Design and Fabricate Ultra-Wideband Antenna for Monitoring Purposes

By

Mohamad Jazlan b Mohamad Rozi
15727

Dissertation submitted in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
Electrical and Electronics Department

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Electrical & Electronic Engineering Department
Universiti Teknologi PETRONAS

CERTIFICATION OF APPROVAL

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Approved by

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(Dr Hanita bt Daud)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my on except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

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(MOHAMAD JAZLAN B MOHAMAD ROZI)

ABSTRACT

There are many cases where victims are trapped in collapsed building, underground mines and many more trapped situation which rescuers need to save them as fast as possible without any lost soul during the rescuing mission. To make sure rescuers are also in a safe condition, a tracking system has been developed to track their movement during the mission. There might be other devices in the current market being used nowadays for the location monitoring purposes, but those products are probably costly. In this study, several design of an optimum antenna will be selected and fabricated. The design which is low weight, low cost and wider coverage will be tested to make sure it meets the requirement so that in the future it can be used by our local rescuers.

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CHAPTER 1
PROJECT BACKGROUND

1.1 Background study

An antenna which is also called an aerial is a device that consists of a conductor that transmits, sends and receives signals being used in a various transmission system such as broadcasting, two-way radio, communications receivers, radar, cell phones, and satellite communications and many more [1]. The first experiments involving the coupling of electricity and magnetism was done by Faraday around 1830s and it has evolved since then. In any radio transmission, antenna is needed to couple from electrical source to the electromagnetic field, electromagnetic wave (radio waves) that carries signals at the speed of light through the air at nearly no transmission loss [1].

Among other wireless protocol, ultra-wideband (UWB) has been chosen due to its reliability. The extensive commercial use of ultra-wideband (UWB) transmission has sparked interest in the subject of ultra-wideband antennas, [2] which ultra-wideband (UWB) system offers a capable solution to the RF spectrum weakness by allowing new system to develop together with the current radio systems with a very minimal or no interference. [3] Thus, an ultra-wideband antenna will be design and constructed to perform analysis and thus a solution to achieve the objectives.

1.2 Problem statement

There are various types of ultra-wideband antenna with different shapes and definitely it has different outcomes. Current conventional radio transmission transmits information by varying these parameters; the power level, frequency, and phase sinusoidal wave. While ultra-wideband system transmits by producing radio energy at particular time intervals and engaging a large bandwidth and this will allow pulse-position or either time modulation [1].

There are few criteria that need to be improved, which are:

- coverage area / effective area
- wider bandwidth
- current and voltage distribution

1.3 Objectives

The objectives of the project are:

1. To design a low power antenna at a low cost that transmits at a wide resolution bandwidth.
2. To design several ultra-wideband antennas, then construct selected design.
3. Simulate the designed ultra-wideband antenna by using CST Studio.
4. Measure the characteristics of the antenna.
5. Fabricate and design the optimum microstrip patch antenna.

1.4 Scope of Study

The scope of study of this project includes:

I. Understanding on the principle of antenna as well as ultra-wideband antenna and its applications in the wide range of industries.

II. Understanding on the microstrip patch antenna design to ensure it meets the requirement needed for an ultra-wideband antenna.

III. Understanding on the simulation software (CST Studio) used to design the microstrip patch antenna.

IV. Understanding and identifying critical parameters (i.e. S-Parameter, return loss, characteristic impedance and phase angle, and radiation patterns) that needs to left constant or to be manipulated throughout the process.

CHAPTER 2
LITERATURE REVIEW

2.1 Chapter overview

Fire-fighters faces dangerous situation while performing rescue mission, they need to save souls and make sure theirs are in good condition as well. There are several cases recorded where fire-fighters trapped inside building in a rescue mission. Due to this, those fire-fighters died when trying to find their way out from the scene [11]. As refer to Figure 1, 3 percent of death of the fire-fighters caused by lost inside the structure, thus monitoring system might be useful to reduce this fatal.

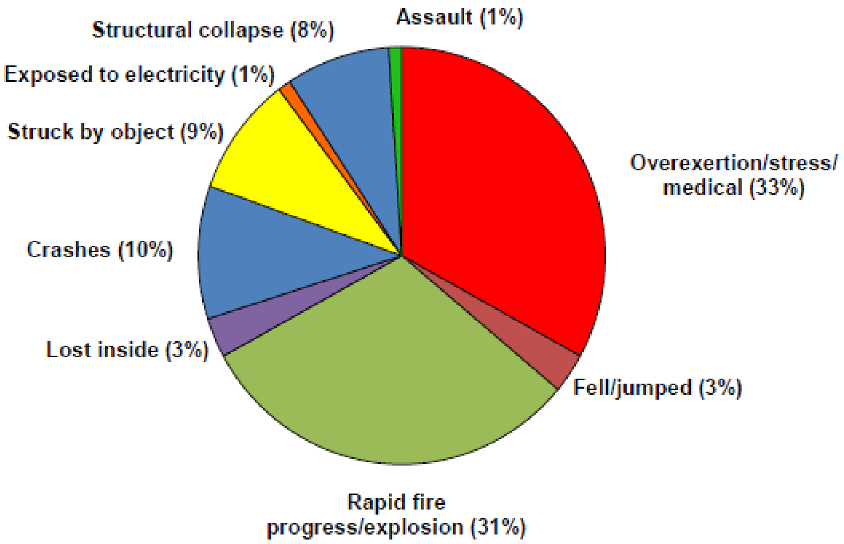


Figure 1: Cause of death of fire-fighters [11].

2.2 Antenna theory

Antenna basically is a guided electro-magnetic wave transformation into an electro-magnetic wave feely propagating in space, with specified directional characteristic [10]. A number of performance measurements need to be considered in designing and selecting antenna for specific usage [1]. In practice, there are numbers of parameters used; including frequency bandwidth, radiation pattern, directivity, gain, input impedance and several other factors.

2.3.1 Radiation Efficiency

Radiation efficiency is the ratio of power of an antenna that radiated (in all direction) to the power absorbed by the antenna receiver. The power that is not radiated during the transmitting process is transformed into heat. This happen through loss resistance in the antenna's conductors, but it is also cause by the dielectric or magnetic core losses in the antenna (or the systems of the antenna) which using such components. The loss of effectively robs power from the transmitter, required a much stronger transmitter in order to transmit a signal at the specific strength [1].

