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The Development of Miniaturized Wearable DRA with a Wideband Circular Polarization

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Abstract: In wireless communication, wearable technology has increased rapidly due to its higher demand in various industries with the benefits of the unconstrained movement freedom a Wireless Body Area Network (WBAN) offers. However, to design a wearable antenna is challenging due to the antenna that must be designed in a compact size with the ability to transmit low power loss during transmission and maintaining the performances of the communication link. In this research project, the antenna is designed singly feed and in a spiral shaped conformal copper strips are used to excite the DRA. The simulated result by CST software stated that S11 below -10 dB is 6.66% with Axial Ratio below 3dB is approximately 5.26%. A prototype antenna is fabricated to validate the simulation result. Hence, the antenna design is beneficial for many people in improving human productivity in daily life in the evolution of WBAN.
Keywords: WBAN, Dielectric Resonator Antenna, Off-Body Communication

1.0 INTRODUCTION

Body centric wireless communication has been applied for indoor and outdoor in wireless communication, that covers a wide variation of situation such as sports applications to monitor the athletes or communication for rescue operations by the rescue team. The wearable technology in wireless communication is a fast developing area which has a lot of benefits due to the unconstrained movement freedom a Wireless Body Area Network (WBAN) offers. A WBAN is a wearable computing device that are invented to be placed eitherin the human body or a surface mounted on the human body in a desired position to transmit the data produced by the wearable devices to a WLAN or to the Internetby using a wireless connection. [1] However, to designa wearable antenna is challenging due to the antenna that must be designed in a compact size with the ability to transmit low power loss during transmission and maintaining the performances of the communication link.

Rescue operations, health care and sports are the example of industries that make higher demands on implementing the wearable devices in daily life these days. Most of the current wearable devices in wireless communications are using microstrip patch antenna that built on the printed circuit board (PCB) substrate. The use of microstrip antennas is common in all fields and areas and now, due to their light weight, low cost of substrate content and simple manufacturing, they [2] arebooming in commercial aspects. Nevertheless, due to low gain, high substrate losses and low radiation efficiency at higher frequencies, the limitation of narrowimpedance bandwidth will cause poor performances from the antenna. [3]-[4]

Next, the electromagnetic waves energy used to transmit the signal is soaked up by the human body for existing antenna. There are differences in designing wearable antenna and non-wearable antenna. Since a wearable antenna is going to be placed near the human body, the biggest challenge to design it is to overcome the fact that the human body is a lossy material towards electromagnetic waves. [1][5][6] In other words, the human body will suck up the energy of the electromagnetic waves. It will reduce the efficiency of theantenna since a high-power loss will lead to only a small range of signals can be transmitted between transceiver. [7]

The circularly polarized antenna is much more preferred as compared to linearly polarized antenna because of its insensitivity to the transmitter and receiver orientation. The linearly polarized antenna waves broadcast on a single plane either vertical or horizontal only. A wave in circular polarization radiates energy in the horizontal planes, vertical planes and in every plane in between that will offer greater possibility of successful communication link. Furthermore, the current wearable applications are mostly designed in frequently used frequency which is 2.4GHz which is likely to have the interference with many other wireless devices.

For this proposed design, the wideband frequency technology is implemented. Wideband is when the percentage of return loss S11 is more than 5% but less than 15% based on this research project. The advantages of using the wideband systems are it is much more reliable in high data rate as hundreds of Mbps, low power transmit, robustness to interference and large channel capacity that can support wide bandwidth. [3][8] In addition, the circular polarization of the wearable antenna gives higher probability of a successful link as it is transmitting on all planes and will make changes with the movement [9-10].

DRA offers more attractive features compared to the microstrip patch antenna. DRA is able to be in insufficient geometrics comprising spherical, rectangular, cylindrical, half-split spherical, disk and hemisphere shaped. One of the advantages of dielectric resonator antenna is they can have lower losses and be more efficient as compared with metal antenna at high microwave and millimetre wave frequencies. [10] Moreover, DRA is being used as wearable antenna for BAN applications. Thus, the development of miniaturized wearable Dielectric Resonator Antenna with a wideband circular polarization is designed and discussed in this research work in detail which has benefits of improving human productivity in daily life.

