-off frequency. This was probably because with every increase in the bottom diameter of the cone, the distance between the cone surface and the disc as a transmitter became smaller, leading to a shorter wavelength and a higher cut-off frequency. On the other hand, the resulting S_{11} values tended to decrease as the bottom diameter of the cone increased. This was probably because the reduced bottom diameter of the cone turned the shape of the antenna into monopole antenna-like, resulting in a decreased bandwidth as seen from the increased S_{11} values. The optimal values were obtained when the diameter of 132 mm was used.

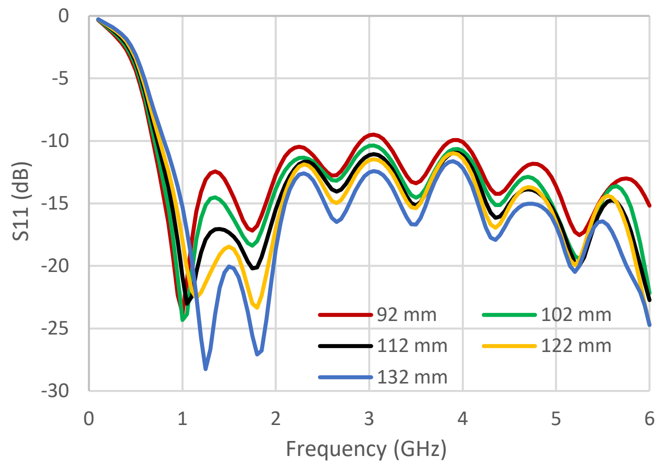

Figure 2. S_{11} characteristics in the discone antenna simulation with variations in the bottom diameter of the cone

B. Variations of Cone Height

Figure 3 shows that, which is consistent with theory, cone height affected the cut-off frequency of the discone antenna. The taller the cone, the lower the cut-off frequency. Meanwhile, the S_{11} value was also influenced by the height of the cone, but no specific pattern was formed. In general, the height of 74 cm had lower S_{11} values in some frequency ranges compared to other cone heights.

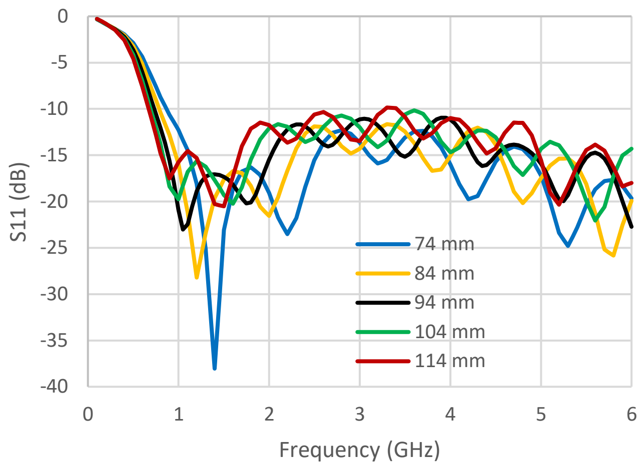

Figure 3. S_{11} characteristics in the discone antenna simulation with variations in the height of the cone

C. Variations of Gap

Figure 4 shows that the distance from the disc to the cone (gap) affected the value of S_{11} in the low-frequency range. In addition, the cut-off frequency was also affected, but not significantly. The greater the cone distance, the lower the cut-off frequency. The S_{11} value tended to be lower around the frequency ranges of 0.9–1.4 GHz and 3.7–6 GHz. The value of S_{11} was affected by the impedance match between the load impedance on the antenna and the impedance on the transmission line. It was assumed that the change in the S_{11} value that went with the gap variation was probably due to the matching impedance.

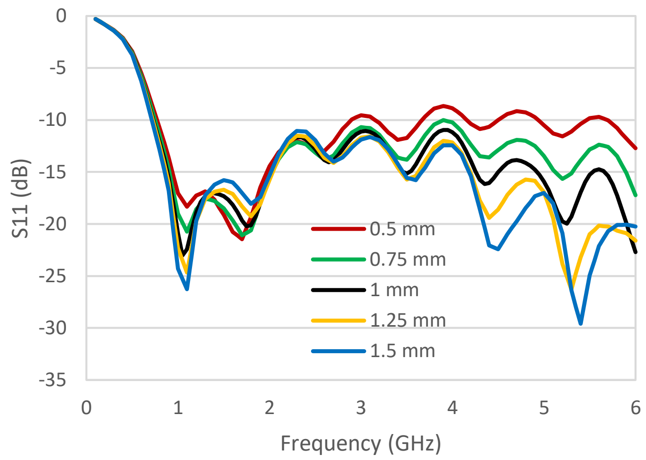

Figure 4. S_{11} characteristics in the discone antenna simulation with variations in gap