Usually only 50% of power supplied is used to transmit, and this happen when the generator impedance and also the antenna are matched at 50Ω. Equation 1 shows the efficiency of an antenna [12].

$$E = \frac{P_{radiated}}{P_a} = \frac{R_r I^2}{(R_r + R_L) I^2} = \frac{R_r}{(R_r + R_L)} = \frac{1}{1 + R_L / R_r} \qquad (2.3.1.1)$$

2.3.2 Directivity and Gain

Gain is a consideration that measures the scale of directivity of the antenna's radiation pattern. An antenna with a high gain will preferentially radiate at a point of direction. The gain of an antenna is a passive occurrence which power is not an added parameter but it simply retransmitted to supply more radiated power in a certain direction than would be transmitted by an isotropic antenna [1].

Directivity which also defined as "the ration radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna where radiating isotropic ally" [14]

As refer to equation 2.3.1.2, which is a Poynting Vector, P which it will produce the average real power per unit area radiated in free space. By multiplying the efficiency with the directivity of the antenna, the maximum possible gain of an antenna can be obtained [12], meanwhile equation 2.3.1.3 is to obtain gain.

$$D = \frac{P}{P_0},\ D|_{dB} = 10\log_{10}\frac{P}{P_0},\quad P_0 = \frac{P_a}{4\pi r r^2} \qquad (2.3.1.2)$$

$$G = D\ \frac{P_a}{P_{accepted\ by\ the\ antenna}} \leq D \qquad (2.3.1.3)$$

2.3.3 Frequency bandwidth

Frequency bandwidth is also defined as the range of frequencies within which the performance of the antenna, with respect to some of the characteristics, conforms to a specified standard. The bandwidth of transmission can be accepted as the range of frequency, which on the other side of the centre frequency, if the antenna parameters are within an acceptable value of those at the centre frequency. Practically, in wireless communications it is a requirement for an antenna to transmit with a return loss less than -10dB over its bandwidth.

The frequency bandwidth of an antenna can be expressed as absolute bandwidth (ABW) as well as fractional bandwidth (FBW). The value of f_H and $f_L$denote the upper and lower edge of the bandwidth, respectively. The absolute bandwidth also defined as the difference of the two edges and the fractional is designated as the percentage of frequency difference over the centre frequency, as in equation 2.3.1.4 and 2.3.1.5

$$\text{ABW} = f_H - f_L \qquad (2.3.1.4)$$

$$\text{FBW} = 2\,\frac{f_H - f_L}{f_H + f_L} \qquad (2.3.1.5)$$

For broadband antenna, the bandwidth can also be defined as the ratio of the upper to the lower frequencies, which the situation where the performance is acceptable, as shown in equation 2.3.1.6.

$$BW = \frac{f_H}{f_L} \qquad (2.3.1.6)$$

2.3 Ultra-wideband

Over the past years, attention in the commercialization of ultra-wideband (UWB) has increased, which results developers of UWB transmission start to forcing the Federal Communications Commission (FCC) to approve UWB for future commercial use. This lead to the FCC to approved the First Report and Order (R&O) for commercial use of UWB technology under strict power emission limits for various devices in February 2002. This current rapid development in technology and the successful commercial operation of wireless communications are extensively affecting our daily lives [5]. One of the features of UWB that brings into attention is that its bandwidth is over 110 Mbps (up to 480 Mbps), and this range are able to suit most of the multimedia devices. At the range of bandwidth over 110Mbps, UWB is also able to play a role as a wireless cable replacement of high speed serial bus [4]. Comparison in between each wireless protocol as shown in Table 1 that UWB have advantages compared to other transmission medium. Showing that UWB transmission has the wider frequency band, and also wider channel bandwidth, highest maximum signal rate and it is also has better data protection which is 32-bit CRC.

Table 1: Comparison between Bluetooth, UWB, ZigBee, and Wi-Fi [4].

Standard	**Bluetooth**	**UWB**	**Zig Bee**	**Wi-Fi**
IEEE spec	802.12.1	802.15.3a	802.15.4	802.11a/b/g
Frequency band	2.4 Ghz	3.1-10.6 Ghz	868/915 Mhz, 2.4 Ghz	2.4Ghz, 5Ghz
Max signal rate	1 Mb/s	110Mb/s	250Kb/s	54 Mb/s
Nominal TX power	0 – 10 dBm	-41.3 dBm/Mhz	(-25)-0 dBm	15-20 dBm

Channel bandwidth	1 Mhz	500 Mhz – 7.5 Ghz	0.3/0.6 Mhz; 2Mhz	22 Mhz
Data protection	16-bit CRC	32-bit CRC	16-bit CRC	32-bit CRC

2.4 Mircostrip patch antenna

In ultra-wideband (UWB) transmission, the main objective is to transmit pulses at very short duration as opposed to traditional communication schemes, which it will send sinusoidal waves. This transmitting pulses need to be transmit as accurately and also very efficient as possible [6]. In order to meet this requirement, several design of microstrip patch antenna need to be considered.

Types of microstrip antennas are classified by their physical parameters, which it have different type of shapes as well as dimensions. There are four basic categories of these microstrip antennas [12];

- *Microstrip patch antennas*

  It is well-suited for embedded antennas due to its low-profile design. The structures make it very suitable for mobile wireless devices. It has many advantages such as very light weight and low volume, it supports either linear or circular polarization, it is also mechanically stable when the unit is being mounted on rigid surfaces, etc.

- *Microstrip dipoles antennas*

  Compared with the microstrip patch antenna, dipoles antennas has a very different bandwidth, radiation resistance, and the cross polar radiation. Since the substrate of this type of antenna is thick, it can be operated at high frequencies.

