# HUMAN BODY'S CHANNEL MODELING AND LOW POWER, HIGH DATA RATE TRANSCEIVER DESIGN FOR WIRELESS CAPSULE ENDOSCOPY

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**UNIVERSITI MALAYSIA PERLIS**

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by

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ADS | Advanced design system |
| AGC | Automatic gain control |
| ASIC | Application specific integrated circuit |
| ASK | Amplitude shift keying |
| BER | Bit error rate |
| CCD | Charge-coupled device |
| CMOS | Complementary metal oxide semiconductor |
| CST | Computer simulation technology |
| CT | Computer tomography |
| DOF | Degree of freedom |
| EM | Electromagnetic |
| FCC | Federal communication commission |
| FDA | Food and drug administration |
| FDTD | Finite difference time domain |
| FIT | Finite integration technique |
| FSK | Frequency Shift Keying |
| GI | Gastrointestinal |
| IF | Intermediate frequency |
| IR-UWB | Impulse radio ultra wide band |
| LA | Logarithmic amplifier |
| MRI | Magnetic resonance imaging |
| NF | Noise figure |
| OGIB | Obscure gastrointestinal bleeding |
| OOK | On off keying |

| | |
|---|---|
| PLL | Phase locked loop |
| RF | Radio frequency |
| SNR | Signal to noise ratio |
| TSMC | Taiwan semiconductor manufacturing company |
| VCO | Voltage control oscillator |
| WBAN | Wireless body area network |
| WCE | Wireless capsule endoscopy |
| WPT | Wireless Power Transmit |

## LIST OF SYMBOLS AND VARIABLES

| | |
|---|---|
| $P_t$ | Transmitted power |
| $P_r$ | Received power |
| $d$ | Distance between the transmitting point and the receiving point |
| $f$ | Frequency |
| $c$ | Speed of light |
| $\bar{\varepsilon}_r$ | Relative permittivity |
| $\bar{\sigma}$ | Conductivity |
| $\alpha_{body}$ | Attenuation constant of body tissue |
| $L_{body}$ | Path loss by the body tissue |
| $d_{body}$ | Distance between the source and the receiving antenna in WCE |
| μ | Permeability |
| $MN$ | NMOS |
| $MP$ | PMOS |
| $L$ | Inductance |
| $C$ | Capacitance |
| $K$ | Boltzmann's constant, |
| $T$ | Absolute temperature, |
| $A$ | Start-up safety factor |
| $\omega_o$ | Frequency of oscillation |
| $\Delta\omega$ | Offset frequency |
| $V$ | Peak output amplitude |
| $Q$ | Quality factor |
| $W_M$ | Width of active device |
| $L_M$ | Length of active devices |

| | |
|---|---|
| $\mu_{p/n}$ | Carrier's mobility of P-type/N-type material |
| $C_{ox}$ | Gate capacitance per unit area |
| $t_{s\text{-}u}$ | Start-up period of oscillator |
| $t_{s\text{-}s}$ | Steady-state period of oscillator |
| $t_d$ | Decay period of oscillator |
| $g_m$ | Transconductance of MOS transistor |

**Permodelan Saluran Tubuh Manusia dan Rekabentuk Penghantarterima Kuasa Rendah Data Berkadar Tinggi untuk Endoskop Kapsul Wayarles**

