SYMMETRIC WIDEBAND FIVE PORT REFLECTOMETER FOR MICROWAVE-IMAGING-BASED BRAIN INJURY DIAGNOSIS

by

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LIST OF ABBREVIATIONS

AUT	antenna under test
BW	bandwidth
CT	computed tomography
DAS	delay and sum (imaging algorithm)
DMAS	delay multiply and sum (imaging algorithm)
DGS	defected ground substrate
DSPNA	dual six port network analyzer
DSPR	dual port six port reflectometer
DUT	device under test
EF	error function
EIT	electrical impedance tomography
ENG	epsilon negative
FCC	Federal Communications Commission
FDTD	finite difference time domain
FPR	five port reflectometer
ICH	intracranial hemorrhage
IF	intermediate frequency
IFFT	inverse fast fourier transformation
LO	local oscillators
LOS	line of sight
MIS	magnetic induction spectroscopy
MIST	microwave space time
MNG	mu negative
MRI	magnetic resonance imaging
MWI	micro-wave imaging
RBI	radar-based imaging
SNG	single negative
SPR	six port reflectometer
SRR	split ring resonator
TCD	transcranial doppler
UWB	ultra wide-band
VNA	vector network analyzer
WB	wide-band

LIST OF SYMBOLS

ϵ_r	Relative Permittivity
σ	Conductivity
c	The speed of light ($3 \times 10^8\ ms^{-1}$)
λ	Free space wavelength
i'_k	Eigen mode excitation current of k^{th} mode for five port reflectometer
C	Capacitance
R	Resistance
L	Inductance
v	Average speed of propagation of wave in brain tissue
f_s	Sampling frequency
ε_{eff}	Effective permittivity
λ_g	Guided Wavelength
Y	Admittance
f_c	Resonance frequency
$BW_{-20\ dB}$	Fractional bandwidth less than -20 dB
$BW_{-10\ dB}$	Fractional bandwidth less than -10 dB

LUASJALUR SIMETRI LIMA LIANG REFLEKTOMETER UNTUK DIAGNOSIS KECEDERAAN OTAK BERASASKAN PENGIMEJAN GELOMBANG MIKRO

ABSTRAK

Kecederaan otak dianggap sebagai salah satu penyebab penting untuk kematian di seluruh dunia dengan lebih daripada 15 juta orang mengalami serangan strok otak setiap tahun, menurut Pertubuhan Kesihatan Sedunia (WHO). Keterbatasan teknik konvensional pengimejan kepala seperti MRI dan scan CT telah ditunjukkan didalam tesis di mana ciri diagnosis mudah alih dan cepat tidak dapat dilakukan. Pengimejan berasaskan radar (RBI) ditangani sebagai penyelesaian yang berpotensi kerana keberkesanan dan kebolehannya untuk diagnosis utama kecederaan otak. Walau bagaimanapun, struktur yang besar dan kos penganalisis rangkaian vektor (VNA) yang tinggi mengehadkan potensi RBI. Lima liang reflektometer (FPR) mempunyai potensi untuk menggantikan VNA. Dua prototaip FPR telah dicadangkan dalam tesis ini. Prototaip pertama melibatkan satu jajaran metamaterial negatif (SNG) yang terletak pada bahagian tanah satu cincin tunggal FPR, manakala yang kedua melibatkan rangkaian penggantian dua peringkat tambahan pada cincin tengah pertama. Dalam prototaip pertama, cincin tunggal FPR direka berdasarkan parameter teoretikal yang disepadukan dengan jajaran metamaterial SNG pada satah tanah yang telah dioptimumkan untuk mendapatkan jalur lebar yang lebih besar. Ia diperhatikan bahawa ketelusan berkesan substrat berubah disebabkan pengaruh metamaterial SNG yang akhirnya mengubah impedans talian penghantaran FPR di bahagian depan substrat. Jajaran metamaterial meningkatkan prestasi keseluruhan cincin tunggal FPR dengan peningkatan sebanyak 65.62% pecahan jalur lebar ($BW_{-10\ dB}$) pada jalur pertama dan 76.23% pada jalur kedua berbanding dengan reka bentuk tanpa jajaran metamaterial. Prototaip pertama mempunyai zon operasi dwi-jalur yang beralih dari 0.93 GHz ke 2.19 GHz dan dari 3.27 GHz hingga 4.49 GHz. Prototaip kedua terdiri daripada rangkaian dua peringkat dengan garisan penghantaran antara peringkat dan pemadanan berbilang bahagian pada setiap lengan. Dalam evolusi prototaip kedua, garisan-garisan penghantaran antara peringkat beralih sebanyak 36˚ (yang merupakan separuh nilai faktorisasi jarak sudut antara-liang 72˚) dalam beberapa langkah mengoptimumkan, iaitu, a) tidak beralih b) beralih sebahagian dan c) reka bentuk beralih sepenuhnya. Reka bentuk beralih sepenuhnya yang mempunyai 36˚ alihan antara peringkat dan satu lagi 36° alihan lengan telah menghasilkan panjang elektrik tambahan yang dilalui oleh isyarat transmisi antara-liang untuk meningkatkan jalur lebar sehingga 88.04% (dari 1.004 GHz hingga 2.583 GHz). Di samping pencapaian jalur lebar, kekompakan FPR yang dicadangkan disumbangkan oleh garis melengkung di bahagian padanan luar yang membolehkan pengurangan panjang sebanyak 43.09% dan lebar sebanyak 43.12% berbanding dengan reka bentuk yang tidak kompak. Kedua-dua prototaip telah direka dan diukur. Perbezaan antara keputusan simulasi dan diukur dinilai dengan menggunakan sisihan mutlak min. 88.04% jalur lebar dari cadandan reka bentuk beralih sepenuhnya FPR adalah jalur lebar tertinggi di antara literatur yang berpotensi membawa kepada ketepatan tertinggi diagnosis kecederaan otak yang berasaskan pengimejan gelombang mikro.