2.0 LITERATURE REVIEW

The major aspects implemented in this research work are by considering the pros and cons of the previous papers. The past research that is related to this research is an important task to be discussed since this antenna design is designed to improve the drawbacks obtained by the existing antenna.

A DRA becomes a resonant radiator and can be manufactured into whatever shape the designer desires by using a low loss dielectric material. The common shape that is formed by the DRA are rectangular, cylindrical hemispherical and many more shapes and itis much simpler to produce with the rectangular form and additional dimensional parameters are offered as theextra degrees of design freedom. [11]-[14]

Based on the previous research paper published by [15], the proposed antenna is designed to perform as a shoulders button. The wearable dielectric resonator antenna that used in the research comes in the form of a ring-shaped dielectric resonator and is managed to carry on support that operates as ground plane associated with device of feed. Therefore, the disadvantages from the antenna design are that the DRA cutting is quite complicated and tiring task since it is ring-shaped DRA. Moreover, the antenna operates in linear polarization that will broadcast on single plane only. Therefore, the antenna cannot properly maintain the possibility of the successful communication link. The designated antenna in the form of ring-shaped is shown in the figure 2.1 below.

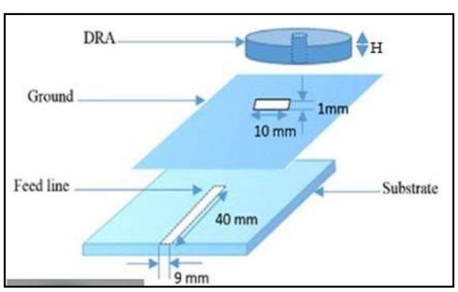

Figure 2.1: Shoulder button antenna

Next, based on second research paper published by [16], the antenna has been designed in a compact cylindrical shape. The proposed antenna is a cylindrical dielectric resonator antenna (CDRA) for Industrial, Scientific and Medical (ISM) applications in compact size. The dielectric resonator antenna productis then placed over a U-shaped metal stripe. However, the drawbacks discovered from the research are that the DRA cutting is a complicated task to do since it iscylindrical shape and need to be obtained together with the cylinder curve. Moreover, the frequency used by the designated antenna is operate in 2.4GHz that might be any interference occurs with other wireless devices since the frequency is same as the standard frequencyfor most wireless devices. In addition, the antenna is operating in linear polarization that can degrade the performances in terms of transmission link between transmitter and receiver. The designated antenna is shown in figure 2.2 below.

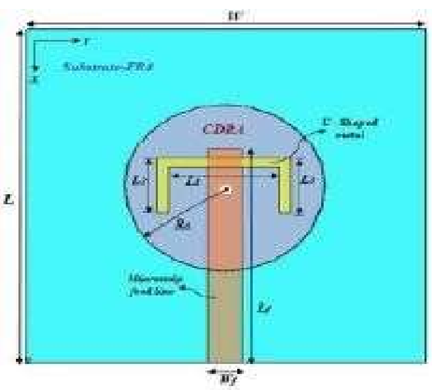

Figure 2.2: U-shaped CDRA

Other than that, third research paper published by [17] shows that the DRA is fabricated in cylindrical shape. The DRA is made of polyester Resin which operates at 5.4 GHz for Wi-MAX and WLAN. The wearable material of indigo blue jeans is used as the substrate for the flexible DRA. Therefore, since it is cylindrical in shape, the DRA cutting and shaping process is a complicated task to do since the material is hard to be cut off. Moreover, the antenna is in compact sizes which are millimeters in unit, the antenna need to be identical in terms of dimensions for both simulation and prototype to obtain better results performances. The microstrip fed line is used for the transmission that will produce an air gap in the middle of the DRA and substrate. Besides, other drawback is that it is also operating in linear polarization that can degrade the performances in terms of transmission link between transmitter and receiver. The designated antenna is shown in figure 2.3 below.

