COMPACT INGESTIBLE PLANAR INVERTED-F ANTENNA (PIFA) FOR BIOTELEMETRY SYSTEMS

by

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THESIS DECLARATION

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LIST OF ABBREVIATIONS

3D	Three-Dimensional
AWGN	White Gaussian Noise
BTSL	Body Tissue Simulating Liquid
BW	Bandwidth
CST	Computer Simulation Technology
CT	Computer Tomography
DGBE	Diethylene Glycol Butyl Ether
ETSI	European Telecommunications Standards Institute
ERM	Electromagnetic compatibility and Radio spectrum Matters
E-field	Electric Field
FCC	Federal Communication Commission
GHz	Giga Hertz
GI	Gastrointestinal Tract
H-field	Magnetic Field
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific and Medical
LED	Light-Emitting Diodes
MCMC	Malaysia Communications and Multimedia Commission
MHz	Mega Hertz
MICS	Medical Implant Communication System
MRI	Magnetic-Resonance Imaging
PIFA	Planar Inverted-F Antenna
RF	Radio Frequency
SAR	Specific Absorption Rate
SI	Small Intestine
SNR	Signal Noise Ratio
SRD	Short Range Devices

ULP-AMI	Ultra-Low Power Active Medical Implants
ULP-AMI-P	Ultra-Low Power Active Medical Implants and Peripherals
UWB	Ultra Wide-band
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

λ	Wavelength
c	Speed of light
dB	Decibel
ε_r	Relative dielectric constant
ε_{eff}	Effective permittivity
$\lvert E \rvert$	RMS electric field
f	Frequency
g	Gram
H_{eff}	Effective height
kg	Kilogram
mm	Millimetre
N	Noise power
σ	Electrical conductivity
ρ	Density
S	Mean signal
$\lvert S_{11} \rvert$	Reflection coefficient
$\lvert S_{21} \rvert$	Coupling strength
W	Watt
V_d	Volume by including dielectric permittivity and resonance frequency

Antenna Satah Terkalih-F (ASTF) Kompak untuk Sistem Biotelemetri

ABSTRAK

Pendarahan dari saluran gastrousus (SG) adalah masalah perubatan umum.. SG bermula dari mulut, menuju ke esofagus, perut, usus kecil, kolon dan berakhir di rektum dan anus. Endoskopi berwayar tradisional memungkinkan ia mengdiagnos esofagus, perut, kolon, rektum dan anus, akan tetapi disebabkan limitasi fizikal, ia meninggalkan usus kecil yang sepanjang 20 kaki, tidak kira dengan menggunakan proses endoskopi dari atas atau bawah. Sebuah peranti bioperubatan tanpa wayar boleh-telan atau kapsul endoskop tanpa wayar yang dipasang dengan kamera video kecil dan cukup kecil untuk ditelan boleh memeriksa tanpa sakit bahagian-bahagian yang endoskopi berwayar tidak dapat sampai untuk memeriksa pendarahan yang tidak diketahui atau keabnormalan lain. Permintaan mencabar terhadap prestasi peranti bioperubatan tanpa wayar boleh-telan mencerminkan kesukaran dalam merekabentuk antena untuk peranti sebegitu disebabkan antena memainkan peranan penting kerana mempunyai banyak pautan komunikasi yang berkualiti dan pengecilan keseluruhan peranti, berbanding dengan komponen-komponen penting yang lain. Dalam tesis ini, satu antenna satah terkalih-F (ASTF) dicadangkan untuk diintegrasikan dengan sistem antena tablet boleh-telan untuk aplikasi biotelemetri dalam jalur industri, saintifik dan perubatan (ISP) 2.4-2.48 GHz. Dengan mengambil ciri-ciri tisu dan kerugiannya, reka bentuk antena yang dicadangkan telah dilakukan di dalam kotak dipenuhi dengan cecair simulasi tisu badan (CSTB) (ε_r = 52.7). Selain mengurangkan masa simulasi, ia juga adalah disebabkan oleh kemudahan yang praktikal untuk mengesahkan dan mengukur prestasi yang sama dalam lingkungan persekitaran yang usus kecil manusia (ε_r = 54.4). Antena yang dicadangkan adalah padat dan disaizkan pada 859 mm^3 (15 mm x 12 mm x 4,7748 mm). Ia dibina menggunakan dua struktur bersusun; substrat Taconic TLY-5 (ε_r = 2.2, tan δ = 0.0009) dan bahan seramik Eccostock HiK500F (ε_r = 30, tan δ = 0.002). Ciri resonans, prestasi radiasi, pengedaran kadar penyerapan spesifik (KPS) dan pautan komunikasi antena yang dicadangkan dalam CSTB dinilai dan dibandingkan dengan prestasinya dalam empat lapisan model tisu kanonikal (kulit, lemak, otot dan usus kecil). Yang paling penting, antena yang dicadangkan mencapai jalur lebar per unit isipadu tertinggi (BW/V_d) berbanding dengan kerja yang lain dalam literatur untuk aplikasi dalam badan.

