Development of U-Shape Slot Wearable Antenna for In-Body Communications

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Abstract. The ability to have a communication with devices implanted inside a human body will cause a great improvement in current wireless medical applications technology. Wireless Capsule Endoscopy (WCE) is a medical device that could send images from inside of human’s intestines to the sensor outside the body. However, this device has few disadvantages like its location cannot be detected once it entered the body and it also cannot be control from outside the body. Considering these factors, an antenna that has the ability to penetrate into human body tissues for in-body communication is proposed. UWB system has considered as the solution for future in-body communication devices since current standard does not allow high data rate wireless connections between implanted nodes. Low part of UWB frequency band which is 3.1 GHz to 5.0 GHz is used in this research in order to reduce the attenuation through the body tissues as the frequency increase. The design of this antenna has taken in consideration of the propagation medium which is the human body tissues. Simulation for the designed antenna was done in CST Software. The size of this antenna is designed to be compact and wearable on human body. The substrate used for this antenna is cotton to ensure comfort once it is placed on the human body. The results that are considered in this research are the S11, directivity and gain of the antenna. Both simulation results and measured results are compared to evaluate the ability of this antenna.

1. Introduction
The ability to establish a link between outside the human body and inside the human will increase the opportunity to detect diseases or abnormalities suffered by patients. People suffering from chronic diseases have been increasing by year and the development of new technology is needed in order to treat these diseases efficiently and low in cost. Wireless Capsule Endoscopy (WCE) is a medical device used to detect diseases inside the gastrointestinal (GI) tract without causing any painful experience to the patient. However, this device still has few limitations which cause it to be less effective. The location of this capsule cannot be identified once it is swallowed by the patient. This is said to be the main disadvantage of WCE technology [1][2].

WCE is very reliable and the most effective way to diagnose GI tract and it is the only method that able to capture color images of the small intestines. Despite from its abilities to do such things, WCE cannot be controlled from the outside. The medical instructor cannot control WCE to go back to certain
position for re-diagnosis and the location of the WCE also cannot be detected. Doctors can only diagnose the patient after few hours after the capsule was swollen. Due to these drawbacks, few researches on antenna performance to detect the location of the WCE and to have communication inside the body have been made. On-body and in-body antenna means that one antenna is placed inside the human body, while the other will be placed on the human body [3]. Challenges in designing this type of antenna are both implanted antenna and on-body antenna cannot be placed too far from each other to ensure a proper link between them. Thus the size of the antenna needs to be small enough to be suitable to be placed on human abdomen. Besides, the antenna matching is important and should be ensured within the whole frequency band of interest. Also, the propagation of radio waves through the human body tissues is found as a challenge for this type of antenna [4].

Ultra Wide Band (UWB) has few main advantages like large bandwidth, low profile of its devices, low power consumption and so on which make it a potential candidate to be used for in-body communication [5]. The low part of UWB frequency is the best choice to overcome the problem [6] in which the attenuation through the human body tissues increases dramatically as the frequency increases as proclaimed by [7]. Therefore, this shows that not whole UWB frequency is needed for this project. Achieving large bandwidths with low-profile structure inside UWB is the advantage of slotted patch antenna [8]. Therefore this type of antenna is predicted to be the best candidate for this research. Apart from that, patch antenna can be made into compact size that is small enough to be put on human abdomen in order to make it comfortable for on-body purpose.

This project will be focused on the antenna used on-body that has the ability to penetrate through human body tissues. The frequency band used is UWB and results will be taken from the S11 reading. The directivity and the gain of the antenna will also be observed to ensure the efficiency of the designed antenna and the suitability to be used on the human body.

2. Antenna Development

The antenna was designed by using CST Software so that the results can be simulated directly. The simulation of CST Software is done in two conditions, free space condition and on human body condition. The purpose of having the antenna tested in two conditions is because the lack of computer’s capability to simulate the antenna if too many layers are present. Type of antenna use is patch antenna and its frequency band is low part of UWB which is from 3.1 GHz until 5.0 GHz. The design specification of the antenna is presented in Table 1. The design of the antenna is shown in Figure 1. The parameters for the antenna are tabulated in Table 2. Substrate that is used for this antenna is textile cotton. The conductive material that is used for the patch is Shieldit Super with thickness of 0.17 mm and electric conductivity of $1.18 \times 10^5$ and the substrate is Pure cotton with thickness of 1.6 mm and dielectric constant of 1.6.