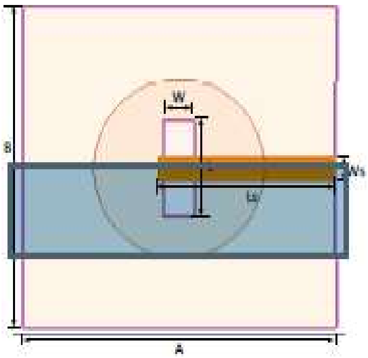

Figure 2.3: Cylindrical shape DRA

Lastly, the fourth research paper published by [2] demonstrated that the microstrip antenna is used for the preliminary development of a wearable textile microstrip patch antenna operating for wireless bodyarea network (WBAN) at the frequency center of 2.4 GHz. Therefore, the usage of that frequency can cause interference between other wireless devices in terms of the same frequency used. The usage of the microstrip patch antenna itself have many drawbacks such as low gain, narrow bandwidth and surface wave excitation that will reduce the radiation efficiency compared to the DRA. In addition, the designated antenna also operating in linear polarization. The designated antenna is shown in figure 2.4 below.

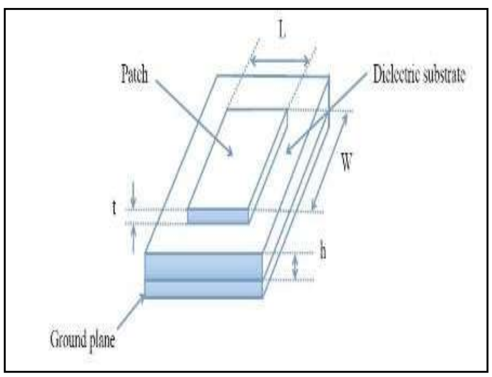

Figure 2.4: Microstrip patch antenna

Therefore, based on the research papers discussed above, a miniaturized wearable DRA with a wideband circular polarization is produced to overcome the drawbacks produced by existing antenna for improving human productivity in daily life for Wireless Body Area Network (WBAN). The shape used for the DRA is rectangular shape since it is flexible compared to other shapes as it is characterized by three independent geographical dimensions which are width, length and height.

3.0 METHODOLOGY

3.1 Background of Antenna Design

The size of DRA can be minimized easily thus it is used in this research project. The material used in making the DRA in this research project is Alumina, with a permittivity that is equal to 10. It can be seen thatDRA size is directly proportional to its permittivity [12][13]. For that reason, the size of DRA can easily be reduced ever since the permittivity of DRA used is high that is equivalent to 10. [13] Conversely, it is stated that the higher the permittivity, the harder it will be to cutthe DRA. Therefore, the DRA can still be cut by consuming a diamond cutter even though thepermittivity of the DRA used is high. In addition, the DRA is designed in rectangular shape that makes the DRA easier to be cut. In this research, the dimension of the DRA is following the research from [18].

3.2 S11 parameter graph below -10 dB

In this research, S11 graph below -10dB is highlighted as it indicates that the antenna has low power loss during transmission. By calculating the value of S11 based on return loss mathematical formula, S11 below - 10dB indicates 90% of the power will be radiated into electromagnetic waves and only 10% of the power will be reflected back. Equation (1) the return loss formula applied. Based on the formula, RL refers to the Return Loss value, Pin refers to the Incident Power and Pref represents the Reflected Power.

$$RL = 10 \log \frac{Pin}{Pref} \tag{1}$$

Return loss shows much of the incident power the antenna represents related to mismatch as seen on the mathematical formula above for return loss. If properly paired, an ideal antenna can radiate all of the energy without even any reflection.

As discussed above, S11 is also sometimes referred to as return loss, which is simply S_{11} but in the positive sign. Thus, when S11 is -10dB, then the value of return loss is equal to 10dB.

