DESIGN A HIGH GAIN UWB MIMO UNIPLANAR MONOPOLE ANTENNA WITH FSS ARRAY FOR METALLIC OBJECT MICROWAVE IMAGING

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“To my beloved parents for their praying and supporting. Specially to my lovely wife your praying, supporting, and patience keeps me up alive and my lovely kids”.

“To my family, country, the Iraqi government, and all the people for safe life”.
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ABSTRACT

Ultra-wideband (UWB) system plays an important role in microwave imaging (MWI) applications due to its broad bandwidth, non-ionising radiation, and cost-efficiency. This study involves the design and development phases for the optimum solution of UWB antenna’s issues. In the design phase, a compact uniplanar hexagonal UWB monopole antenna with a coplanar waveguide (CPW) feed is designed. The proposed UWB antenna has an oscillate impedance (Za) of 50 Ω. A meander-line notch filter is loaded on the designed antenna that achieves a high rejection (S_{11} = -1.75 dB) at the band of 3.0 GHz for 5G mid-band. A T-strip is inserted between the two proposed MIMO antennas to improve the isolation. Moreover, the smallest uniplanar UWB frequency selective surface (FSS) unit cell size (0.095λ×0.095λ) is miniaturized on the FR4 substrate. The simulations are compared with the equivalent circuit models of the proposed solutions, then validate with the measurement results. In the development phase, the hexagonal monopole MIMO antenna, the CPW feed, the isolation T-strip, and the 3 × 7 FSS array are assembled to develop the MWI. The isolated MIMO antenna with FSS (IMAF) achieves a bandwidth of 3-11.7 GHz, unidirectional radiation patterns, mutual coupling (S_{21} about -27 dB) and gain (6-8.5 dBi), and it better than the existing antennas of 3.1-10.6 GHz, -20 dB, and 5.5 dBi, respectively. Additionally, the baggage–scanner scheme is developed as a case study to evaluate the IMAF for near-field MWI. The evaluated images show a resolution of the IMAF is 55% higher than that of the MIMO antenna without an FSS array. Thus, the proposed IMAF detects the smallest (0.5 × 2 cm²) metallic object with a location accuracy of ± 0.5 cm compared with the recent simulation study of (0.6 × 0.6 cm² and ±1.1 cm, respectively). A good agreement is observed between the simulated and measured images of the MWI. Consequently, the IMAF is proved to be applicable as part of the detection system for low-cost and non-intricate baggage–scanner imaging to detect metallic objects.
ABSTRAK