D. Variations of Disc Diameter

Figure 5 shows the variations of the disc diameter size, as, in theory, diameter affects the cut-off frequency of the discone antenna. This graph shows that the larger the size of the disc, the smaller the cut-off frequency. This was probably because the greater the disc size, the wider the range of electromagnetic waves. It also allowed for more contact with the ground surface, i.e., the cone, which made the wavelength shorter. Meanwhile, for the S_{11} results as a whole, the disc size had regular patterns of effect at low frequencies (around 0.7–1.2 GHz) and high frequencies (around 3.2–5 GHz), where the larger the disc size, the smaller the S_{11} value. However, the relationship was inversely proportional around the 1.2 – 3.2 GHz frequency range. This might be due to the influence of the electrical length of the antenna. Based on the cut-off frequency and the optimal values of S_{11}, the disc diameter of 0.8 L was considered to be the optimal parameter.

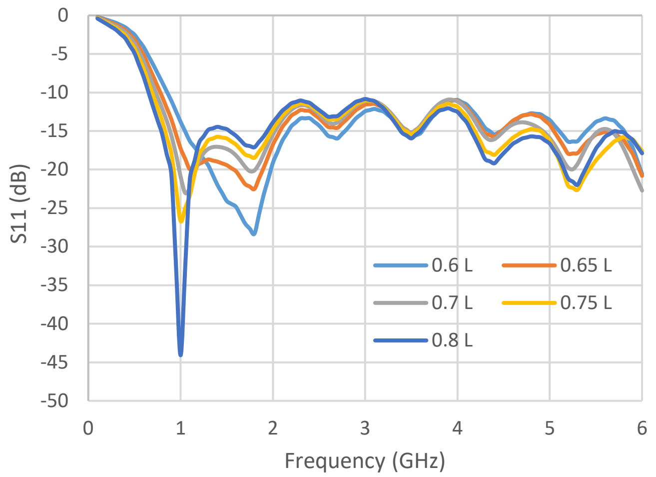

Figure 5. S_{11} characteristics in the discone antenna simulation with variations in the disc diameter

E. Optimization

The optimization values obtained from the analysis of variations in parameters, particularly the optimization values of Design A, are shown in Table II. A simulation was carried out on Design A, and the resulting S_{11} graph is shown in Figure 6. The S_{11} values of Design A were compared against the S_{11} values obtained in a previous study [23], which were lower. In other words, Design A was considered more optimal. However, the cut-off frequency of Design A was around 1 GHz, which did not meet the frequency requirement for making an optimized discone antenna, i.e., 0.915 GHz (for measuring interference from RFID equipment).

To find a design that meets the criteria for optimal S_{11} frequency coverage and value, another simulation was carried out on a variety of parameters, and it was found that Design B was able to meet these criteria. The value for each parameter of Design B can be seen in Table II, while the resulting S_{11} graph can be seen in Figure 6. The table shows that the increase in cone height, reduction of disc diameter, and reduction of the gap between the cone and disc made Design B optimal. Based on the data and analysis of the optimization results for each of the parameters previously described, the lower cut-off frequency obtained by increasing the cone height and reducing the gap helped meet the required frequency criteria. Meanwhile, the values of S_{11} were maintained below -10 dB by reducing the disc diameter.

TABLE II. OPTIMIZATION OF DISCONE ANTENNA

Parametric Variation	Dimensions When S_{11} Values Were Optimal in Design A (mm)	Dimensions When S_{11} Values Were Optimal in Design B (mm)
D_{bottom}	132	132
t	74	94
a	0.8 L	0.7 L
g	1.5	1

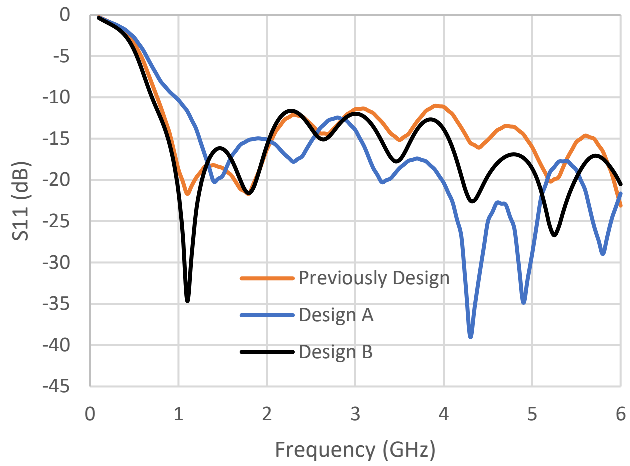

Figure 6. Comparison of S_{11} values among simulations, the optimized design in this research, and the previous research design [23]

F. Antenna Characteristics Measurement

After the design optimization was carried out, the Design B discone antenna was created in a physical form using the same material used in the simulation. The antenna created was then measured for its S_{11} values using a Vector Network Analyzer to ascertain the values derived from the optimization, especially at the frequencies 0.915, 2.4, 5.2, and 5.8 GHz. Then, measurements of the radiation pattern were carried out in the E field at each of these frequencies as it represents the actual measurement with scanning for interference sources in all directions.