| Parameter                  | Details       |
|----------------------------|---------------|
| Antenna type               | Patch antenna |
| Technique                  | Slotted       |
| Frequency (free space condition) | Range of 3.1 – 5 GHz |
| Frequency                  | 4.2 GHz       |
| Bandwidth                  | 600 MHz       |
| Radiation pattern          | Directional   |
Table 2. Dimensions for the antenna

| Parameter | Dimension (mm) | Parameter | Dimension (mm) |
|-----------|----------------|-----------|----------------|
| G_w       | 80             | P_2       | 36             |
| G_l       | 80             | P_3       | 46             |
| S_w       | 70             | P_4       | 24             |
| S_1       | 15             | P_5       | 24             |
| P_1       | 9              | P_6       | 6              |

Figure 1. Design of the antenna

By using CST Software, the antenna is designed in order to simulate the S11 results. In this part of process, as long as reflection coefficient of -10 dB can be obtained in any 3.1 to 5.0 GHz frequency, the result is acceptable. Figure 2 shows the interface of CST Software with the designed antenna on its menu. Once the desired frequencies are obtained, human tissues model is added onto the design. This is where the important part is since the objective of this project is to having an antenna that can work through human tissues. Since the objective of this antenna is to enable the connection inside the human body, human tissues model is simulated inside the CST Software according to the human tissues layers proposed by [9] and by using the dielectric constant for every layers by [7]. The simulated human tissue layers are as shown in Figure 3 and the parameters of every layers are tabulated in Table 3.

Table 3. Electrical properties for the tissues model

| Layer               | Dielectric constant | Conductivity (S/m) | Height (mm) |
|---------------------|---------------------|--------------------|-------------|
| Skin                | 33.13               | 4.420              | 1.5         |
| Sub-cutaneous fat   | 4.194               | 0.330              | 17          |
| Muscle              | 47.21               | 7.313              | 8.0         |
| Visceral fat        | 4.194               | 0.330              | 15          |
| Small intestines    | 47.83               | 9.368              | 0.5         |
The designed antenna was fabricated once the results from the simulation were as predicted. The designed antenna was tested out to see if it can properly work in real environment or not. The designed antenna was placed on a human body and a network analyzer was used as the device to measure the performance of the fabricated antenna. The reflection coefficient, $S11$ was measured.

The illustration of the measurement set up is shown in Figure 4. The illustration shows is the set up for measurement on human body condition. The antenna has been designed under two conditions, thus measurement on free space condition is also conducted.
2.2. On Body Condition Measurement Setup

Three persons have volunteered to be used as human sample for this project. All the humans are adult males. The antenna is placed on the abdomen of the human. Figure 6 shows the set up for the measurement on a human body. The results for the measurement on the human body are the one that will determine whether this antenna is suitable to be used for in-body communication or not. The results for these measurements and the comparison between simulated and measured results are presented in details in next section.

3. Results and Discussion

Results from the experiment are presented and discussed in this section. For simulation results, reflection coefficient and radiation pattern are presented while for measurement results, reflection coefficient for the fabricated antenna is presented.

The designed antenna has been tested in two different conditions, which are free space and on human body condition. Figure 7 shows the results for both conditions during simulation using CST software. Frequency shift occurred after the antenna is placed on the human body. This is due to the loss in the tissues layers. However, this antenna is aimed to work at 4.2 GHz with reflection coefficient of lower than -10dB when it is placed on a human body. The frequency band obtained was from 3.9 – 4.7 GHz and the impedance bandwidth (BW) is 800 MHz (44%). Impedance bandwidth is determined by -10 dB reflection coefficient. Simulation results for S11 on human body condition show a positive feedback.
Figure 7. S11 result for simulation on human body and on free space condition

Figure 8 shows the S11 result for simulation and measured of free space condition while Figure 9 (a) until (d), shows the S11 for on human body condition. For on human body condition, the antenna has been tested on three different human samples. Figure 10 shows the combination of simulation and measurement for both conditions. In Figure 8, Reflection coefficient results for simulation and measurement for free space is presented. The measurement result shows better performance of the antenna. Apart from that, the operational frequencies between simulation and measurement remained the same which are at 3.8 GHz and 4.9 GHz.