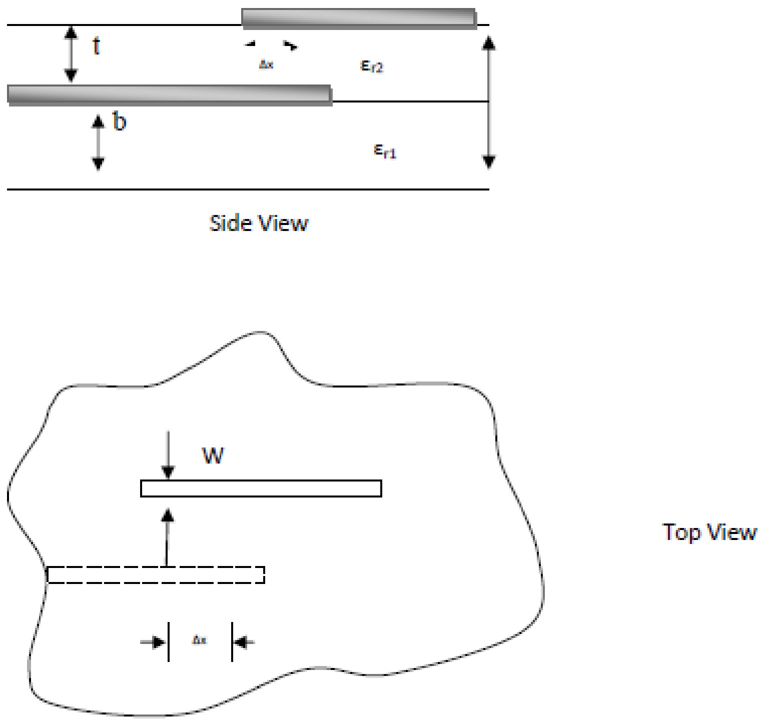


Figure 2: Structure of a Microstrip and printed dipoles.

- *Printed Slot Antennas*

  These printed slot antennas have the slot in the ground plane of a grounded substrate, and it can be radiate in either bi-directional, meaning that it can be radiate at both sides or unidirectional.

- *Microstrip travelling wave antennas*

  It has a long microstrip line so that the main structure lying in any direction from broadside to end fire.

Table 2: Comparison between microstrip patch antennas [12].

Characteristics	**Microstrip Patch Antennas**	**Microstrip Slot Antennas**	**Printed Dipole Antennas**
Profile	Thin	Thin	Thin
Fabrication	Very easy	Easy	Easy
Polarization	Both linear and circular	Both linear and circular	Linear
Dual-Frequency Operation	Possible	Possible	Possible
Shape Flexibility	Any shape	Mostly rectangular and circular shape	Rectangular and triangular
Spurious Radiation	Exists	Exists	Exists
Bandwidth	2-50%	5-30%	≈ 30%

As refer to Table 2, it is shown that microstrip patch antenna have a better characteristics compared to the other two type of microstrip antennas. Thus, in this project, a thin square patch of one side of a dielectric substrate and the other side is a plane to the ground design has been chosen (microstrip patch antenna).

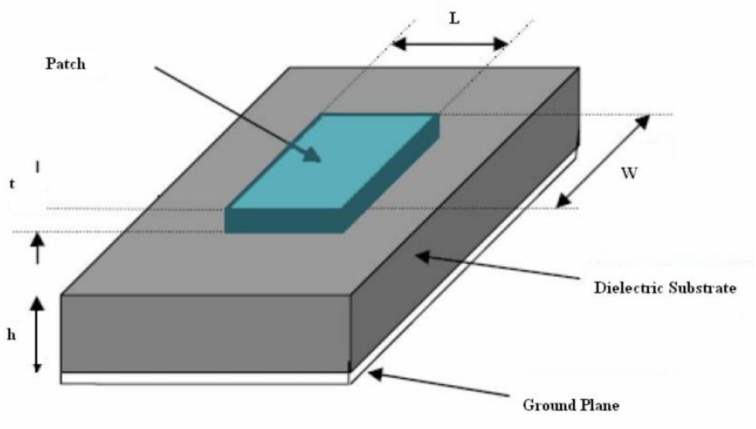


Figure 3: Example structure of microstrip patch antenna.

In study paper [9], it shows that rectangular design has a smaller size and also wider bandwidth compared with the triangle slot antenna design. To design the antenna, it takes several considerations such as matching & spectral control, directivity and system performance, antenna size and its bandwidth, and also antenna size and its gain [2].

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

The early stage of this study needed simulation software, CST Microwave Studio for designing and simulation purposes. The simulation of the process is preferred to the experimental data collection method in order to select the best output from several design that will be fabricated and test it in a real situation.