SYMMETRIC WIDEBAND FIVE PORT REFLECTOMETER FOR MICROWAVE-IMAGING-BASED BRAIN INJURY DIAGNOSIS

ABSTRACT

Brain injury is considered as one of the vital reasons for death worldwide with more than 15 million people suffer from brain stroke attack each year, according to World Health Organization (WHO). The limitations of conventional head imaging techniques such as MRI and CT-scan have been pointed out in the thesis where a portable and prompt diagnosis features are not made possible. Radar-based imaging (RBI) is addressed as a potential solution due to its effectiveness and aptness for a primary diagnosis of brain injury. However, the bulky structure and high-cost of vector network analyzer (VNA) limit the RBI potential. Five port reflectometer (FPR) has potential to substitute VNA. Two prototypes of FPR have been proposed in this thesis. First prototype involves a single negative (SNG) metamaterial array located at the ground of single ring FPR, whereas the second one involves double tier compensating network in additional to the first central ring. In the first prototype, the single ring FPR is designed based on the theoretical parameters integrated with SNG metamaterial array at the ground plane which has been optimized to obtain a larger bandwidth. It is observed that the effective permittivity of the substrate is changed due to the influence of SNG metamaterial which eventually changed the characteristic impedance of the transmission lines of the FPR at the front side of the substrate. The metamaterial array enhances the overall performance of single ring FPR with an increment of 65.62% fractional bandwidth ($BW_{-10\ dB}$) in the first band and 76.23% in the second band as compared to the design without metamaterial array. The first prototype has a dual-band operating zone extending from 0.93 GHz to 2.19 GHz and from 3.27 GHz to 4.49 GHz. The second prototype consists of double tier networks with inter-tier transmission lines and multi-section matching at each of arms. In the evolution of the second prototype, inter-tier transmission lines are shifted by 36˚ (which is half factorized value of inter-port angular distance of 72˚) in several optimizing steps, namely, a) non-shifted b) partially shifted and c) fully shifted design. Fully shifted design which has 36˚ shifted inter-tier and another 36˚ shifted arms has created additional electrical length traversed by inter-port transmission signals to enhance the bandwidth up to 88.04% (from 1.004 GHz to 2.583 GHz). In addition of bandwidth achievement, such compactness of proposed FPR is contributed by the curved lines at the outer matching sections which enable a reduction of 43.09% in length and 43.12% in width compared to the non-compact design. Both prototypes have been fabricated and measured. Discrepancies between simulated and measured results are assessed using mean absolute deviation. The 88.04% bandwidth of the proposed fully shifted FPR is the highest bandwidth among literatures which potentially leads to a higher accuracy of microwave imaging-based brain injury diagnosis.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

Brain injury, a medical emergency is one of the major causes of death and physical and mental disability worldwide. It can occur from external and internal force suddenly forces the brain, causing some organ or the whole body to malfunction owing to the damage of the part of the brain controlling that limb or organ. Sometimes it may cause death to the affected person if the injury is severe.

