UWB Antenna Optimization Using Linear Regression for Wireless Capsule Endoscopy Application in WBAN

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Abstract. Wireless Capsule Endoscopy (WCE) is a wireless technique of endoscopic exploration which offers to depict whole gastrointestinal (GI) tract including small intestine which is hard to explore using conventional endoscopy. Transmitting high image resolution data with low power consumption is main challenge of WCE, where the antenna plays major role in WCE system. In this research, we proposed a technique to optimize the Ultra Wide Band (UWB) antenna working in the frequency band between 3.1 GHz to 10.6 GHz. The antenna performs well inside human body in terms of bandwidth, gain, size, and radiation pattern. In order to improve antenna's performance, we propose an antenna optimization by using a linear regression. The optimization is based on analyzis using pre-designed antenna from previous research, that is a UWB slotted microstrip antenna with half ground plane with size of 10 x 8 mm. The validation of this optimization technique is done by using a simulation. This UWB Capsule Endoscopy antenna performance is assesed in terms of return loss, antenna gain and radiation pattern which has lower than -10 dB, higher than -9 dB, and omnidirectional radiation pattern, respectively.

Keywords: Antenna Formula, Wireless Body Area Network (WBAN), Ultra Wideband (UWB), Capsule Endoscopy.

1. Introduction

The best way to diagnose and detect gastrointestinal (GI) tract diseases is by directly view and explore the GI tract itself. There are many methods to explore the GI tract such as conventional endoscopic, colonoscopy and wireless endoscopy. Conventional endoscopy and colonoscopy is an invasive way to explore th GI tract while Wireless Capsule Endoscopy (WCE) is a non-invasive way [1], [2]. WCE is a wireless technique of endoscopic exploration which offers to depict whole GI tract. WCE consist of a wireless chip camera which captures the condition of GI tract, a lens, an LED, a radio transmitter and battery module to power up the whole system. Patient will swallow the capsule which mostly has size of 11 x 22 mm [3]. The WCE will explore the GI tract by the help of peristaltic movement inside the body and will be excreted naturally[4].

Providing high image resolution with low power consumption and high data rate transmission is main challenge in WCE system. It is stated that WCE system is one of WBAN application which need high data rate to give a real time and up-to-date exploration and high image resolution that will resulted more accurate diagnosis [5][6]. Antenna plays major role in WCE system. An UWB antenna is a good choice to overcome the challenges. Federal

Communication Comission (FCC) defined UWB has bandwidth of at least 500 MHz and operate in the 3.1 – 10.6 GHz band and the transmitted power density limited to less than -41.3 dBm/MHz [5][6][7]. IR-UWB communication has been choosen by IEEE 802.15.6 task group as a possible physical layer solution for WBAN. On previous research, an UWB antenna is proposed with size of 12 mm x 8 mm x 1.94 mm and gain value between -11.87 dB to -6.584 dB [8]. This antenna occupy 6 IR-UWB channels with the -10 dB bandwith of antenna approximately 3 GHz [8].

The main objective of this paper is to get a technique or formula to make the most optimized antenna which works well with WCE system inside human body with working frequency between 3.1 GHz to 10.6 GHz. In order to get the most optimized antenna, a formula for optimization is proposed using linear regression. The formula is analyzed using the antenna design from previous research. The formula obtained from the research will be validated using a simulation software and presented in math model.The WCE devices later will be working inside human body and will have direct contact with it. To find the formula to get the most optimize antenna, human tissues electrical properties should be taken into account because human body tissues are highly frequency dependent.

This paper is organized as follows: Section 2 Antenna Design and scenario. Section 3 presents Results and Analysis and finally Section 4 will concludes the paper.

2.   Antenna Design and Scenario
2.1   Antenna and Phantom Design

The proposed math model (formula) from linear regression and antenna will be analyze and simulated in a analysis tools and simulation software. The formula obtained from this research will be validated using simulation software and later the antenna design will be validate using pig's abdominal part as substitute of human body (phantom).
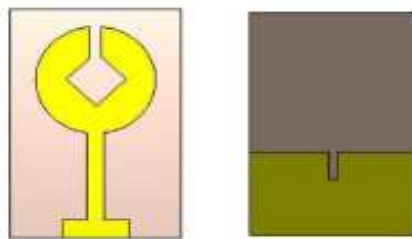

Figure 1. Front view of UWB antenna (left) and back view (right) [8]

The antenna design that will be use as standard antenna to obtain a formula in this paper is a UWB antenna from previous research shown in figure 1 [8]. The planar antenna is choosen since it can gives omnidirectional radiation pattern with low profile shape rather than monopole antenna [9][10]. The size of the antenna is also a challange in WCE system, it should be fitted into the capsule considering WCE's capsule has to be swallow by the patient [11][12]. Mostly the size of the capsule is 11 x 22 mm. High frequency material, Roger 6010 will be use with dielectric constant of εr 10.2 and thickness of 1.9 mm antenna. It is choosen because its low loss

and it has high dielectric constant to minimize the antenna size. This substrate also has low moisture absorption that will reduce the effect of moisture in electrical loss. Figure 2 and Tabel 1 shows the antenna dimension that will be use in this research.
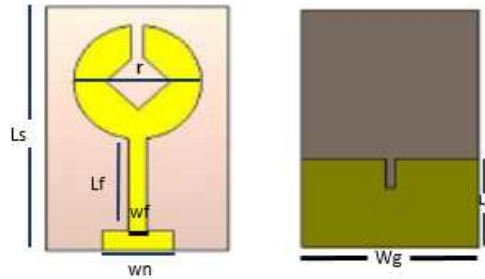
Figure 2. Antenna Design and Parameters