## ABSTRAK

Endoskop Kapsul Wayarles (EKW) boleh hadam adalah satu-satunya teknologi diagnostik baru yang tidak menyakitkan dan efektif untuk memeriksa keseluruhan laluan penyakit gastrousus (GU). Tetapi beberapa batasan utama, resolusi imej yang teruk, masa penggunaan yang terhad dan tidak mampu untuk melihat kawasan kritikal secara berulang menghadkan penggunaan teknologi ini secara meluas. Untuk pembangunan EKW yang seterusnya, tumpuan utama ialah membangunkan sistem telemetri berkuasa rendah dan kelajuan tinggi yang mampu menghantar imej beresolusi tinggi pada kadar bingkai yang lebih tinggi. Oleh itu, tesis ini melaporkan penyiasatan kehilangan laluan dan perubahannya dalam saluran badan manusia melaluai rekabentuk penghantarterima (penghantar dan penerima) berprestasi tinggi. Untuk menyiasat kehilangan laluan dalam saluran badan, model tubuh manusia yang berbeza-beza telah digunakan, yang mana lebih setanding dengan badan manusia daripada model seragam. Teknik integrasi terhingga (TIT) dalam perisian *Computer Simulation Technology (CST) Microwave Studio* telah digunakan dalam simulasi. Kehilangan laluan dianalisa dalam julat frekuensi 100 MHz hingga 2450 MHz. Kehilangan laluan didapati paling nyata lebih rendah pada frekuensi bawah 900 MHz. Kehilangan terkecil didapati di sekitar frekuensi 450 MHz, di mana perubahan kehilangan laluan sepanjang saluran GI adalah 29 dB, dengan minimum -9 dB dan maksimum -38 dB. Walau bagaimanapun, pada 900 MHz, perubahan ini telah diperhatikan menjadi 38 dB, dengan minimum -10 dB dan maksimum -48 dB. Kehilangan laluan menjadi agak tinggi semasa pemeriksaan di bahagian anatomi-kompleks, seperti di usus atas dan esofagus bawah berbanding dengan perut kurang kompleks dan bahagian esofagus atas. Oleh itu, adalah disyorkan bahawa spektrum yang dipusatkan pada 450 MHz menjadi pilihan yang optima bagi memihak kepada kehilangan laluan kecil. Akhirnya, sebuah pemancar modulasi langsung yang sangat cekap dan analog RF berdigital kepada penerima penukaran digital yang kedua-duaanya menyokong kadar data sehingga 100 Mbps, telah direka dalam perisian Advanced Design System (ADS) pada 450 MHz. Laluan penghantaran hanya terdiri daripada pengayun kuasa rendah, penapis terkandung dan sebuah rangkaian sepadan. Keseluruhan litar pemancar secara purata menggunakan 2 mA dari bekalan 1.5 V DC. Permulaan tempoh fasa pengayun telah dioptimumkan kepada kurang daripada 6 ns untuk menyokong penghantaran data digital pada kadar 100 Mbps. Disamping itu, penerima telah dilaksana dengan menggunakan penguat hingar rendah (PHR), penguat logaritma (PL), pengesan kuasa dan pembanding. PHR tersebut dan tiga peringkat PL memberikan gandaan sebanyak 80 dB yang menjadikan penerima dapat mengesan input isyarat yang lemah sehingga dari peringkat -80 dBm.

**Human Body's Channel Modeling and Low Power, High Data Rate Transceiver Design for Wireless Capsule Endoscopy**

## ABSTRACT

Ingestible wireless capsule endoscopy (WCE) is one and only the painless effective novel diagnostic technology for inspecting entire gastrointestinal (GI) track diseases. But some major limitations, poor image resolution, limited working time and unable to repeated view of critical area confine the wider application of this technology. For the further development of WCE, the main concern is the development of a low power and high-speed telemetry system that is capable of transmitting high-resolution images at a higher frame rate. In this regard, this thesis report on investigation of path loss and its variation in human body channel with high performance transceiver (transmitter and receiver) design. To investigate the path loss in the body channel, a heterogeneous human body model was used, which is more comparable to the human body than a homogenous model. The finite integration technique (FIT) in Computer Simulation Technology's (CST's) Microwave Studio was used in the simulation. The path loss was analyzed in the frequency range of 100 MHz to 2450 MHz. The path loss was found to be saliently lower at frequencies below 900 MHz. The smallest loss was found around the frequency of 450 MHz, where the variation of path loss throughout the GI tract was 29 dB, with a minimum of -9 dB and a maximum of -38 dB. However, at 900 MHz, this variation was observed to be 38 dB, with a minimum of -10 dB and a maximum of -48 dB. The path loss was comparatively higher during examination of anatomically-complex regions, such as the upper intestine and the lower esophagus as compared to the less complex stomach and upper esophagus areas. Therefore, it is recommended that the spectrum centralized at 450 MHz should be the optimum selection in favour of smallest path loss. Finally, a highly efficient direct modulation transmitter and a digitalized RF analog to digital conversion receiver, both of supporting the data rate up to 100 Mbps, have been designed in Advanced Design System (ADS) at 450 MHz. The transmitting path consists only a low power oscillator, an envelope filter and a matching network. The entire transmitter circuit draws average 2 mA current from a 1.5 V DC supply. The start-up transient period of oscillator is optimized to less than 6 ns to support digital data transmission at the rate of 100 Mbps. On the other hand, the receiver is implemented using a low noise amplifier (LNA), logarithmic amplifier (LA), power detector and comparator. The LNA and the three stages LA provide the gain 80 dB which makes able the receiver sense the input weak signal up to the level -80 dBm.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Endoscopy is a system that makes it possible to conduct visual examinations inside the body for medical reasons. Most of the lethal diseases in the gastrointestinal (GI) track such as cancer, tumors, obscure gastrointestinal bleeding (OGIB), crohn's disease, and celiac disease can be controlled and cured if it is possible to detect in their earlier stages (Pan et al., 2012). Angiography, Ultrasonography, X-radiography, computer tomography (CT), and magnetic resonance imaging (MRI) are conventional, indirect technologies for examining GI tract diseases. Regrettably, these technologies have low diagnostic yields because their inability to show the wall of the GI tract. Another typical technology, probe/wired endoscopy, is used for diagnosing diseases of the GI tract, but, in addition to being painful and creating discomfort, it is incapable of reaching some critical locations in the GI tract.