As calculated above, 10% of the power is reflected when S11 = -10dB which is considered as low power reflected. This indicates that the 90% of the power will be radiated by the antenna into electromagnetic waves. Hence, it is validated that 90% of the power is transmitted into the electromagnetic waves, which is resulting of good condition of the antenna since the reflected power is only 10% of the total power. [19][20]

3.3 Axial Ratio parameter graph below 3 dB

Next, the Axial Ratio graph below 3 dB is also highlighted in this research as it indicates that the antenna operate in circular polarization. As mentioned before, a circularly polarized wave radiates energy both in the horizontal and vertical planes and in every plane between them. The advantage of circularly polarizedantenna by comparing to linear polarized antenna is the reflectivity. Since circular polarized antennas send and receive in all planes, the signal strength is not lost, but istransferred to a different plane and is still utilized.

DRA is the best candidate to be used in designing the antenna as it is easier to control the polarization characteristics. Axial Ratio is clarified by means of the ratio in between minor as well as major axis of the polarization orbit [21]. To shows that the antenna operates in circular polarization, the minor and major axis should be identical to form a circle.

$$AR = \frac{\text{Major Axis}}{\text{Minor Axis}} \tag{2}$$

$$AR(dB) = 20 \log AR \tag{3}$$

To clarify that the antenna functions in circular polarization, the minor and major axis should be identical to form a circle, this means that the AxialRatio is equal to 1 or 0 in dB.

However, it is not easy to obtain the ideal valueof Axial Ratio = 1 (0dB) to clarify the circular polarization antenna operation. Thus, the antenna is designed below 3dB for the Axial Ratio. According to [21][22], the Axial Ratio below 3dB is tolerable to specify that the antenna is circularly polarized. However, to obtain a good performance of the designated antenna, it is better for a circularly polarized antenna to obtain the Axial Ratio as nearer to 0 dB.

3.4 Block Diagram and Flowchart Process of Research

Firstly, the development of this research project starts with organizing the dimensions of the DRA that is same as [18] to make up the research. As mentioned before, three independent geometrical dimensions which are height, length and width is used in designing the dimensions of the rectangular DRA. Next, the optimizations of the copper strips parameter are being done which is the height and length of the copper strips. After that, the dimensions of the copper ground are also being set up by considering the height and length of the copper ground.

Next, the CST software will produce both graph of S11 and Axial Ratio. For S11 graph, the result obtained need to be below -10dB while for Axial Ratio graph, the result obtained must be below 3dB. If the results obtained from the simulation is not following the requirement above which are S11 graph below -10dB and AR graph below 3dB, the optimizations of the copper strips need to be recreate again and repeateduntil the graphs result are following the requirements stated above. This is because if the S11 graph obtainedis higher than -10dB, the designated antenna will produce higher power loss. In addition, if the AR graph obtained is higher than 3dB, the designated antenna will not operate in circular polarization.

After the S11 graph and AR graph obtained fulfills the requirements, the next process is by doing the calculation of the overlapped bandwidth obtained of S11 less than -10dB and the AR graph less than 3dB. The parameter sweep process is implemented so that the dimensions for the antenna can be determined based on the greater overlapped bandwidth. The condition is that the calculation for overlapped bandwidth of S11 graph and AR graph within the same frequencies is higher than 5%. If the calculation obtained does not meet the requirement which is the overlapped bandwidth less than 5%, then the process of optimizing the copper strips need to be redo and repeated until the overlapped bandwidth is more than 5%. Once the designated antenna satisfy the condition, the CST simulation is over and the fabrication and measurement of the prototype designated antenna is being started by following the exact dimensions of the antenna from the simulation.

After fabrication of prototype antenna is successfully developed, the result of S11 graph is recorded by using Network Analyzer for near field region and the Axial Ratio is recorded in the anechoic chamber. The next process is the validation of results for both graph between the simulation antenna and fabricated antenna. If the S11 graph created by the fabricated antenna is incompatible with the simulated antenna, the fabricated antenna is required to be refabricated until it is approximately identical with the simulation antenna.