Compact Ingestible Planar Inverted-F Antenna (PIFA) for Biotelemetry Systems

ABSTRACT

Bleeding from the gastrointestinal (GI) tract is a common medical problem. The GI tract starts at the mouth, going to the oesophagus, stomach, small intestine, colon and end at the rectum and anus. The traditional wired endoscopy made it possible to diagnose the oesophagus, stomach, colon, rectum and anus, but limited by physical reasons, leaving the remaining 20 feet of the small intestines regardless using upper or lower endoscopy procedures. An ingestible wireless biomedical device or wireless capsule endoscope fitted with a mini video camera and small enough to swallow can painlessly examine the parts that wired endoscopy cannot reach for diagnosing unexplained bleeding or other abnormalities. The challenging demand of ingestible wireless biomedical device performance reflects on the difficulties of designing the antenna for those device since the antenna plays a key role for having an abundance of quality communication links and miniaturization of the whole device, compared to the other essential components. In this thesis, a compact planar inverted-F antenna (PIFA) is proposed to be integrated with an ingestible tablet antenna system for biotelemetry application in the 2.4-2.48 GHz industrial, scientific, and medical (ISM) band. By taking the tissue properties and its losses, the design of the proposed antenna was performed inside a phantom box filled with body tissue simulating liquid (BTSL) (ε_r = 52.7). Besides reducing simulation time, this is mainly due to the practical ease to validate and measure its similar performance within the environment of a human small intestine (ε_r = 54.4). The proposed antenna is compact and is sized at 859 mm^3 (15 mm x 12 mm x 4.7748 mm). It is built using two-stacked structures; Taconic TLY-5 (ε_r = 2.2, tan δ = 0.0009) substrate and Eccostock HiK500F ceramic material (ε_r = 30, tan δ = 0.002). The resonance characteristic, radiation performance, specific absorption rate (SAR) distribution and communication link of the proposed antenna inside the BTSL is evaluated and compared with its performance inside a four-layer canonical tissue model (skin, fat, muscle and small intestine). Most importantly, the proposed antenna achieved the highest bandwidth per unit volume (BW/V_d) compared to other work in literature for in-body applications.

CHAPTER 1

INTRODUCTION

1.1 Introduction

For several decades, electromagnetism has been popular and continuously used in medical application such as microwave imaging, breast tumour detection, diagnosis, cancer treatment and many more (Rosen, Stuchly, & Vander Vorst, 2002). Nowadays, in the modern medical application, the wireless capabilities in electromagnetism world are extremely useful especially in biological telemetry (biotelemetry) application for diagnostic purposes. The biotelemetry is defined as transmitting biological or physiological information from inaccessible location to a remote monitoring site that has capability to interpret the data and affect decision making (Güler & Übeyli, 2002). The wireless biomedical devices for such biotelemetry system that can be used deeper inside the human body and transmit information to a receiver outside the body is no longer be the stuff of science fiction. A recent in-body wireless biomedical device that is gaining a lot of attention due to the capabilities of enabling the monitoring within the human body is the ingestible wireless biomedical device for endoscopy or sometimes called wireless capsule endoscopy.

1.2 Problem Statement

Most diseases such as ulcer, tumour or tissue bleeding will degenerate into cancer or some other critical diseases if not cured or controlled in their early stages, but it is not that easy to diagnosing all these diseases due to lack of specific equipment or technologies. The angiography, ultrasonography, X-radiography or other current technologies used to detect such diseases in the gastrointestinal (GI) tract were reported to give low diagnostic outputs for bleeding detection (Lewis, 2000; Zuckerman, Prakash, Askin, & Lewis, 2000), unless the bleeding become severely active (Howarth, Tang, & Lees, 2002). Bleeding from the GI tract is a common medical problem and the tract is a long, hollow, muscular passage where food and nutrients passes and absorbed. It starts at the mouth, going to the oesophagus, stomach, small intestine, colon and end at the rectum and anus. The traditional wired endoscopy made it possible to diagnose the oesophagus, stomach, colon, rectum and anus, but limited by physical reasons, leaving the remaining 20 feet of the small intestines regardless upper or lower endoscopy procedures as shown in Figure 1.1. Additionally, the use of wired endoscopy is usually very inconvenient for the patients, cause an intense pain and can increase the risk of having cross-contamination.