Figure 8. S11 result for free space condition

For on human body condition, Figure 9 (a) to (b) show the results when the measurement is compared with simulation for every human sample. Figure 9(d) is the comparison of all samples with the simulation results. Based from Figure 9(d), it can be seen that there are not much different between simulation and measurement for all three samples. When tested, the antenna managed to work on 4.2 GHz for all three samples. This is a great achievement since every human has different thickness for their body tissues and it may disturb the performance of the antenna. Table 4 summarized the performance of the antenna for on body condition.
(a) Simulation and measurement result for human sample 1

(b) Simulation and measurement result for human sample 2

(c) Simulation and measurement result for human sample 3

(d) Simulation and measurement for all three human samples

**Figure 9.** S11 result for on human body condition.

**Figure 10.** Combination of S11 results for both conditions
Table 4. Bandwidth for Measured S11 Results for On Body Condition

| Condition        | Operating Frequency | Frequency Band (MHz) | Bandwidth (MHz) |
|------------------|---------------------|----------------------|-----------------|
| Human Sample 1   | 4.2 GHz             | 4000 - 4600          | 600             |
| Human Sample 2   | 4.2 GHz             | 4100 - 4660          | 560             |
| Human Sample 3   | 4.2 GHz             | 4050 - 4650          | 600             |

One of the main antenna properties that were analyzed when considering the ability of the designed antenna in free space was the radiation pattern. Radiation pattern of an antenna is represented by the energy radiated. Radiation pattern results that are presented in this section are simulated results from free space condition. Since in free space condition, two frequency bands were obtained. Those frequencies are at 3.8 GHz and 4.8 GHz. Figure 11 shows the results at 3.8 GHz while Figure 12 shows the results at 4.8 GHz.

Figure 11 shows the simulated radiation pattern at 3.8 GHz for free space condition. The directivity of the antenna at that frequency can be seen in Figure 11(a) and Figure 11(b). Figure 11(a) is the 3D version of the radiation pattern while (b) is the polar version of the radiation pattern. From the figures, it shows that the antenna has a directional directivity of 7.343 dBi. For Figure 11(c), the 3D radiation pattern is plotted in linear scaling. From the figure, it shows that the total efficiency of the antenna is
0.6792 which is 67.92 % efficient. Figure 11(d) shows the gain of the antenna. From the figure, it shows that the antenna has a gain of 5.663 dB. Figure 12(a) until Figure 12(d) are the radiation pattern results for frequency at 4.8 GHz in free space condition.

![Simulated 3D radiation pattern at 4.8 GHz for directivity](image1)

![Simulated polar radiation pattern at 4.8 GHz for directivity](image2)

![Simulated 3D radiation pattern at 4.8 GHz for total efficiency](image3)

![Simulated 3D radiation pattern at 4.8 GHz for realized gain](image4)

**Figure 12.** Simulated radiation pattern at 4.8 GHz

Figure 12 shows the simulated radiation pattern at 4.8 GHz for free space condition. The directivity of the antenna at that frequency can be seen in Figure 12(a) and Figure 12(b). Figure 12(a) is the 3D version of the radiation pattern while (b) is the polar version of the radiation pattern. From the figures, it shows that the antenna has a directional directivity of 8.768 dBi. This value is a bit higher compared to at 3.8 GHz. For Figure 12(c), the 3D radiation pattern is plotted in linear scaling. From the figure, it shows that the total efficiency of the antenna is 0.4678 which is 46.78 % efficient. The total efficiency drops around 20% compared to at the 3.8 GHz. Figure 12(d) shows the gain of the antenna. From the figure, it shows that the antenna has a gain of 5.470 dB.

### 4. Conclusion

The designed antenna is aimed to enable communications inside the human body. In order to reduce attenuation through the tissues, lower band of UWB which is 4.2 GHz is used as the operational frequency. Based on the measurement S11 results on the human body, frequency of 4.2 GHz is successfully obtained. The size of the antenna is also small enough to be placed on human abdomen and it was made from cotton substrate. Cotton substrate is very soft and light in weight so it is suitable to be used on body. The objective of this research is successfully achieved because this antenna has been
fabricated and the coefficient results, $S11$ shows positive results as desired. Even after it has been tested on three different human samples, the results are acceptable and barely any different from the simulation.

5. References

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