To validate the characteristics of the discone antenna, gain and antenna factor measurements were carried out. The gain value of the discone antenna was obtained using the gain-comparison method, involving a comparison antenna with a standardized gain value (which was already known). In this study, a Bicolog Aaronia 30100 antenna was used at the frequency 0.915 GHz and a Hyperlog Aaronia 30100 antenna was used at the frequencies 2.4, 5.2, and 5.8 GHz as both are often used in electromagnetic interference measurements. The gain value of the discone antenna (GT) was calculated using (4).

$$G_T(dB) = G_b(dB) + 10 \log \left(\frac{P_T}{P_S}\right) \quad (4)$$

Where GS is the gain value of the comparison antenna, i.e., 2.85 dBi for the bicolog antenna (the typical gain in the operating frequency range of this antenna model) and 5 dBi for the hyperlog antenna, P_T is the power received by the discone antenna, and P_S is the power received by the comparison antenna. The gain value obtained from this calculation was then compared with the gain value obtained from the simulation

The antenna factor is an important characteristic that must be known for an antenna so that it can be used in measuring electromagnetic interference and electromagnetic compatibility [25]. This also indicates that the antenna already went through calibration and measurement stages with accuracy. The antenna factor (AF) of the antenna was calculated using (5) [26].

$$AF = \frac{1}{\lambda}\sqrt{\frac{4\pi Z_0}{Z_L G}} \quad (5)$$

Where Z_0 is the impedance of a vacuum of 120π, Z_L is the impedance of the antenna system, which is assumed to be 50 ohms, and G is the gain value, which in this study was obtained using the gain-comparison method.

G. Medical Device Electromagnetic Interference Measurement Modeling

Electromagnetic interference can come from the environment or from the operation of the medical device itself, for instance from the operations of Bluetooth and WLAN at the 2.4 GHz frequency [15]. It was also proven by [27], which showed that electromagnetic emissions can potentially interfere with wireless medical devices at the 2.4 GHz frequency. Therefore, to ensure the performance of the discone antenna that was designed to measure electromagnetic interference, the electromagnetic interference source at that frequency was modeled using a Planar Inverted F Antenna (PIFA) with a sampling frequency of 2.4 GHz. This antenna was chosen as some medical devices use it for data transmission and telemetry [28], [29].

Modeling of electromagnetic interference measurements was carried out by placing a PIFA at a distance of 1.5 m from the discone antenna in a semi-anechoic chamber and then varying the signal magnitude at 0, 2.5, 5, 7.5, and 10 dBm, where the signals were transmitted by the PIFA as a source of interference. The signal magnitudes 5, 7.5, and 10 dBm were chosen to interpret the magnitude of the emissions of electromagnetic waves that could cause interference to medical devices [30], while the signal magnitudes 0 and 2.5 dBm were chosen to see the potential ability of the discone antenna to measure interference below those signal magnitudes aforementioned. The discone antenna received the signal transmission and then calculated the magnitude of the electric field strength by adding the antenna factor to the amplitude value received in dBμV. Conversion from dBm (power) to dBμV (voltage) was done by adding the dBm value to 107. The antenna factor in this measurement also marked that the measurement results of the discone antenna had been validated because this value was obtained using the gain-comparison method against a comparison antenna whose characteristics had already been known. In addition, measurement was also conducted on the radiation pattern by rotating the antenna for 360 degrees to model the interference signal captured from the PIFA from various directions at a signal magnitude of 5 dBm, which was adjusted to the interference value from research [30], equivalent to the receiver amplitude value.

III. Results and Discussion

Based on the optimization performed, Design B was found to have the optimal S_{11} values and meet the required frequency coverage for electromagnetic interference measurements on wireless medical equipment. Therefore, a discone antenna was created based on Design B, on which S_{11} measurements were then carried out using a vector network analyzer. A photograph of the Design B discone antenna is shown in Figure 7.

A. Characteristics of the Optimized Discone Antenna

The comparison of S_{11} values between the optimized discone antenna and the simulation is shown in Figure 8. The Design B discone antenna during measurement met the criteria for a discone antenna to measure electromagnetic interference in medical devices: it is a wideband discone antenna with S_{11} values below -10 dB that belongs in the wireless medical device frequency range (0.915–5.8 GHz).

The Design B discone antenna actual measurement and simulation differed in cut-off frequency, where the former had a higher cut-off frequency of around 0.85 GHz. Meanwhile, the S_{11} results appeared to have similar patterns with only a slight difference. The differences in the cut-off frequency and S_{11} between the Design B discone antenna actual measurement and simulation might be due to the inaccuracy of the antenna dimension for each of the parameters, which affected the antenna impedance. As the antenna was made manually, the level of precision was not good.