The development of ingestible wireless capsule endoscopy (WCE) is viewed as a revolutionary advancement in GI tract endoscopy. This emerging technique overcame the previous complexities associated with inspecting the entire small intestine, which is the most complex part of the GI tract and is unreachable by conventional probe endoscopy. In 2000, Iddan et. al., (2000) first developed a wireless video capsule endoscopy system that patients could swallow, but its development has been started since long ago.

The concept of the swallowable wireless capsule realized with the development of parametric capsule for measuring physiological parameter of GI track such as pressure, temperature and pH. The invention of parameter capsule was possible, due to the development of the transistor that allowed to design small size radio-telemetry for capsule. However, this capsule was unable to see the GI track wall. In 1981, Iddan first developed the concept of wireless video capsule endoscopy to see the wall of the GI tract painlessly, but the state of the development of the required technology deterred the realization of this concept. Fourteen years later, Swain et. al., (1997) developed several prototypes of a capsule endoscopy system and successfully conducted a vast number of experiments on post-mortem and live pigs. In those prototypes, they used a miniature charge-coupled device (CCD) camera, a video processor, a 10-mW microwave transmitter with a 1.5-cm dipole antenna, a light source, and a battery. In 2000, the introduction of the low-power, complementary metal oxide semiconductor-based (CMOS-based) image sensor and application specific integrated circuit (ASIC) made the video capsule possible (Iddan et.al., 2000).



Since the development of this technology, several companies have made remarkable improvements in their clinical products, but there are still some limitations that relate to the use of conventional, wired endoscopy. Some of the major limitations that currently impede its wider application include its working time constraints, poor image quality and inability to repeat the view of critical areas. Many research groups currently are working on ways to solve these limitations. Developing the low power high data rate telemetry system is the most promising area of improving capsule's performance, because it can allow high speed transmission of high quality image, consuming low power which can increase also capsule's working time.

## 1.2 Motivation for This Research

The GI track disorder is a very common problem of human being. Due to the severe pain and discomfort in typical probe endoscopy (cannulae with embedded light source and image sensor that are inserted through the mouth, anus or nose), patients are quite sick to go through the endoscope. Along with this, the limited level of insertion of endoscopic probe makes this technology unable to view inside the small bowel (Loeve et al., 2010). In the recent past, the development of technology for low power CMOS image sensor, ASIC and miniaturized LEDs enable the realization of WCE that overcomes the downsides of conventional endoscopy (Ciuti et al., 2011). However, the limited working time, lower frame rate and low image regulation deter the wider application of WCE and made still existing of probe endoscopy in the clinic. This leads to remarkable ongoing research on the further development of WCE.

The path loss by the wireless body channel, between in body capsule and on body receiving antenna, can't be readily calculated due to the complex multilayer structure of human body and the frequency dependent properties of its different tissues. Few researches have been conducted on the investigation of radiation characteristics (Alomainy et al., 2006; Alomainy et al., 2009; Chirwa et al., 2003; Takizawa et al., 2011) where the path loss and the variation of path loss with the possible capsule locations are not reported properly. Some of these researches are using a homogeneous body model which is less comparable to the actual human body than the heterogeneous body model (Ji-Hyun Jung et la., 2010; Theilmann et al., 2012). Therefore, the path loss analysis in the human body channel using a heterogeneous body model is an essential task to develop an efficient telemetry system for high quality image transmission.