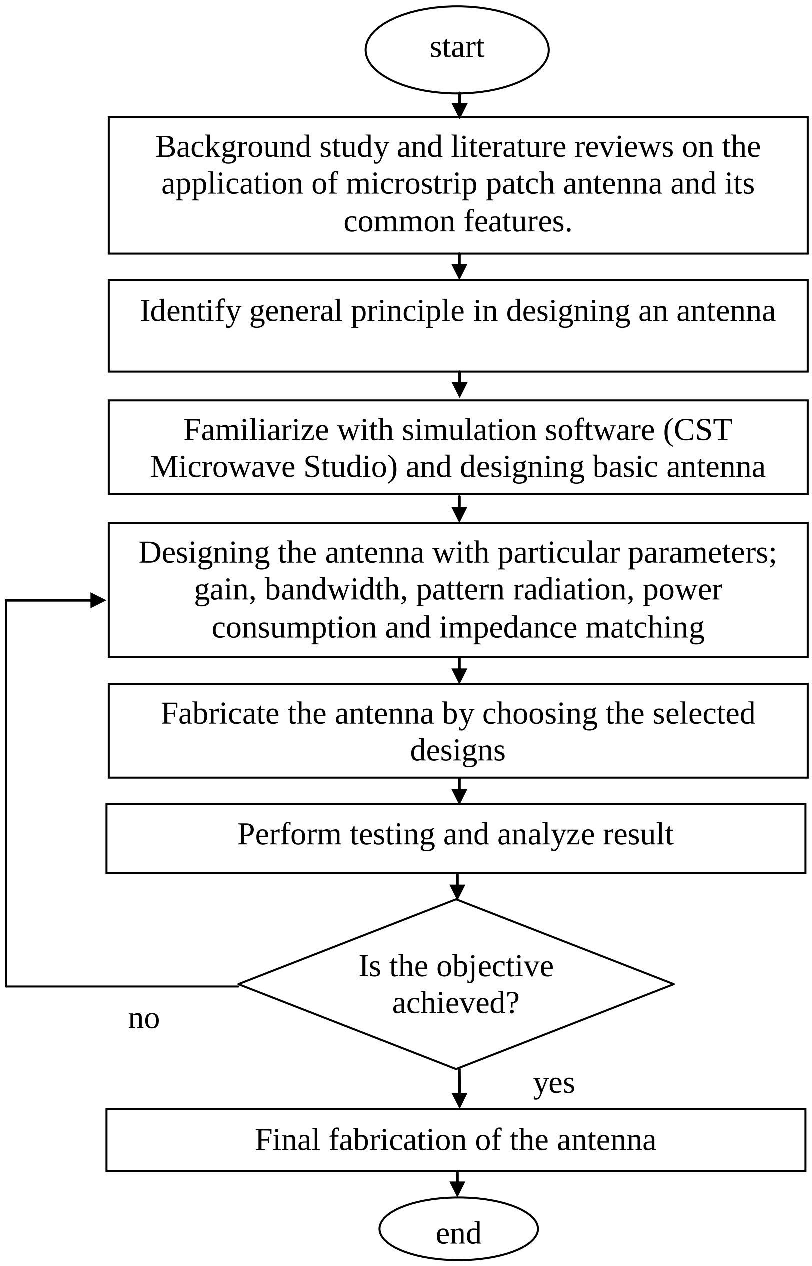


Figure 4: Research methodology and project activities

3.2 Key Milestone

Final Year Project 1															
No	**Item/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project title selection														
2	Extended proposal submission														
3	Proposal defence														
4	Draft report submission														
5	Final report submission														

Table 3: Key Milestone of Final Year Project 1

3.3 Gantt Chart

Final Year Project 1															
No	**Item/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project title selection														
2	Background study and literature reviews on the application of microstrip UWB antenna and its common features														
3	Identifying suitable design to minimize return loss and acceptable bandwidth														
4	Extended proposal														
5	Study on the parameters needed to minimize return loss														
6	Proposal														

	defence								■	■					
7	Familiarize with simulation software										■	■			
8	Design several prototype and analyze the results											■	■	■	
9	Draft report												■	■	
10	Final report												■	■	■
Final Year Project 2															
No	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
11	Fabricate selected design of microstrip patch antenna	■	■	■	■	■	■	■	■	■	■	■	■	■	■
12	Perform testing and analyze result	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 4: Gantt Chart of Final Year Project 1 and 2

3.4 Tool & Software Required

Software

- Microsoft Office
- CST Microwave Studio

Hardware

- Printed circuit board (PCB)
- FR4
- Network Analyzer

3.5 Result and discussion

3.5.1 Parametric study on rectangular patch antenna with full ground

Figure shown below is a simulation base 3-D view rectangular patch antenna with characteristic impedance of Z_o = 50ohm. This rectangular patch antenna is the design which the cooper covered all the substrate as ground. Several simulations have been done to study on the behaviour of the designed antenna. Changes on the parameter have been made to satisfy the return loss output which is below -10 dB in S-Parameter magnitude, thus the diameter of the patch has been changed to meet the requirement.

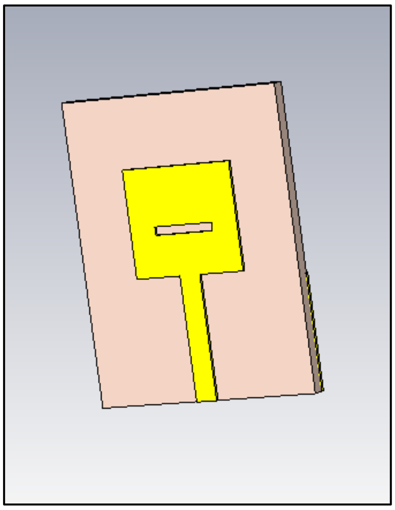


Figure 5: 3-D view of modelled antenna in CST Studio Microwave.

Return loss of the antenna from port S1,1 shown in figure 6. The simulation result showing the return loss is having an unstable output and it did not meet the requirement. Targeted return loss is below -10dB from port S1,1 or VSWR more than 2:1.

The working plane size is set with 100mm for single element, the Raster width is 2 and Snap width is 0.01. The rectangular patch antenna size is 42x32x0.035.

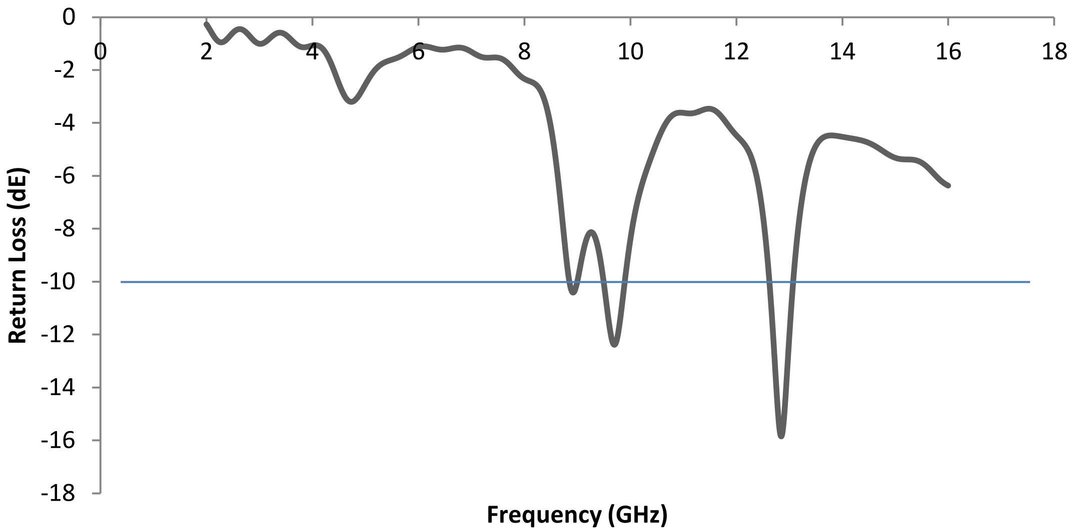


Figure 6: Simulated return loss from port S1,1.