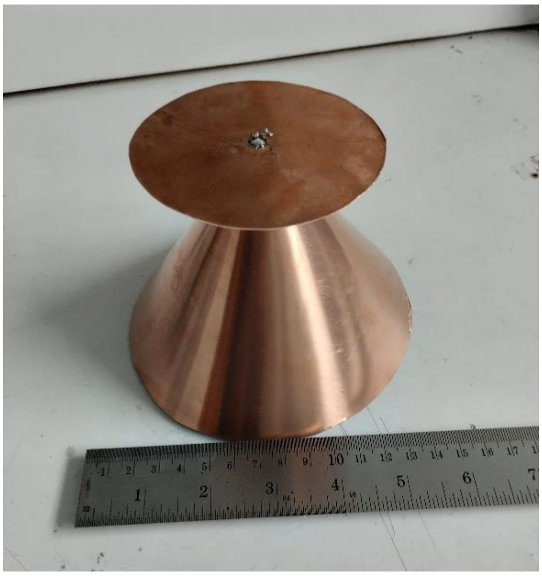

Figure 7. Photo of the Design B discone antenna

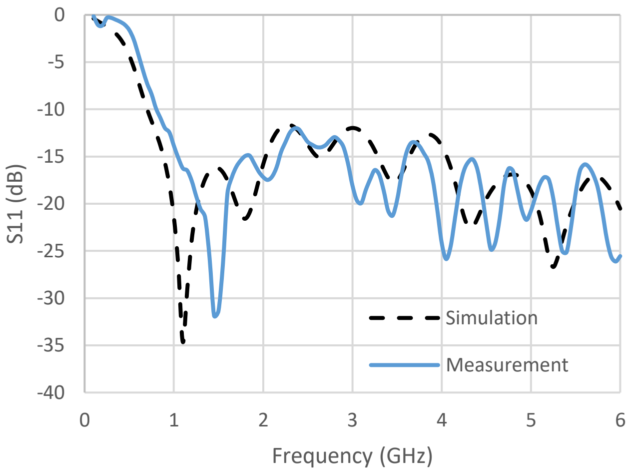

Figure 8. Comparison of S_{11} measurement results between the actual measurement and simulation of the Design B discone antenna

The comparison of S_{11} measurement between the discone antenna designed in the previous study [23] and the Design B discone antenna is shown in Figure 9. At the frequency of 0.915 and 2.4 GHz, the S_{11} values of the Design B discone antenna were higher, but the Design B discone antenna still had good performance because the S_{11} values remained below -10 dB. Meanwhile, at the 5.2 GHz frequency, the S_{11} value of the Design B discone antenna was better than that of the previous research discone antenna, whose value was above -10 dB. Similarly, at 5.8 GHz, the S_{11} value of the Design B discone antenna was better than that of the previous research discone antenna. This shows that the optimized Design B discone antenna could function in the operating frequency range for electromagnetic interference measurement in wireless medical equipment. Based on the data and simulation analysis carried out previously, the greater the diameter of the cone used in the Design B discone antenna, the smaller the S_{11} value. A description of the comparison of S_{11} values within the wireless frequency coverage in medical equipment can be seen in Table III.

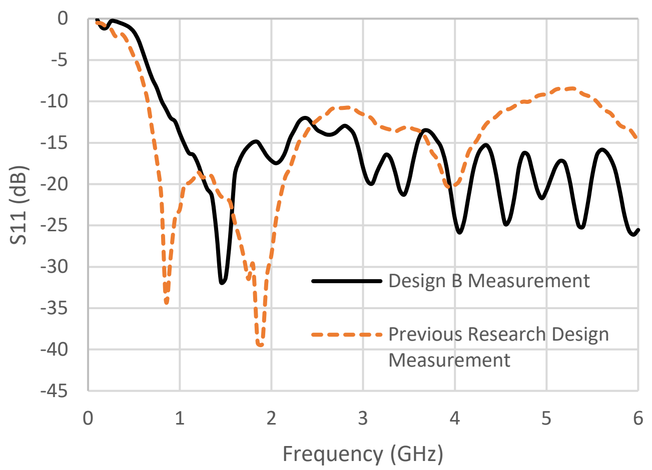

Figure 9. Comparison of the characterization of S11 from the measurement results between the Design B discone antenna and the previous research design [23]

TABLE III. COMPARISON OF S_{11} VALUES AT WIRELESS MEDICAL DEVICE FREQUENCY BETWEEN THE PREVIOUS RESEARCH DESIGN [23] AND THE DESIGN B DISCONE ANTENNA

Frequency (GHz)	Value of S_{11} (dB)	
	Previous Design	Design B
0.915	-27.757	-12.745
2.4	-13.429	-12.114
5.2	-8.551	-17.443
5.8	-12.869	-20.833

The discone antenna in this study can also be compared with the discone antenna in [21], even though the application is different. The material and some of the design steps used are the same, and the cut-off frequencies are not significantly different. However, the thicknesses of the cones are different. This designed discone antenna in this study had better S_{11} values than the discone antenna design in [21]. The discone antenna design in [21] had worse S_{11} values at around 2.1 and 3.1 GHz because no optimization was carried out. On the other hand, this study performed optimization on its discone antenna design, which resulted in lower S_{11} values at frequencies that were below those of the previous discone antenna design. Meanwhile, the thickness of the material used cannot be considered a major factor in comparing the performance of the two designs because, according to how it works, the radiation generated by the disc will be reflected only on the outside of the cone. As a result, the thickness of the cone does not really affect the performance.