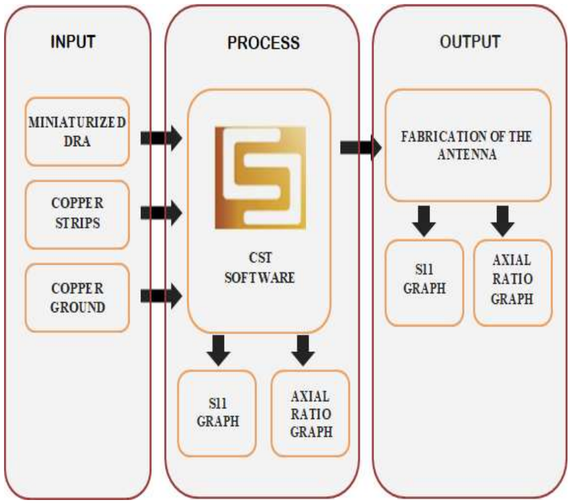

Figure 3.4: Block Diagram of Research

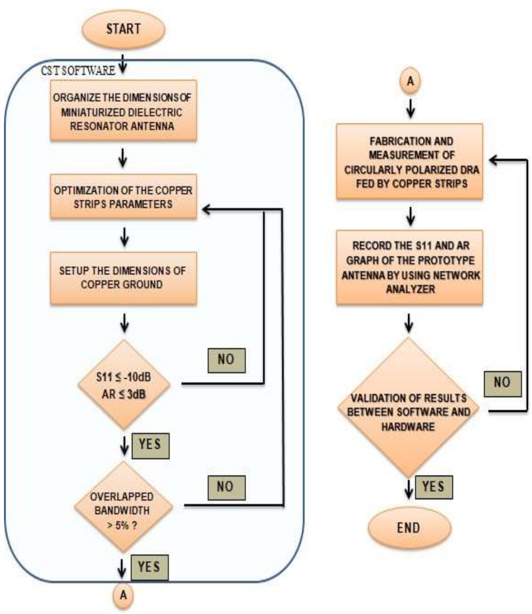

Figure 3.5: Flowchart of Research

4.0 RESULTS

4.1 Simulation Results

A total of 83 simulations have been simulated for the purpose of designing an antenna that meets all of the objectives mentioned in the previous section. The antenna is designed singly feed and a unique spiral shaped conformal copper strips are used to excite the DRA. The antenna proposes a simulated S11 below -10 dB of 6.66 % while the Axial Ratio bandwidth below 3 dB is approximately 5.26%. In addition, the antenna designed in this research project managed to achieve an overlapped bandwidth of ~7.41% which indicates that the antenna are able to radiate 90% of the power into electromagnetic waves in circular polarization along the bandwidth. A prototype antenna is fabricated to validate the simulation result.