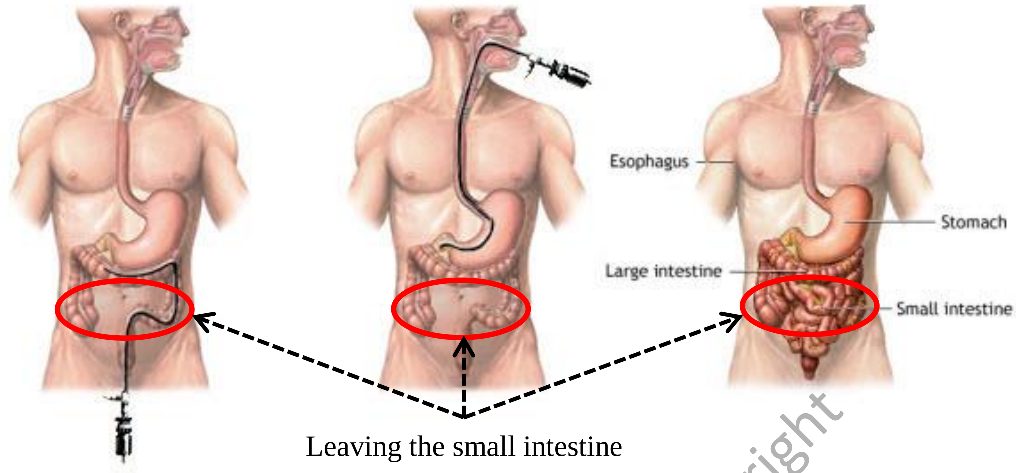

Figure 1.1: The traditional upper and lower endoscopy procedures neglecting small intestines. Human body image is taken from ("Animated Dissection of Anatomy for Medicine (A.D.A.M),").

An ingestible wireless biomedical device or wireless capsule endoscope fitted with a mini video camera and small enough to swallow can painlessly examine the parts that wired endoscopy cannot reach for diagnosing unexplained bleeding or other abnormalities (Mylonaki, Fritscher-Ravens, & Swain, 2003). The video data is transmitted wirelessly (as shown in Figure 1.2) and directly to a receiver or to a recorder attached to the patient's abdomen and later downloaded onto a computer for analysis.