After the S_{11} values were known, the next step was to measure the radiation pattern. The measurement and simulation of the discone antenna radiation patterns are shown in Figure 10. Based on the comparison, in general, the radiation patterns, when the discone antenna was measured and simulated at all frequencies, had some differences and similarities, and most of the time both were omnidirectional. In conclusion, the radiation pattern met the pattern criterion for a discone antenna that is suitable for measuring electromagnetic interference. This was most likely because the discone antenna was made manually so that the antenna shape was less symmetrical in the disc and cone parts.

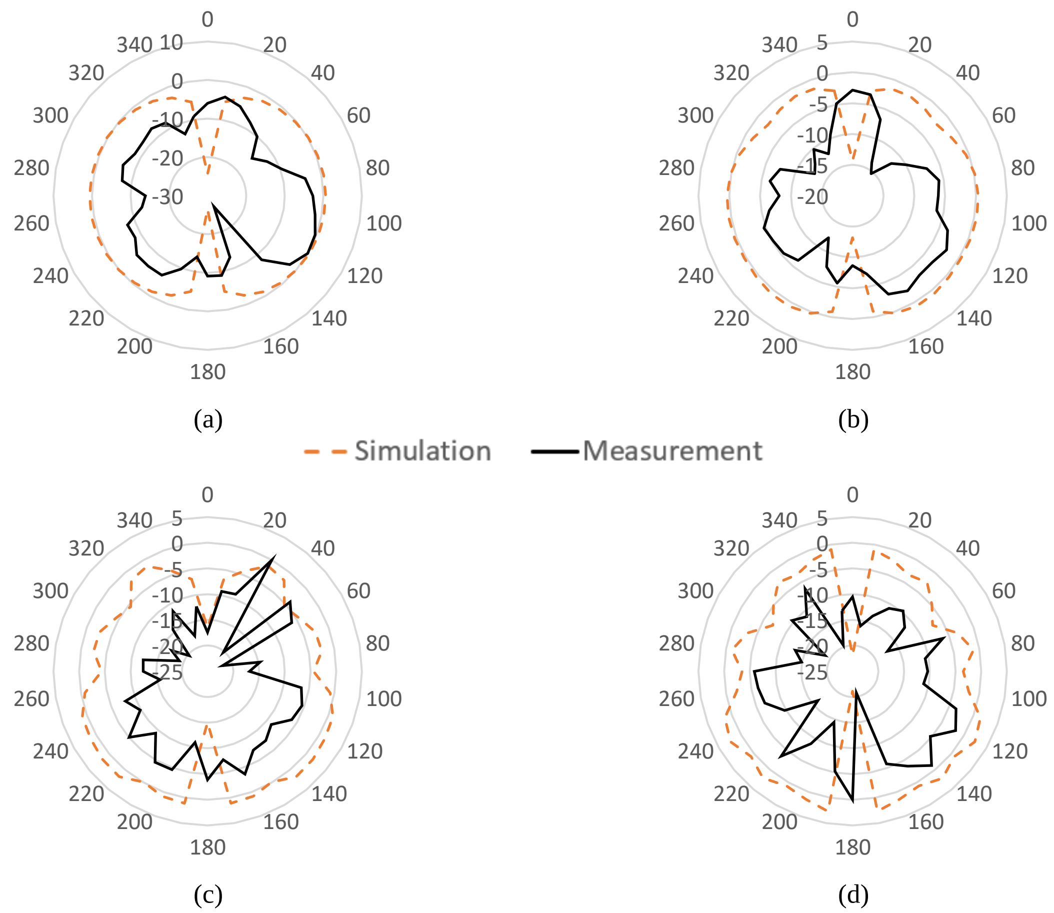

Figure 10. The Radiation Pattern of the Design B discone antenna at the frequencies (a) 0.915 GHz, (b) 2.4 GHz, (c) 5.2 GHz, dan (d) 5.8 GHz

Table IV presents the results of the gain measurement on the discone antenna at each wireless medical device frequency using the gain-comparison method. All the gain values were negative, which means that there was a loss in the discone antenna that was made. As for the antenna factor, as previously explained, it is an important requirement that must be known in the antenna used for measuring electromagnetic interference and electromagnetic compatibility. With the antenna factor, the magnitude of the electric field strength generated by a piece of equipment that has the potential to cause damage to other electronic equipment is known. The antenna factor of the Design B discone antenna is also shown in Table IV.