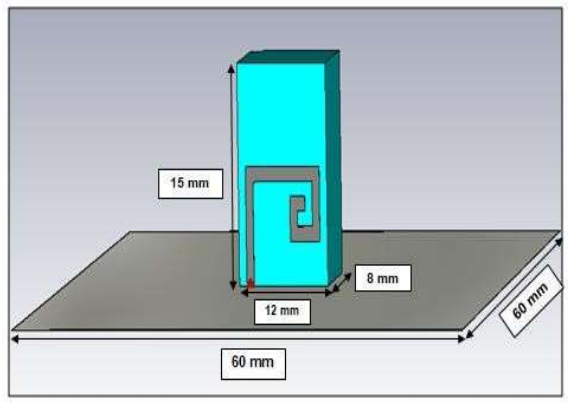

Figure 4.1: Dimensions of Dielectric Resonator Antenna and Ground Plane

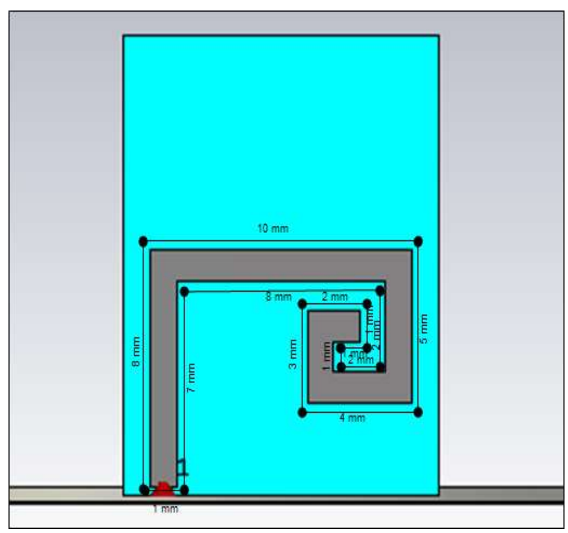

Figure 4.2: Dimensions of conformal copper strips

4.2 Fabricated Antenna Prototype

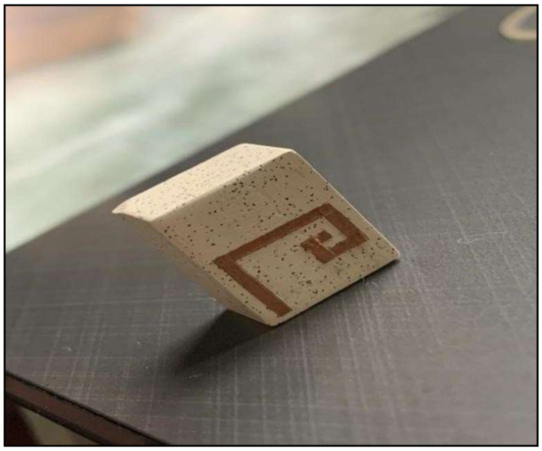

Figure 4.3: Fabricated Antenna Prototype following the dimensions of simulated antenna