Table. 1 Antenna Dimension

Parameters	Value (mm)
Length of ground (Lg)	4.5
Width of ground an substrate (Wg)	8
Thickness of ground and patch (hg)	0.035
Thickness of substrate (hs)	1.9
Width of ground notch (Wn)	0.4
Length of ground notch (Lgs)	1.5
Length of substrate (Ls)	12
Width of rectangular slit in patch (ws)	0.6
Length and wide of square slot in patch (sq)	3
Width of feed line (wf)	0.8

As mentioned before, human tissues electrical properties should be taken into account because human body tissues are highly frequency dependent. To validate that the formula and the antenna works well inside human body, then the simulation should be done using a gastrointestinal phantom shown in figure 3. In this paper, the simulation only use small intestine phantom as shown in figure 4.
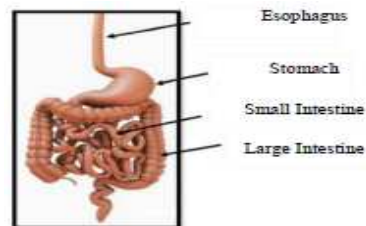

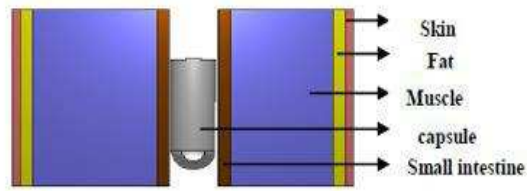**Figure 3**. Human Gastrointestinal Tract [4]

Figure 4. Small Intestine Phantom

Phantom is a modeling of the human body used in antenna simulation. Phantom has permittivity characteristics (ε), permeability (μ) and conductivity value according to body part where antenna is placed. Phantom is very important in the design of wireless body area netwok because the human body has a very significant influence on the characteristics of the antenna to be designed. Table 2 below shows that each tissues in human body has different electrical properties value.

Table. 2 Tissues Electrical Properties in 9.31 GHz [13]

Tissue	Dielectric Constant	Conductivity [S/m]	Loss tangent
Skin (Dry)	31.955	7.2373	0.43729
Fat	4.6558	0.5359	0.22224
Muscle	43.702	9.6333	0.4256
Small Intestine	43.087	11.665	0.52272

Phantom used in the simulation is a composition of the human body tissue of the abdomen that is, skin, fat, muscle and small intestine with the value of permittivity, conductivity and different thickness.

2.2 Scenario

To improve the aforementioned UWB antenna which works well inside human body in the frequency between 3.1 GHz to 10.6 GHz, an optimization formula is needed. The analysis starts from choosing the basic antenna design, later, with the choosen antenna design, each of the variable in the antenna will be change one by one to build pairs of possibilities. There are two kind of variables, dependent and independent variables. The independent variable is the changing variable while the dependent variable are gain and bandwidth.
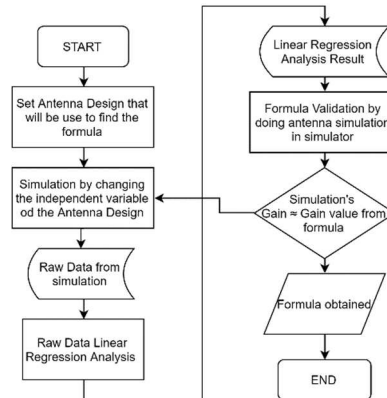

Figure 5. Flow chart scenario

Figure 5 explains the flow chart of this reasearch. First step, the antenna from previous works [14] will be simulated in simulator shown in figure 6 to obtain raw data. The parameter of the antenna which are length and width of feed, groundplane, radius will be changed one by one. The changing variable above called independent variable in linear regression. Once the data has been collected, the data will be analyze using linear regression to see if the characteristic of datas is linear or not. There will be error value in the data analysis, if the error value is less tatn 1% then the simulation will be performed again to ensure that the math model obtained from the raw data analysis is valid or not.

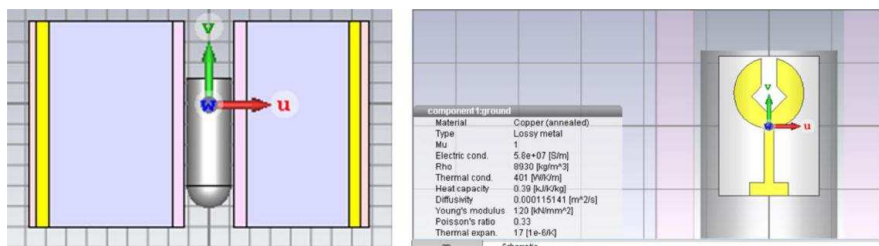
Figure 6. Validation Simulation

After simulation performed, we will check whether the value from math model obtained and the simulation result obtain is the same or not. If the differences between the math model

value and simulation value is small, then the math model is confirmed as a valid formula to obtain the most optimized antenna.