TABLE IV. DESIGN B ANTENNA DISCONE GAIN AND ANTENNA FACTOR

Frequency (GHz)	Gain (dB)	Antenna Factor (dB/m)
0.915	-20.03	24.740
2.4	-27.49	25.003
5.2	-16.76	30.651
5.8	-25.56	35.526

B. Medical Device Electromagnetic Interference Measurement Modeling

Table V and Figure 11 are proofs that the designed discone antenna could be used for measuring electromagnetic interference in medical devices. Table V provides the measurement results of the discone antenna against the modeling of electromagnetic interference sources with various variations of the amplitude of the transmission signal. In the table, there is a value of the electric field strength received by the discone antenna after adding the antenna factor. The summing up with the antenna factor shows that the value of the electric field strength had been validated using a comparison antenna and was considered the final, accurate value of the measurement. As the value of electric field strength is also a measure of electromagnetic interference, it is concluded that this discone antenna can be applied to electromagnetic interference measurements. Meanwhile, Figure 11 shows that the discone antenna is omnidirectional, so it can be used to measure electromagnetic interference.

As shown in Table V, the unit of the receiving amplitude was converted from dBm to dBμV to adjust to the unit of the antenna factor for the purpose of finding the electric field strength value. Electric field strength is the emission of radiation which, at a certain magnitude, will cause electromagnetic wave interference and can cause performance damage to electronic equipment. Figure 11 shows that in the angle range 160–230°, the radiation emission from the electromagnetic wave interference source model had a greater value than that captured on this discone antenna.

TABLE V. DISCONE ANTENNA MEASUREMENT RESULTS IN ELECTROMAGNETIC INTERFERENCE SOURCE MODELING

Amplitude of Transmission (dBm)	Amplitude of Receiver (dBm)	Amplitude of Receiver (dBμV)	Field Strength (dBμV/m)
0.0	-72.49	34.51	59.513
2.5	-69.03	37.97	62.973
5.0	-67.52	39.48	64.483
7.5	-64.89	42.11	67.113
10.0	-63.07	43.93	68.933

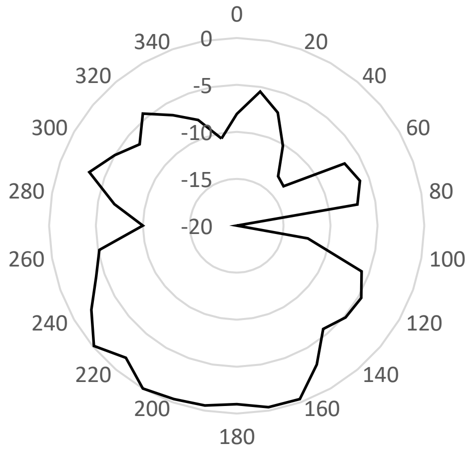

Figure 11. The radiation pattern from the inverted F antenna as a model of interference electromagnetic source

C. Mitigation of Electromagnetic Interference in Medical Devices

It was mentioned at the beginning of the paper that this discone antenna was optimized so that it can be applied to interference measurements in medical equipment, and in the end, the data obtained are used to mitigate the interference that occurs. In [31], a risk assessment was carried out for mitigation in the hospital environment to prevent medical equipment from being exposed to interference from the outside or other medical equipment. The stages of this mitigation included measuring the hospital environment, which in the study used discone antennas, followed by identifying the characteristics of electric field sources in medical equipment and external sources. The measurement in a previous study [27] found a significant change in value from -67 dBm to -72.5 dBm at the 2.432 GHz frequency originating from a Wi-Fi signal. Then, at that frequency, a deeper measurement was carried out within 24 hours to obtain a maximum value of -45 dBm. The measurement data were then analyzed statistically. The results of the statistical analysis were then made into a matrix and classified into several risk zones, namely, low, medium, and high. This information is used as data to make adjustments to the location of medical devices and sources of interference and to evaluate medical equipment manufacturers and hospital rooms.

IV. CONCLUSION

Optimization of the discone antenna design by varying the dimension of each parameter and analyzing the S_{11} results through simulation has been successfully carried out. The results of the analysis of the characteristics of S_{11} for each dimension variation in each parameter are indicators of the optimization of the discone antenna. The success of the optimization carried out was evidenced by the discone antenna created based on the optimized design having S_{11} values below -10 dB in the wireless frequency range for medical equipment (0.915–5.8 MHz), which was better than previous studies. In addition, the resulting radiation pattern is omnidirectional, which meets the expectation. The discone antenna was designed to be used for measuring electromagnetic interference in medical devices. Based on the results of the modeling carried out, it could capture interference signals accurately at various amplitudes and in all directions (omnidirectional), especially at the 2.4 GHz frequency. The accuracy of the measurement results was indicated by the final electric field value, which was calculated taking into account the antenna factor value, in which case the antenna factor was obtained from validation results using the gain-comparison method. The optimization in this study was carried out only by varying the dimensions of the discone antenna. Therefore, in further research, optimization and development can be carried out by varying the shape or material used.