Among other brain injuries, each year 2.5 people among 10,000 people are affected by intracranial hemorrhage (ICH) alone each year. About 44% of those affected die within a month. As per the statement of World Health Organization (WHO), each year about 15 million people suffer from brain stroke attack. Among them, 5 million of them die while 5 million of them go to permanent disability (B. Mohammed, Abbosh, Henin, & Sharpe, 2012).

A stroke occurs when a blood vessel within the brain bursts or swell due to the external force or internal disease. This hampers the adequate oxygen supply to the brain tissues, causing the brain cells to die and consecutively failure of brain function. Therefore, rapid diagnosis of brain injury is needed to recover the affected patient completely.

1.2 Research Background

To-the-date there are sensitive technologies for head imaging like computed tomography (CT) scan and magnetic resonance imaging (MRI) for primary diagnosis of brain injuries. These technologies are bulky, immobile and expensive.

Moreover, MRI technology made compulsory for the subject (patient) to lay down on a table, which can invoke fear of being in narrow space (Claustrophobia). Three-quarter of the affected patients do not get proper affordable medical imaging according to WHO (Ahmed Toaha Mobashsher, 2016). Moreover, heavy machineries used in MRI and CT scan retard the portability of these technologies and paramedic teams cannot carry these heavy machineries to the patient on-the-spot for early diagnosis. Therefore, it is imperative to facilitate a new non-invasive, non-ionizing, low-cost alternative to these technologies, which can be affordable to the rural clinics and carried out by ambulance to ensure early diagnosis.

1.2.1 Microwave Imaging (MWI): An Alternative Brain Imaging Technology

Researchers have proposed a technique called microwave imaging (MWI), as an alternative on-the-spot detection system for stroke and brain tumor. Among other advantages of MWI include being non-invasive, the capability to focus the energy, wide range of frequencies, less expensive and portable features (Ahmed Toaha Mobashsher, 2016; Zubaida Abdul Sattar, 2012). MWI has been successfully implemented in breast tumor detection (Fear et al., 2013; Fear, Meaney, & Stuchly, 2003) and more recently in head injury detection (D Ireland & Bialkowski, 2011a; A. T. Mobashsher, Nguyen, & Abbosh, 2013; Ahmed Toaha Mobashsher, 2016; Ahmed Toaha Mobashsher & Abbosh, 2016; B. J. Mohammed, Abbosh, Ireland, & Bialkowski, 2012; S. Mustafa, Mohammed, & Abbosh, 2013).

Blood has different dielectric property than brain tissue, accumulation of blood in hemorrhagic or ischemic condition creates a dielectric contrast among the bleeding affected area and surrounding area. The dielectric contrast is the basic property that creates a difference in the transmitted microwave signals, carrying information of the stroke in MWI-based brain injury diagnosis system.

There are different types of MWI techniques which include passive, hybrid and active approaches (Xu Li, Davis, Hagness, Van Der Weide, & Van Veen, 2004). Only active approach has been reported for head injury diagnosis. There are two types of active MWI, namely microwave tomography (MT) and wideband (WB) radar-based imaging (RBI). Different algorithm has been proposed for RBI, which include delay and sum (DAS) beamformer, delay multiply and sum (DMAS) beamformer (Lim, Nhung, Li, & Thang, 2008), coherence weighted beamformer and microwave space time (MIST) beamformer (Bond, Li, Hagness, & Van Veen, 2003). DAS algorithm is the basis of the enormous mainstream of RBI.

In RBI, the head is illuminated with microwave pulse. The dielectric contrast between the normal and tumor tissue or the stroke zone generates backscattered signals which are then collected through the receivers at microwave frequencies. The RBI uses delay and sum (DAS) or confocal beamformer which is based on a time-shift algorithm to collect the backscattered energy from a particular synthetic focal point within the head. The measurements are carried out in the frequency domain and then the data are converted into time domain backscattered signal by inverse fast Fourier transformation