Sistem jalurlebar-ultra (UWB) memainkan peranan penting dalam aplikasi pengimekan gelombang mikro (MWI) kerana lebar jalur yang luas, sinaran tak mengion, dan kecepatan kos. Kajian ini melibatkan fasa rekabentuk dan pembangunan untuk penyelesaian optimum masalah antena UWB. Dalam fasa rekabentuk, sebuah antena padat ekakutub UWB heksagon satah sesisi dengan suapan pandu gelombang sesatah (CPW) telah direkabentuk. Antena UWB yang dicadangkan mempunyai galangan berayun (Za) sebanyak 50 Ω. Sebuah penapis takuk garisan liku dimuatkan pada antena yang direkabentuk yang mencapai penolakan tinggi (S_{11} = -1.75 dB) pada jalur 3.0 GHz untuk band 5G. Sebuah jalur-T telah dimasukkan di antara dua antena MIMO yang dicadangkan untuk meningkatkan pemencilan. Tambahan lagi, saiz sel unit terkecil permukaan pemilihan frekuensi (FSS) UWB satah sesisi (0.095λ × 0.095λ) telah dipatikan pada substratum FR4. Simulator dibandingkan dengan model litar bersamaan bagi penyelesaian yang dicadangkan, kemudian disahkan dengan hasil pengukuran. Dalam fasa pembangunan, antena MIMO ekakutub heksagon, suapan CPW, pemencilan jalur-T, dan 3 × 7 tatususun FSS telah dihipumkan untuk membangunkan MWI. Antena MIMO terpencil dengan FSS (IMAF) mencapai lebar jalur 3-11.7 GHz, corak sinaran searah, gandiking bersama (S_{21} bout -27 dB) dan keuntungan (6-8.5 dBi), dan lebih baik daripada antena sedia ada 3.1-10.6 GHz, -20 dB, and 5.5 dBi, masing-masing. Di samping itu, skima pengimbas bagasi telah dibangunkan sebagai kajian kes untuk menilai IMAF bagi MWI medan berhampiran. Imej yang dinilai menunjukkan resolusi IMAF 55% lebih tinggi daripada antena MIMO tanpa tatususun FSS. Oleh itu, IMAF yang dicadangkan mengesan objek logam yang terkecil (0.5 × 2 cm²) dengan ketepatan lokasi ± 0.5 cm berbanding dengan kajian simulasi baru-baru ini ada (0.6 × 0.6 cm² dan ± 1.1 cm). Persetujuan yang baik dipatuhi antara imej MWI yang telah disimulasi dan diukur. Akibatnya, IMAF dibuktikan dapat digunakan sebagai sebahagian daripada sistem pengesanan
untuk pengimejan pengimbas bagasi kos rendah dan tidak rumit bagi mengesan objek logam.
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<td>AMC</td>
<td>Artificial magnetic conductor</td>
</tr>
<tr>
<td>AND</td>
<td>Logic operator</td>
</tr>
<tr>
<td>AUT</td>
<td>Antenna under test</td>
</tr>
<tr>
<td>AVA</td>
<td>Antipodal Vivaldi antenna</td>
</tr>
<tr>
<td>BiD</td>
<td>Bidirectional radiation pattern</td>
</tr>
<tr>
<td>BW</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>CPW</td>
<td>Coplanar waveguide feed</td>
</tr>
<tr>
<td>CST</td>
<td>Computer simulation technology</td>
</tr>
<tr>
<td>DG</td>
<td>Diversity gain</td>
</tr>
<tr>
<td>DGS</td>
<td>Defected ground structure</td>
</tr>
<tr>
<td>EBG</td>
<td>Electromagnetic band-gap</td>
</tr>
<tr>
<td>ECC</td>
<td>Envelope correlation coefficient</td>
</tr>
<tr>
<td>ECM</td>
<td>Equivalent circuit model</td>
</tr>
<tr>
<td>EM</td>
<td>Electromagnetic</td>
</tr>
<tr>
<td>EMI</td>
<td>Electromagnetic interference</td>
</tr>
<tr>
<td>FBW</td>
<td>Fractional bandwidth</td>
</tr>
<tr>
<td>FCC</td>
<td>Federal Communications Commission USA</td>
</tr>
<tr>
<td>FIT</td>
<td>Finite integration technique</td>
</tr>
<tr>
<td>FKEE</td>
<td>Faculty of Electrical and Electronic Engineering</td>
</tr>
<tr>
<td>FR4</td>
<td>Glass-reinforced epoxy laminate material</td>
</tr>
<tr>
<td>FSS</td>
<td>Frequency selective surface</td>
</tr>
<tr>
<td>GPR</td>
<td>Ground-penetrating radar</td>
</tr>
<tr>
<td>HPBW</td>
<td>Half power beamwidth</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IFFT</td>
<td>Inverse fast Fourier transform</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>---------</td>
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</tr>
<tr>
<td>IMA</td>
<td>Isolated UWB MIMO antenna</td>
</tr>
<tr>
<td>IMAF</td>
<td>Isolated UWB MIMO antenna with FSS array</td>
</tr>
<tr>
<td>ISM</td>
<td>Industrial, scientific and medical radio band</td>
</tr>
<tr>
<td>MATLAB</td>
<td>Matrix laboratory software</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multiple-input and multiple-output</td>
</tr>
<tr>
<td>MS Excel</td>
<td>Microsoft Excel</td>
</tr>
<tr>
<td>MWI</td>
<td>Microwave imaging</td>
</tr>
<tr>
<td>OD</td>
<td>Omnidirectional radiation pattern</td>
</tr>
<tr>
<td>OFDM</td>
<td>Orthogonal frequency division multiplexing</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed circuit board</td>
</tr>
<tr>
<td>PHMAS</td>
<td>Printed hexagonal monopole antenna side-feed</td>
</tr>
<tr>
<td>PHMAV</td>
<td>Printed hexagonal monopole antenna vertex-feed</td>
</tr>
<tr>
<td>PL</td>
<td>Path length</td>
</tr>
<tr>
<td>RF</td>
<td>Radio frequency</td>
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<tr>
<td>RLC</td>
<td>Resistor, inductor, and a capacitor resonant circuit</td>
</tr>
<tr>
<td>Rx</td>
<td>Receiver</td>
</tr>
<tr>
<td>SAR</td>
<td>Specific absorption rate value</td>
</tr>
<tr>
<td>SMA</td>
<td>SubMiniature version A 50 ohm connector</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal-to-noise power ratio</td>
</tr>
<tr>
<td>SRR</td>
<td>Split ring resonator</td>
</tr>
<tr>
<td>STW</td>
<td>See-through wall</td>
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<tr>
<td>SVM</td>
<td>Support vector machine</td>
</tr>
<tr>
<td>TE</td>
<td>Transverse electric</td>
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<tr>
<td>Tx</td>
<td>Transmitter</td>
</tr>
<tr>
<td>UDRP</td>
<td>Unidirectional radiation pattern</td>
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<tr>
<td>UTHM</td>
<td>Universiti Tun Hussein Onn Malaysia</td>
</tr>
<tr>
<td>UWB</td>
<td>Ultra-wideband</td>
</tr>
<tr>
<td>VNA</td>
<td>Vector network analyzer</td>
</tr>
<tr>
<td>VSWR</td>
<td>Voltage standing wave ratio</td>
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<tr>
<td>WiMAX</td>
<td>Worldwide interoperability for microwave access</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless local area network</td>
</tr>
<tr>
<td>WPAN</td>
<td>Wireless personal area network</td>
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LIST OF SYMBOLS