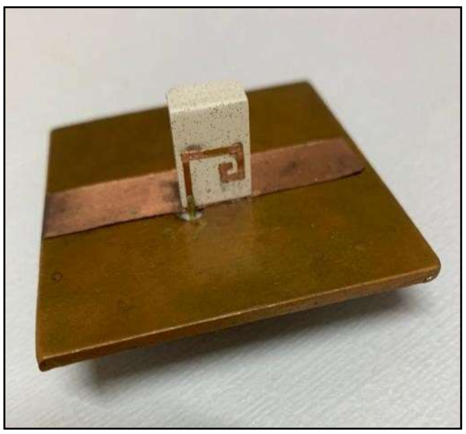

Figure 4.4: Fabricated Antenna Prototype attached on ground plane

4.3 Validation of Antenna Prototype

Figure 4.5: Validate the fabricated antenna on human body

4.4 Results on S11 and Axial Ratio for both simulated and measured antenna

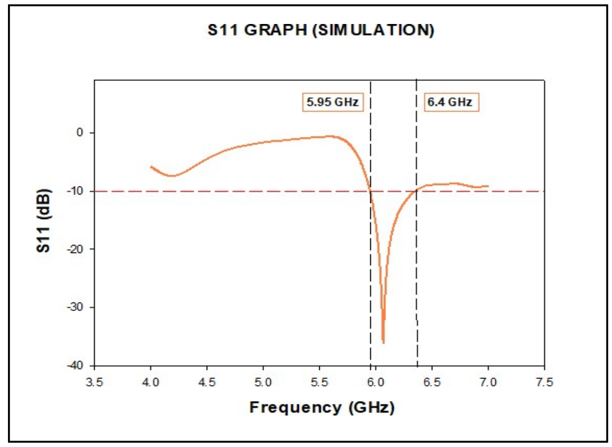

Figure 4.6: S11 graph below -10 dB for simulated result

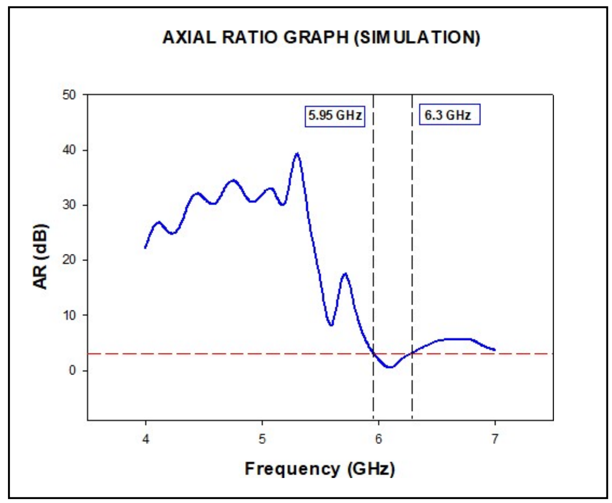

Figure 4.7: Axial Ratio graph below 3 dB for simulated result

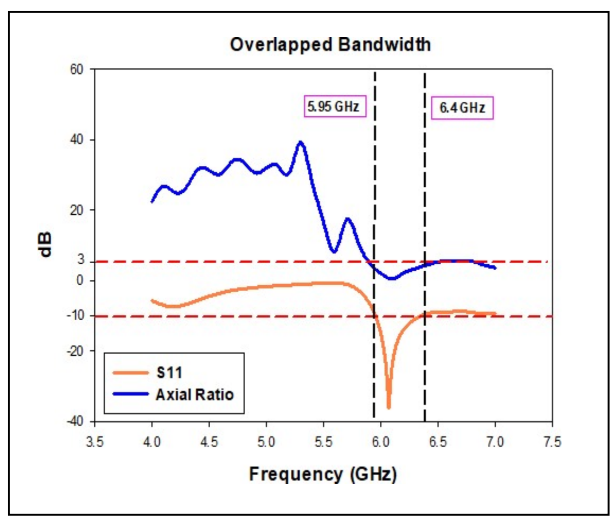

Figure 4.8: Overlapped bandwidth of simulated result for S11 and Axial Ratio

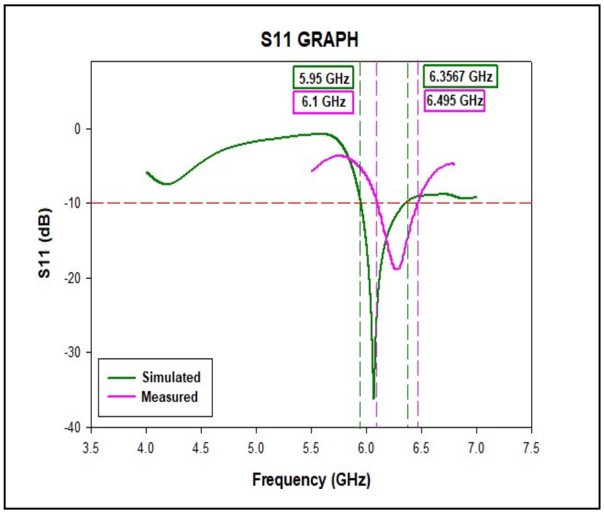

Figure 4.9 : Overlapped S11 and AR bandwidths

4.5 Discussion

A total of 83 simulations have been simulated for the purpose of designing an antenna that meets all of the objectives mentioned in the previous section. In the simulation, the dimensions and type of materials used for both DRA and ground plane are fixed, except for conformal copper strips. In the simulation, the dimensions and type of materials used for both DRA and ground plane are fixed, except for conformal copper

Based on the graph obtained for S11 and Axial Ratio graph, the S11 graph that achieved below -10dB indicates that the antenna has low power loss during transmission and Axial Ratio graph below 3dB indicates that the antenna is circularly polarized for establishing and maintaining the performance of the communication

The bandwidth is generally stated in terms of Fractional Bandwidth (FBW). FBW is used to define the wideness of a bandwidth by using the mathematical calculation method as shown in equation (4):

$$\text{FBW} = \frac{fu - fl}{fc} \quad (4)$$

Where,
f2 = Upper Frequency
f1 = Lower Frequency
fc = Resonant Frequency

Therefore, by applying the mathematical formula as stated in figure 4.10 above, it is shown that the 14th simulation has the widest overlapped bandwidth among all 83 simulations.