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REFERENCES

[1] S. Chakraborty and V. Bhatt, "Mobile IoT adoption as antecedent to Care-Service Efficiency and Improvement: Empirical study in Healthcare-context," *J. Int. Technol. Inf. Manag.*, vol. 28, no. 3, pp. 101–120, 2019.

[2] B. Pradhan, S. Bhattacharyya, and K. Pal, "IoT-Based Applications in Healthcare Devices," *J. Healthc. Eng.*, vol. 2021, Article ID 6632599, pp. 1 - 18, 2021. https://doi.org/10.1155/2021/6632599.

[3] S. Ariyanti, "Kajian Tekno-Ekonomi pada Telehealth di Indonesia Techno-Economic Study on Telehealth in Indonesia," *Bul. Pos dan Telekomun.*, vol. 15, no. 1, pp. 43–54, 2017.

[4] A. Aborujilah and A. F. M. Elsebaie, "IoT MEMS : IoT-Based Paradigm for Medical Equipment Management Systems of ICUs in Light of COVID-19 Outbreak," *IEEE Access*, vol. 9, pp. 131120–131133, 2021, doi: 10.1109/ACCESS.2021.3069255.

[5] X. Ding *et al.*, "Wearable Sensing and Telehealth Technology with Potential Applications in the Coronavirus Pandemic," *IEEE Rev. Biomed. Eng.*, vol. 14, pp. 48–70, 2021, doi: 10.1109/RBME.2020.2992838.

[6] F. Alshehri and G. Muhammad, "A Comprehensive Survey of the Internet of Things (IoT) and AI-Based Smart Healthcare," *IEEE Access*, vol. 9, pp. 3660–3678, 2021, doi: 10.1109/ACCESS.2020.3047960.

[7] S. Chung, J. Yi, and S. W. Park, "Electromagnetic interference of wireless local area network on electrocardiogram monitoring system: A case report," *Korean Circ. J.*, vol. 43, no. 3, pp. 187–188, 2013, doi: 10.4070/kcj.2013.43.3.187.

[8] V. Ramos *et al.*, "Electromagnetic Assessment of UHF-RFID Devices in Healthcare Environment," *Appl. Sci.*, vol. 12, no. 20: 10667, pp. 1-22, 2022, doi: 10.3390/app122010667.

[9] P. M. Mariappan, D. R. Raghavan, S. H. E. Abdel Aleem, and A. F. Zobaa, "Effects of electromagnetic interference on the functional usage of medical equipment by 2G/3G/4G cellular phones: A review," *J. Adv. Res.*, vol. 7, no. 5, pp. 727–738, 2016, doi: 10.1016/j.jare.2016.04.004.

[10] T. Wisaratapong and N. Pechaksorn, "Effects of electromagnetic interference produced by smartphones on patients with permanent pacemakers (EMS-PPM study) ESC Congress 2022 – Barcelona , Spain," *Eur. Heart J.*, vol. 43, Issue Supplement_2, p. 650, October, 2022.

[11] N. D. Badizadegan, S. Greenberg, H. Lawrence, and K. Badizadegan, "Radiofrequency interference in the clinical laboratory: Case report and review of the literature," *Am. J. Clin. Pathol.*, vol. 151, no. 5, pp. 522–528, 2019, doi: 10.1093/ajcp/aqy174.

[12] C. Schwabe, "Investigating Electromagnetic Interference of Oscillating Ventilators by Radio Transmitting Devices," *J. Clin. Eng.*, vol. 44, no. 4, pp. 186–198, 2019, [Online]. Available: https://www.embase.com/search/results?subaction=viewrecord&id=L630643557&from=export%0Ahttp://dx.doi.org/10.1097/JCE.0000000000000363.

[13] Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement, International Standard CISPR 11 Edition 6, 2015.

[14] Medical electrical equipment - Part 1-2: General requirements for basic safety and essential performance - Collateral Standard: Electromagnetic disturbances - Requirements and tests, IEC 60601-1-2, 2014.

[15] M. Das, R. Vogt-Ardatjew, B. Van Den Berg, and F. Leferink, "Risk-based EMC Approach in Hospital Environment," *2020 IEEE Int. Symp. Electromagn. Compat. Signal/Power Integrity, EMCSI 2020*, pp. 676–680, 2020, doi: 10.1109/EMCSI38923.2020.9191637.