$dB$, $dBi$ - Logarithmic scale unit, and Isotropic logarithmic scale unit
$S_{11}$, $S_{22}$ - Reflection coefficients
$S_{21}$, $S_{12}$ - Transmission coefficients
$cm$, $cm^2$, $cm^3$ - Centimeter, square centimeter, cubic centimeter are units
$mm$, $mm^2$, $mm^3$ - Millimeter, square millimeter, cubic millimeter are units
$GHz$ - Gigahertz is unit
$MHz$ - Megahertz is unit
$Da$ - Distance between the MIMO antenna elements
$Dz$ - Distance between the antenna and FSS array
$Da$ - Largest dimension of the antenna
$Rd$ - Near-field region
$\lambda$ - Wavelength
$\lambda_0$ - Wavelength of resonance frequency
$f$, $f_0$, $f_r$ - Resonant frequency
$f_c$ - Centre frequency
$f_l$ - Lowest frequency
$f_H$ - Highest frequency
$\Omega$, $nH$, $pF$ - Ohm, nanohenry, picofarad are units
$N$ - Number of articles
$\varepsilon_r$, $\varepsilon_{reff}$ - Dielectric constant, Effective dielectric constant
$L$ - Monopole antenna length
$W$ - Monopole antenna width
$r$ - Effective radius of the cylindrical monopole antenna
$p$ - Gap between the ground plane and the patch
$k$ - Constant for the FR4 substrate
$Wf$ - Width of the feed line
$H$ - Substrate thickness
$La, Wa$ - Substrate length and width
$S, S_1, S_2$ - Patch sides length
$a^2$ - Patch sides angle
$R$ - The radius of the hexagonal patch
$Lf, Wf$ - Feed line length and width
$Lg, Wg$ - Ground plane length and width
$t$ - Copper patch thickness
$Dh$ - Distance between the edge of the patch and the ground plane
$tan\delta$ - Tangent dielectric loss angle
$S_{cpw}$ - Gap between CPW-fed wire and the ground plane
$f_{notch}, f_n$ - Notched frequency
$L_{slot}$ - Slot’s length
$pe$ - Envelope correlation coefficient
$\pi$ - Constant, the ratio of a circle’s circumference to diameter
$R, L, C$ - Resistor, inductor, and capacitor
$Z_o$ - 377 $\Omega$ free space wave impedance
$A_1$ and $A_2$ - Areas of the ground plane and the radiation patch
$Z_a$ - Antenna impedance
$L_s$ - Horizontal length of meander-line strip arms
$L_2$ - Vertical length of meander-line strip arms
$ths$ - Width of meander-line strip arms
$L_{strip}$ - Total length of meander-line strip arms
$T_{p1}, T_{p2}, W_{p1}$ - T-strip lengths and width
$g_{sp}$ - Gap between the T-strip and the radiator patch
$c$ - Speed of light
$s$ - Spacing between the metal of FSS unit cells
$T_{fib}$ - Substrate thickness of FSS unit cell
$D_x, D_y$ - Physical dimensions width and length of the unit cell
$g, L_f$ - Square ring width, Square ring length
$W_{fc}, L_{fc}$ - Cross-dipole width, Cross-dipole length
$n$ - Constant
$\phi$ - Phase
\[ \beta \quad - \quad \text{Propagation constant of free space} \]
\[ \theta \quad - \quad \text{Angle of incidence wave on the FSS unit cell} \]
\[ A_{\text{eff}} \quad - \quad \text{Effective angle of incidence wave on the FSS unit cell} \]
\[ \Delta x, \Delta y \quad - \quad \text{Step shift of xy scanning plane} \]
# LIST OF APPENDICES