By referring to Figure 4.6, the upper frequency that obtained S11 below -10dB is at 6.3567 GHz while the lower frequency of the graph is at 5.9524 GHz. The lowest value of S11 is -36.269 dB which is located atthe frequency of 6.07 GHz. Thus, the bandwidth of S11 below -10dB is calculated to be 6.66%. By referring to Figure 4.7, the upper frequency that obtained AR below 3 dB is at 6.2849 GHz while thelower frequency of the graph is at 5.9647 GHz. The lowest value of S11 is 0.45 dB which is located at the frequency of 6.09 GHz. Thus, the bandwidth of ARbelow 3 dB can be calculated to be 5.26%:

The overlapped bandwidth is calculated based on the same frequency obtained when S11 graph is below -10 dB and Axial Ratio graph is below 3 dB. The overlapped bandwidth of S11 below -10dB and Axial Ratio below 3dB is illustrated in Figure 4.8 above. It can be seen that the bandwidth starts to overlap from 5.95 GHz until 6.4 GHz. This indicates that within this overlapped bandwidth, the antenna are capable to do these 2 things simultaneously which are radiate at least 90% of the power generated by source into electromagnetic waves or low transmission loss and operates in circular polarization. The overlapped bandwidth is calculated to be 7.41%.

The antenna designed in this research project managed to achieve an overlapped bandwidth of ~7.41% with simulated S11 bandwidth below -10dB approximately 6.66% and Axial Ratio bandwidth below 3dB of 5.26%. Referring to Figure 4.3, a prototype antenna is fabricated according to the 14th simulation to validate the simulation result.

Figure 4.9 shows the S11 graph below -10dB for both simulated and measured. The measured result is obtained by testing the prototype antenna using network analyser while the simulated result is obtained by simulating the simulated antenna using CST software. It is noticeable that the patterns of the graphs for both simulated and measured results are basically the same with two minimum points in each graphs.

It is clearly shown that the patterns of the graphs for both simulated and measured results are basically the same pattern with minimum points in each graph. On the other hand, the bandwidths for each graphare different. The bandwidth obtained by the simulated antenna is from 5.95 GHz until 6.4 GHz. In addition, as for the measured result, the bandwidth of the prototype antenna obtained from 6.1 GHz up to 6.495 GHz. It is clearly can be observed that the measured result is shifted slightly to the right from the simulated result.

By referring to calculation for both S11 graphs, it can be seen that the percentage of S11 bandwidth below -10dB for simulated result is higher compared to the S11 bandwidth below -10dB for measured result with a difference of 0.37%. The higher the percentage of the bandwidth, the wider the bandwidth as well as thebetter the performances of the antenna. This indicates that the bandwidth of simulated result is wider than the measured result.

The results obtained are proposed to be excellent. This is because the measured result is developed by testing the antenna in a real-life situation, where the conduction dielectric losses might exist due to the reflections losses at the interface between the fabricated prototype antenna and the transmission line, as well as due to the lossy nature of the transmissionline and the fabricated antenna. However, the simulated result is obtained without the presence of any conduction-dielectric losses.

In addition, the simulation itself consists of many assumptions including the materials used and the losses. Thus, the fact that simulated result is better than the measured result is expected and acceptable. Plus, the cutting of the copper strips might not be accurate since it is cut only by using the scissors. Therefore, a prototype antenna that is fabricated according to thedesign of the antenna in the 14th simulation is proved tobe able to meet the objectives of this research project. With that, the antenna is successfully designed.

5.0 CONCLUSION

In conclusions, this research project that focus in designing a miniaturized wearable DRA with a Wideband Circular Polarization is believed to be successful. By accomplishing the objectives, the existing problems that have been discussed can be overcome.The antenna is designed singly fed with a spiral shaped conformal copper strips are used to excite the DRA in order to operate in circular polarization. The antenna offers a simulated Axial Ratio bandwidth below 3dB of ~5.26%, with bandwidth of S11 below -10dB approximately 6.66%. In addition, the antenna in this research project managed to achieve an overlapped bandwidth of ~7.41%. The antenna can be used over a wide frequency range with the ability to have low power loss during transmission and maintaining the performances of the communication link by operating in circular polarization. Hence, a miniaturized wearable dielectric resonator antenna with wideband circular polarization is verified to be beneficial for many people in improving human productivity in daily life in the evolution of Wireless Body Area Network (WBAN).

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