[16] K. K. Mistry, P. I. Lazaridis, Z. D. Zaharis, T. D. Xenos, E. N. Tziris, and I. A. Glover, "An optimal design of printed log-periodic antenna for L-band EMC applications," in *2018 IEEE International Symposium on Electromagnetic Compatibility and 2018 IEEE Asia-Pacific Symposium on Electromagnetic Compatibility, EMC/APEMC 2018*, pp. 1150–1155, 2018, doi: 10.1109/ISEMC.2018.8393968.

[17] D. Ratan Sanjay and S. Azeemuddin, "A comprehensive review of high voltage wideband and ultra-wide band antennas for IEMI applications," *Eng. Res. Express*, vol. 3, no. 1, pp. 1-24, 2021, doi: 10.1088/2631-8695/abd873.

[18] M. B. Perotoni and M. S. Vieira, "Increasing the interest in antennas and microwave courses," *Int. J. Electr. Eng. Educ.*, vol. 56, no. 3, pp. 193–207, 2019, doi: 10.1177/0020720918790098.

[19] E. Chuma, Y. Iano, L. Roger, and S. Carvalho, "A Novel UWB Antenna for a Broadcasting Television System," *SET Int. J. Broadcast Eng.*, vol. 2017, no. 3, pp. 62–65, 2017, doi: 10.18580/setijbe.2017.8.

[20] B. W. Martins, R. M. S. De Oliveira, V. Dmitriev, F. J. B. Barros, and N. R. N. M. Rodrigues, "Indoor characterization of power delay profile using equivalent antenna representation in uniform FDTD lattices," *J. Microwaves, Optoelectron. Electromagn. Appl.*, vol. 16, no. 1, pp. 1–15, 2017, doi: 10.1590/2179-10742017v16i1704.

[21] M. G. Tampouratzis, D. Vouyioukas, D. Stratakis, and T. Yioultsis, "Use Ultra-Wideband Discone Rectenna for Broadband RF Energy Harvesting Applications," *Technologies*, vol. 8, no. 2:21, pp. 1 - 13, 2020, doi: 10.3390/technologies8020021.

[22] R. Umar *et al.*, "Performance Analysis of Discone Antenna for Radio Frequency Interference (RFI) Measurement," *Int. J. Eng. Technol.*, vol. 7, no. 3.14 Special Issue 14, pp. 333–336, 2018.

[23] H. D. Prananto and A. Munir, "Development of Wide band Discone Antenna for Medical Devices Interference," 2021 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC), Nusa Dua - Bali, Indonesia, 2021, pp. 1-4, doi: 10.1109/APEMC49932.2021.9596811.

[24] M. Dionigi, M. Mongiardo, and C. Tomassoni, "Investigation on the Phase Center of Ultra Wideband Monopole Antennas," in *German Microwave Conference Digest of Papers*, 2010, pp. 59–62, doi: 10.1007/978-0-387-77845-7_22.

[25] A. A. Abdulhameed and Z. Kubík, "Design a Compact Printed Log-Periodic Biconical Dipole Array Antenna for EMC Measurements," *Electron.*, vol. 11, no. 18, pp. 1–20, 2022, doi: 10.3390/electronics11182877.

[26] IEEE Recommended Practice for Antenna Measurements, IEEE Std. 149TM, 2021.

[27] M. Das, R. Vogt-Ardatjew, B. van den Berg and F. Leferink, "Studying the Probability of EMI through Time-Variance Behavior of Environment on Medical Devices," 2021 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC), Nusa Dua - Bali, Indonesia, 2021, pp. 1-4, doi: 10.1109/APEMC49932.2021.9596842.

[28] L. Y. Sabila, T. Prakoso, and M. A. Riyadi, "Miniaturized Spiral Planar Inverted F Antenna of 2.4 GHz Using Design of Experiment Method for EEG-based Controlled Prosthetic Arm," *J. Elektron. dan Telekomun.*, vol. 22, no. 1, pp. 23-29, 2022, doi: 10.55981/jet.445.

[29] S. Kumar *et al.*, "A Wristwatch-Based Wireless Sensor Platform for IoT Health Monitoring Applications," *Sensors*, vol. 20:1675, pp 1 - 25, 2020.

[30] M. Das, R. Vogt-Ardatjew, B. Van Den Berg, and F. Leferink, "Time-efficient EMI Risk Evaluation Method in a Hospital Environment," *2021 Jt. IEEE Int. Symp. Electromagn. Compat. Signal Power Integrity, EMC Eur. EMC/SI/PI/EMC Eur. 2021*, pp. 857–861, 2021, doi: 10.1109/EMC/SI/PI/EMCEurope52599.2021.9559356.

[31] M. Das, R. Vogt-Ardatjew, B. Van Den Berg, and F. Leferink, "Risk Management Plan For the Hospital Environment," *IEEE Int. Symp. Electromagn. Compat.*, vol. 2022-Septe, pp. 828–833, 2022, doi: 10.1109/EMCEurope51680.2022.9901309.