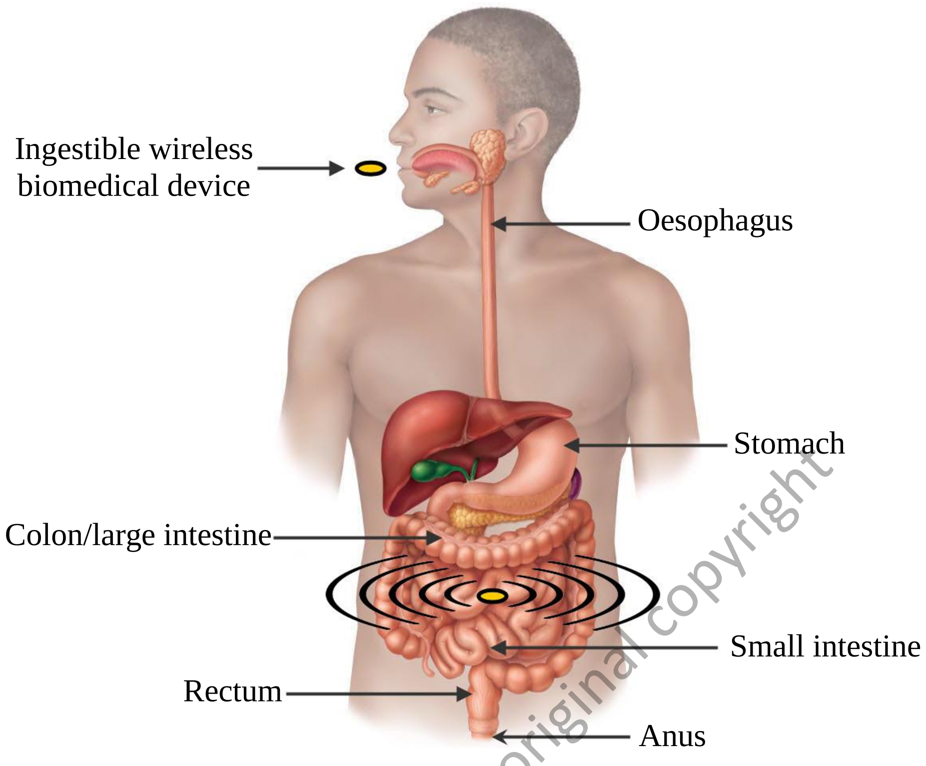

Figure 1.2: The operation of ingestible wireless biomedical device. Human body image is taken from ("Animated Dissection of Anatomy for Medicine (A.D.A.M),").

From the analysis, doctors or physicians able to make early, accurate diagnosis problems and make appropriate treatment. The patient also can relax in comfort without a hospital stay. There is no sedation involved during the procedure and additional investigations can often be avoided. Typical ingestible wireless biomedical device system contains many components as shown in Figure 1.3 including antenna, transmitter, batteries, camera, short focal length lens, light-emitting diodes (LED), lens holder and optical dome.

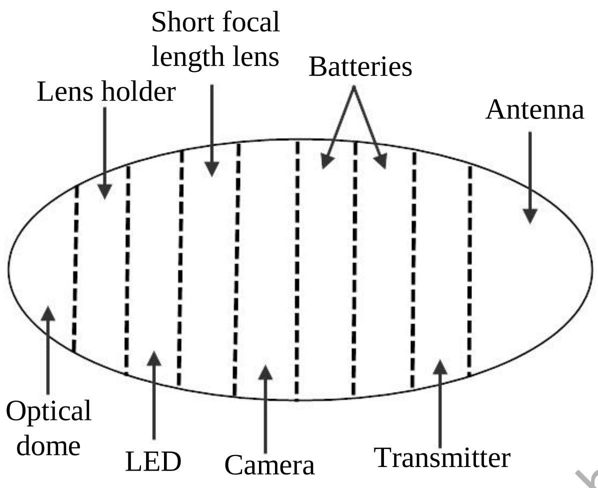

Figure 1.3: Ingestible wireless biomedical device layout.

1.3 Motivation

The challenging demand of in-body wireless biomedical device performance reflects on the difficulties of designing the antenna for those devices since the antenna plays a key role for having an abundance of quality communication links and miniaturization of the whole device, compared to the other essential components. In many ways, the design of antennas for the ingestible wireless biomedical device is similar to the design of antennas for implantable biotelemetry application in general, and there are some several requirements and challenging issues in designing these types of antenna:

a) Size constraints: The size of the antenna has to be very small and minimized as the antenna supposed to fit in dense packaging that also includes other essential components as the whole device is intended to operate in the human body.
b) Wide bandwidth: The antenna has to radiate into a complex lossy environment (human body) rather than into free space, thus antenna performance becomes

dependent on the surrounding tissue type with different layers and dielectric properties. Therefore, the antenna need to have a wide bandwidth to withstand the frequency shifting caused by those environments.

c) Radiation and coupling performance: The radiation characteristic of an antenna may have standard definitions (Balanis, 2012). However, the gain of the antenna for this type of application usually low due to the losses in the tissue and it is very difficult to get the radiation performance near to the ideal lossless antenna. Therefore, the communication link in terms of coupling between antenna inside the body and external receiving unit need to be evaluated to ensure the communication robustness.

d) Patient safety: Due to the fact that the radiation and propagation of the antenna from inside to the outside of the human body will cause the rise of temperature in the body tissues, the antenna has to comply with the maximum specific absorption rate (SAR) set by certain regulators and standards.

Motivated in part by the need of new antenna for ingestible wireless biomedical device that have a wide bandwidth, compact and at the same time can deal with patient safety, this thesis aims to design an ingestible antenna at 2.4 GHz - 2.48 GHz ISM band, since this band have the most potential to become promising solutions to be used for the in-body wireless biomedical devices inside the human body as the frequency band being well-developed in terms of technology (i.e: Wi-Fi) and favourable for high data rate applications such as real-time video transmission. Recent commercial products operate at 433 MHz and such lower frequency may give an advantage on propagation to an outside body, but not able to support high data rate communication and high quality real-time continuous image transmission.