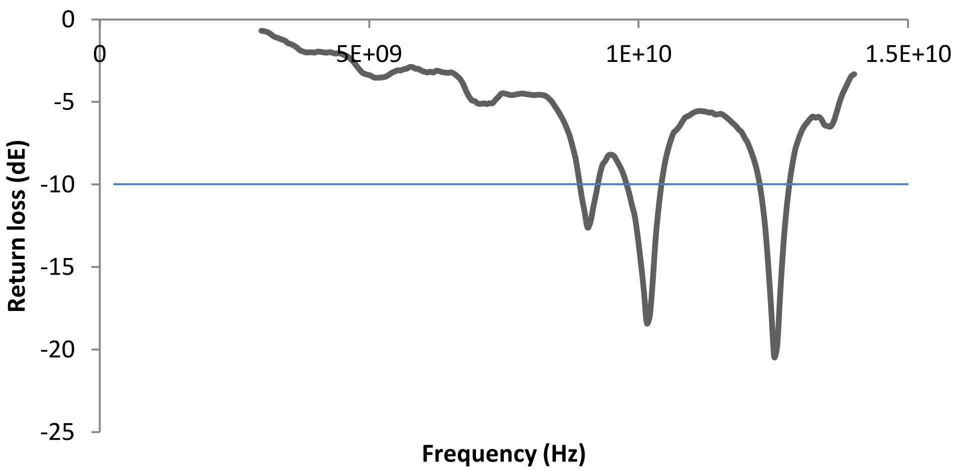


Figure 7: Measured antenna with full ground.

As refer to the simulation result (Figure 6), it shows that the port S1,1 transmitting frequency at the range of 2 to 16 GHz. The return loss showing it did exceed below -10db, but not in a smooth outcome, which it has to be below -10dB with a smooth bouncing graph. As well as the measured fabricated antenna (figure 7), the outcome almost similar to the simulation which result bad return loss when transmitting data. The measured antenna starts from 2GHz to 14GHz due to the limit of the network analyzer which can only measure up to 14GHz only.

Meanwhile, radiation pattern are consist of function or graphical representation of the radiation properties on antenna as a function of space coordination. In practice, the 3-D pattern is measured and recorded in a series of 2-D pattern. The antena design at almost radiated energy in omnidirectional is prefered. In order to have a monitoring antenna, having a good omnidirectional radiated energy is important to transmit the data. In this study, monitoring a fire-fighter during rescuing mission will need an antenna which transmits data at any direction. Figure 7 showing an antenna with a full ground covered transmits at 4 GHz with weak Z plane data transmitting.

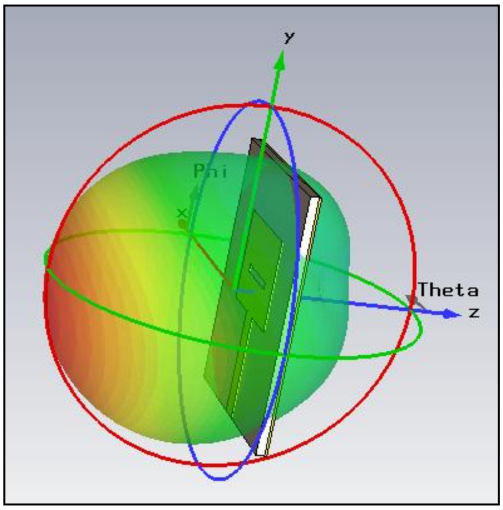
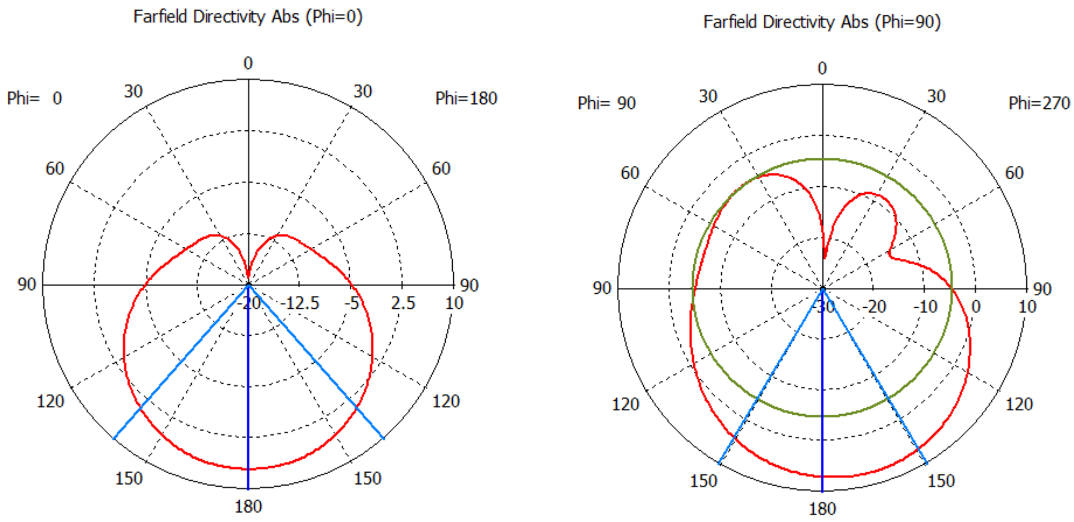


Figure 8: Radiation pattern (farfield) at 4 GHz.



(a) (b)

Figure 9: E-Field (a) and (b) of full ground antenna.

For a linearly-polarized antenna, E-plane contains the electric field vector and the direction of maximum radiation. The electric field or "E" plane determines the polarization or orientation of the radio wave. H-plane on the other hand, contains the magnetic field vector and the direction of maximum radiation. Both planes were measured (Figure 9) on fully covered ground to indentify the outcome of the designed antenna and determine whether the design is suitable for monitoring purposes.

It clearly shown the radiation of the antenna did not satisfy the requirement which it need to be radiating evenly instead of focus at one particular point.