After the body channel analysis, high speed radio frequency (RF) transceiver system will need to be designed which is not straightforward. In the RF system design the bandwidth of system is a vital issue as in the digital system data rate is strongly related to the system bandwidth (Lee et al., 2011). So, the bandwidth should be wider enough to support the transmission of high resolution image data. The present capsule system has the data rate around 2 Mbps (Chi et al., 2007; Itoh et al., 2006), that is able to transmit the image with the resolution of 256x256 pixel at the rate of 2 frames per second. Recently, many RF telemetry systems have been developed (Gao et al., 2011; Kim et al., 2012; Thone et al., 2009) and the maximum data rate have been achieved 20 Mbps that also not sufficient for transmitting 640x640 pixel image at the rate of 30 frames per second. Hence, a potential research is required to develop highly efficient and high data rate telemetry system.



## 1.3 Thesis Objectives

The main purpose of this thesis is addressing the solution of the major limitations of the present WCE system those deter the wider application of WCE in clinic. Considering the practicality, to accomplish the goal, this research work opted into the following objectives:

1. To investigate the human body's channel condition through path loss analysis and to determine the optimum frequency spectrum for the efficient telemetry system of WCE.

2. To design high speed RF transmitter at the optimum frequency to support high quality image transmission at higher number of frames per second with lowest power consumption.

3. To design high speed, simplified RF receiver at the optimum frequency with sufficient bandwidth to support high speed data reception while keeping the optimum power consumption and the sufficient receiver's sensitivity.

## 1.4 Methodology

In order to investigate the human body's channel condition and optimum system frequency for WCE, path loss and its variation has been analyzed in heterogeneous digital body model using Computer Simulation Technology's (CST's) Microwave Studio, which based on the finite integration technique (FIT). The simulation environment is created by cutting the digital body model in a brick shape (10cm x 10cm x Dcm). Where, D is the depth of the brick and the value of D vary in the simulation from 4cm to 17cm according to the consideration of the actual depth of the capsule. Setting the boundary condition, the brick is considered virtual waveguide. Two waveguide ports were used at the opposite end of the virtual waveguide to evaluate the microwave transmission coefficient $S_{21}$.



Taiwan Semiconductor Manufacturing Company's RF CMOS 0.18 µm process (version 3.0) is used in Advanced Design System (ADS) for simulating both of transmitter and receiver circuit symmetry. To ensure the low power design, the on-off keying (OOK) modulation scheme is adopted in direct modulation transmitter architecture. The current reuse oscillator is turned on and off by the transmitting bits that consequences the OOK signal. Furthermore, an envelope filter and matching network are used to filter the OOK signal and to match antenna input impedance 50 Ω. The direct RF analog to digital conversion architecture is used at the receiving end. In the receiver subsequent block, the common source cascade low noise amplifier (LNA) is designed to have a high LNA gain, reverse isolation and low noise figure (NF) and wider bandwidth. Finally, to extract the transmitted data bit, logarithmic amplifier (LA), the rectifier and the DC level comparator are added sequentially to the receiver section.

## 1.5 Organization of the Thesis

This thesis is organized with five distinct chapters and the contains of each chapter is as described below:

Chapter 1 demonstrates brief background of the tropic, motivation for this research, objectives and used methodology alongside this chapter cover the organization of this thesis.

Chapter 2 illustrates the present wireless endoscopic capsules those are currently using in clinic, detailed literature review of current research on the betterment of present capsule, achievement and technical challenges, and the overall discussion with the promising side of capsule to develop.

Chapter 3 describes the methods of path loss analysis in the human body's channel using digital body phantom, simulation setup to determine the path loss in terms of different frequency and location of the capsule in GI path, architectures of proposed RF transmitter and receiver, low power circuit design approach, and the design of low power high data transmitter and receiver with the optimization to enhance the data rate and to reduce the power consumption.

Chapter 4 explains the channel characteristics of human body for electrom-agnetic (EM) signal propagation to figure out the optimum frequency for WCE, the performance of the proposed RF transmitter and receiver in the most favorable