3. Result and Analysis

Table. 3 Raw Data from Simulation

No	Gain (numeric)	Frequency (GHz)	Return Loss (numeric)	Length of feed line (mm)	Radius of patch (mm)
1	0.058884	6.85	0.042228	5.3	2.8
2	0.113763	8.35	0.033052	5.3	2.8
3	0.058884	6.85	0.043202	5.4	2.8
4	0.11246	8.35	0.035596	5.4	2.8
5	0.060256	6.85	0.044937	5.1	2.8
6	0.116145	8.35	0.034898	5.1	2.8
7	0.057544	6.85	0.048273	5.3	2.7
8	0.11324	8.35	0.045279	5.3	2.7
9	0.058884	6.85	0.032337	5.3	2.9
10	0.110154	8.35	0.031246	5.3	2.9

Table 3 show the result of antenna simulation with changing variable (independent variable) that will be use as raw data to be tested in linear regression analysis and antenna simulation validation. The raw data consist of independent variable, gain value, working frequency and return loss.The raw data above will be analyze using anlysis tools to calculate if the data gain from the simulation is valid and have low error value or not. The analysis will use linear regression method which resulted like this :

Table. 4. Regression Statistic from Raw Data

Regression Statistics	
R Square	0.999158
Adjusted R Square	0.998485
Standard Error	0.001115
Observation	50

From table 4 it shows that the raw data presented in table 3.5 has 0.001114928 or 0.1 % standard error. So, the raw data is good enough to be analyze and the formula that shown later is good enough because it has small standard error.

Table 5. Result of raw data analysis

	Coefficients	*Standard Error*
Intercept	-0.102475312	0.033321547
f	0.035788706	0.00058149
RL	-0.093635665	0.083061933
lf	-0.00961199	0.003676385
r	-0.010183271	0.003633275

Table 5 shows the formula that will be validate using simulator software. This table resulting a formula from length of feed and patch radius variable pairs only.

$$\text{Gain} \cong (0.0357887061264201 \text{ x f}) + (-0.00961199\text{x lf}) + (-0.010183271 \text{ x r}) + (-0.102475312) \qquad (1)$$

With above math model, a simulation is performed to ensure that the formula is valid or not. The simulation will change the length of antenna feed from 5.4, 5.3, 5.2 and 5.1 with 0.1 mm steps in each simulation and no changes in other parameter. While in the second simulation the simulation will change the radius of patch with 0.1 mm steps start from 2.9 mm to 2.7 mm.

Table 6. Gain Value from math model and simulation

No	F (GHz)	lf (mm)	r (mm)	Gain from formula (dB)	Gain from simulation (dB)	Deviation
1	6.85	5.3	2.8	-12.27	-12.3	0.03
2	8.35	5.3	2.8	-9.44	-9.44	0.00
3	6.85	5.4	2.8	-12.35	-12.3	0.05
4	8.35	5.4	2.8	-9.48	-9.49	0.01
5	6.85	5.1	2.8	-12.15	-12.2	0.05
6	8.35	5.1	2.8	-9.37	-9.35	0.02
7	6.85	5.3	2.7	-12.24	-12.4	0.16
8	8.35	5.3	2.7	-9.44	-9.46	0.02
9	6.85	5.3	2.9	-12.28	-12.3	0.02
10	8.35	5.3	2.9	-9.47	-9.58	0.11
						0.05

Table 6 above shows Gain obtained from formula (1) and Gain obtained from simulation. It shows that both techinque has slightly difference value of Gain. The average deviation between this technique is 0.05. Antenna gain value must be suitable for WCE system because later the antenna will operate inside human body which has different temperature and conditions [15].
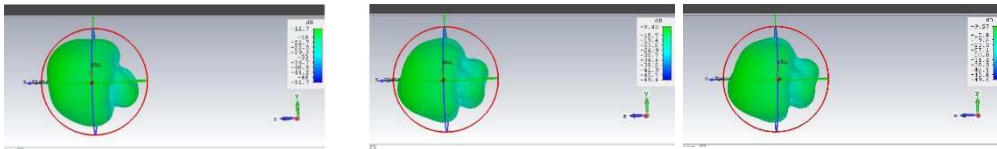

Figure 7. Radiation pattern in lowest, middle and highest working frequency

4. Conclusion

The formula obtain from this research is valid enough because it has low error value and low deviation but further reserach is needed to ensure that the math model is valid to obtain better antenna. More datas from previous research will be analyze and more independent variables will be added to make the math model more accurate. The frequency that will be use as dependent variable also should be develop in to 3 working frequency which are lowest working frequency, middle and highest working frequency. The formula obtained also has to be checked in other range of frequency as long as the antenna still placed inside the body.

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