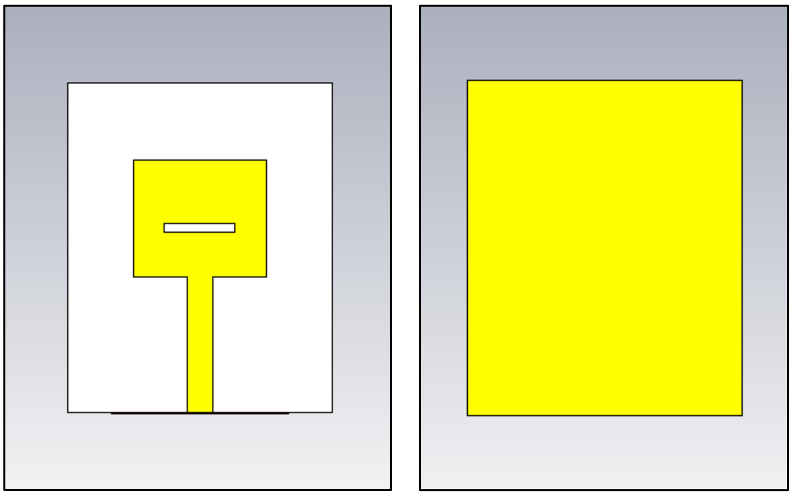


Figure 10: Front and back design of fully covered ground antenna.

3.5.2 Parametric study on rectangular patch antenna with partial ground

To have an efficient data transmitting antenna, several changes are made from the full ground antenna design in order to meet the requirement. Study shows that having a partial ground produce a good omnidirectional data transmitting compare with fully covered ground. The partial ground on the antenna, equation below is needed which the correlation of plates and ground plane are:

Conductor loss,

$$P_c = I^2 R \qquad \text{eq(3.1)}$$

Current density,

$$P_c = 2\, R_s \left(\iint_s . J J^*\right) ds \qquad \text{eq(3.2)}$$

Pc: conductor loss

RS: surface impedance.

s: patch area.

Radiated power, Pr

$$P_r = ½\, \mathrm{Re} \left(\iint_{\text{aperture}} E \times H^*\right) ds \qquad \text{eq(3.3)}$$

$$P_r = (1/2\eta_o) \iint (|E_\theta|^2 + |E_\varphi|^2)\, r^2 \sin\theta\, d\theta\, d\varphi \qquad \text{eq(3.4)}$$

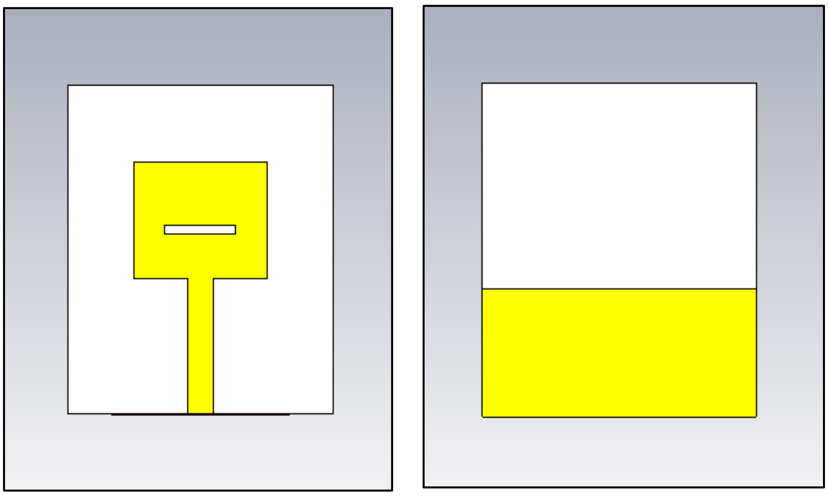


Figure 11: Front and back design of partial ground antenna.

After calculation is made to determine the partial ground dimension, it was designed and tested by using CST Microwave Studio. Result shows that by having a partial ground, it increases the area of transmitting plane. Covered ground will have a good gain but transmitting data will only focus at certain plane and this cannot be proceed in order to have an optimize omnidirectional antenna.

Figure above shows that partial ground design has a better simulated return loss and gives better impedance bandwidth span, 8 GHz compare to fully covered ground due to the increased of inductance of the patch radiator. By using the transmission line model, the patch width and length is calculated.

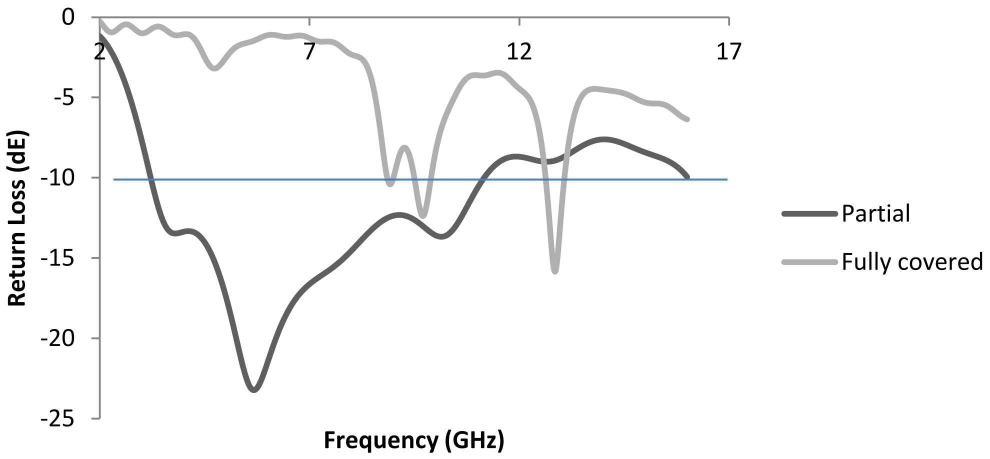


Figure 12: Comparison between fully covered ground and partial ground.

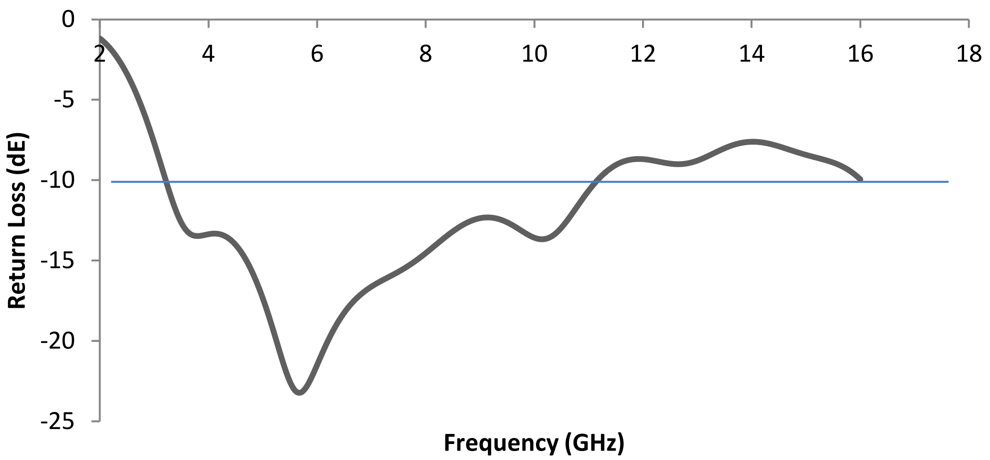


Figure 13: Return loss of the partial ground design.

The resonant frequency, *fr* is 6.85 GHz. The bandwidth of the system is often described as relative to the upper and lower bound of frequency.

fH= 11.174 GHz ; high operation band

fL= 3.192 GHz *;* low operation band

BW= *fH*- *fL*

= 7.97 GHz

Bandwidth with 8 GHz is a good span in ultra-wideband data transmitting. The designed antenna operated in between of 3 to 11 GHz, which it is in the range of ultra-wideband spectrum. Radiation pattern in Figure 14 shows that having partial ground will generate a better radiation energy compared to fully covered ground. Having a design with almost radiated energy is important, which the data will be transmitted at any omnidirectional plane.

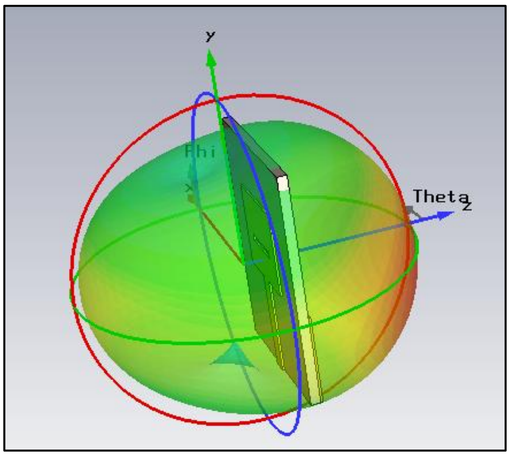
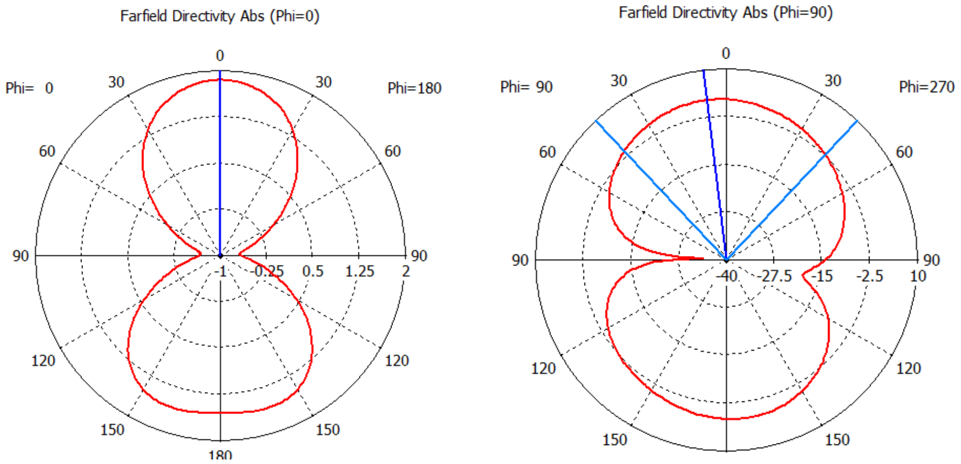


Figure 14: Radiation pattern for partial ground.



(a) (b)

Figure 15: E-Field (a) and (b) of partial ground antenna.

The partial ground antenna produces an optimum radiation pattern on E-field as well as on H-field as refer to Figure 15. The direction of the radiation on both planes suits the omnidirectional data transmitting criteria, which it radiate at almost every direction.

After fabricating the antenna, a test need to be done to measure whether it is working as simulated. The antenna that was measured using network analyzer is proving that it is generating the output as simulated.

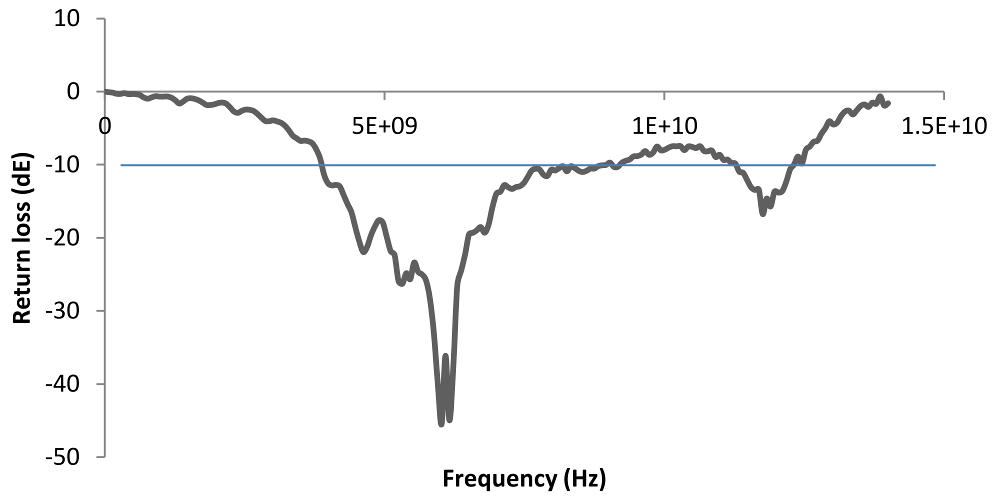


Figure 16: Measured antenna.

3.5.2 Final design antenna

Optimized final antenna design is shown below with the geometry as well as the fabricated antenna on the PCB, figure 16.

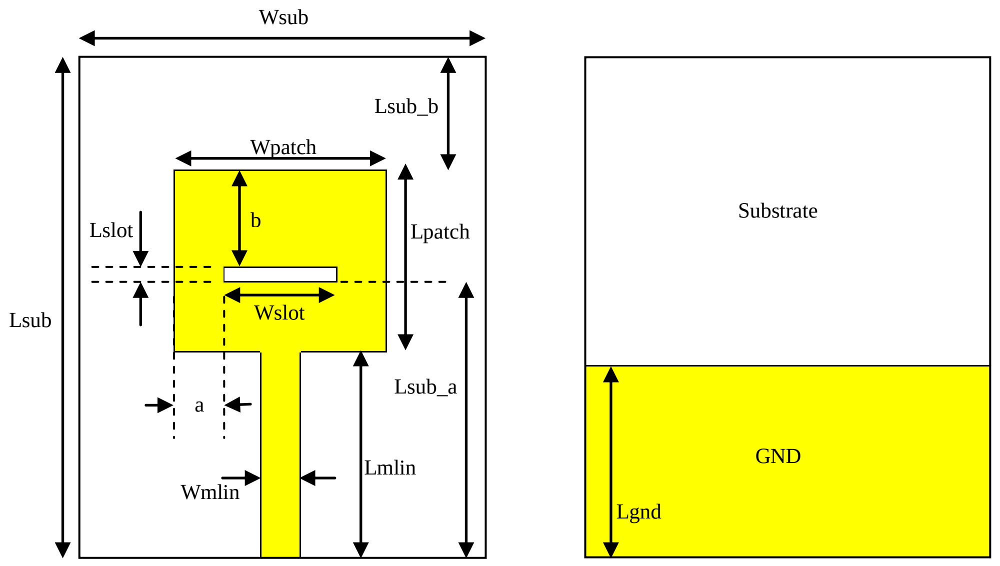


Figure 17: Antenna geometry.

The measurement for the design is:

Wsub = 30mm, Lsub = 30mm, Lsub_a = 20mm,
Lsub_b = 2mm, Wpatch = 15mm, Lpatch = 13mm,
Wmlin = 2.8mm, Lmlin = 15mm, Wslot = 8mm,
Lslot = 1mm, a = 3.5mm, b = 7mm, Lgnd = 14mm

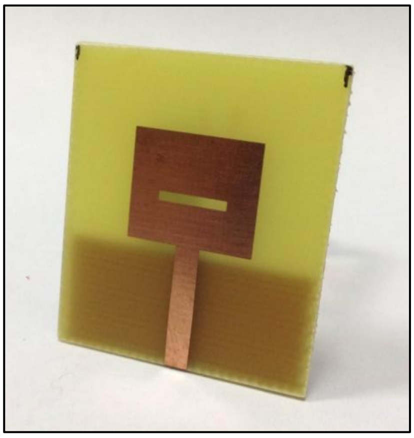


Figure 18: Fabricated ultra-wideband antenna.

CHAPTER 4
CONCLUSION AND RECOMMENDATION

Ultra-wideband antennas have a better parameters compared to the other conventional antenna. The selection of this transmission system is to prove that ultra-wideband is the most reliable wireless protocol to be used in rescue mission compared to transmission medium. The outcome of the prototype was tested and analyzed and this will be very useful in monitoring rescuers during real rescue situation.

Implementation of array antenna in order to achieve higher gain is recommended in further experiment. Further testing is needed in order to have a better understanding on the capability of the designed antenna which it might produce a difference outcome since the simulation data is only on the basis of ideal situation. On field situation with proper equipment is an example of test that can be conducted to test the capability of the antenna.

REFERENCES

[1]. Antenna (radio) [Online]. Available: http://en.wikipedia.org/wiki/Antenna_(radio)

[2]. H. Schantz, “A Brief History of UWB Antennas” IEEE UWBST 2003.

[3]. R. Fontana, “A Brief History of UWB Communications,” online article, http://www.multispectral.com/history.html

[4]. L. Jin-Shyan, S. Yu-Wei, and S. Chung-Chou, "A Comparative Study of Wireless Protocols: Bluetooth, UWB, ZigBee, and Wi-Fi", *The 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON),* Taipei, Taiwan, 2007.

[5]. R.S. Kshetrimayum, "Introduction to Ultra-Wideband Communications", *Potentials, IEEE*, vol 28, pp.9 - 13 March-April 2009.

[6]. R.Clarke, R. Karunaratne, C. Schrader, "Ultra-Wideband Antenna", *EE198B*, 2004.

[7]. R. Garg, P. Bartia, I. Bahl, A. Ittipiboon, ‘’Microstrip Antenna Design Handbook’’, Artech House Inc. Norwood, MA, pp 1-68, 253-316, 2001.

[8]. A.I. Abunjaileh, I.C. Hunter, A.H. Kemp,”Multi-Band Matching Technique for Microstrip Patch Antenna Receivers”, *School of electronic and electrical engineerin*g, The University of Leeds” IEEE, EUMC.2007.4405174.

[9]. Eldek, A. A., A. Z. Elsherbeni, and C. E. Smith, “Design of wideband triangle slot antennas with tuning stub,” *Progress In Electromagnetic Research*, J. A. Kong (ed.), PIER 48, pp.233–248, 2004.

[10]. Stutzman, Warren L.; Thiele, Gary A. "Antenna Theory and Design", 3rd Ed. John Wiley & Sons. pp.560–564, 2012.

[11] R. F. Fahy, P. R. LeBlanc, J. L. Molis, "Cause of Fatal Injury or Illness", *Firefighter Fatalities in the United State - 2013,* NFPA Fire Analysis and Research, Quincy, MA, June 2014.

[12]. C. Fung, "Basic Antenna Theory and Application", *A Major Qualifying Project Report*, Worcester Polytechnic Institute, pp.12-15, 2011.

[13]. P. S. Nakar, "Design of a compact Microstrip Patch Antenna for use in Wireless/Cellular Devices", *Electronic Theses, Treatises and Dissertations,* Florida State University, Paper 2790.

[14] IEEE, "IEEE Standard Definitions of Terms for Antennas," IEEE, pp. 0-1, February 1983. [Online]. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=30651&isnumber=1290