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CHAPTER 1

INTRODUCTION

This chapter presents the research motivation, a short background, the problem statement, the objectives, and the scope of this work. Section 1.1 describes the events and the existing technologies that offer significant motivations to carry out this study. The UWB standard and followed by a short background about implementing UWB systems for microwave imaging (MWI) applications are discussed in Section 1.2 and 1.3, respectively. Describing the general problem, several existing issues, and the research direction to fill a gap are elaborated in Section 1.4. The objectives, aim, scope, and the contributions of this study are described in Sections 1.5, 1.6, and 1.7, respectively. Lastly, Section 1.8 briefly reposts the thesis organisation. The details are depicted in the following sections.

1.1 Motivation

Some horrendous events of attacks, such as the September 11 2001 New York City twin towers attack, 2004 Madrid train attack, and 2007 London car bombings, have generated new security adoption processes across the globe. Hence, as a safety measure, the Schiphol airport has begun scanning passengers' body since 2007 [1]. Safeguarding humans from potential attackers have become a top priority. With various cutting-edge approaches devised by attackers to circumvent security inspection, a strong need is present to perform quality security screening in airports and public transportations [2]. While thousands of strangers arrive and depart every single day through airplanes, international airports are the most critical public
transportation constrictions. Thus, both international and local airports have been supported by state-of-the-art security systems and devices [2].

Typically, the conventional scanners in airports are X-ray machines. Passengers are required to take-off all their belongings at the security terminal of both local and international airports. The checklist includes wallets, handbags, hats, keys, and phones, to name a few. Next, the belongings are arranged in a plastic box and scanned using the X-ray system machine. Laptops, cans, and containers exceeding 100 ml must be removed from the handbags, and arranged in a box to be scanned by X-ray scanner. This process lengthens the time of loading the luggage bags into the airplane and takes up passengers’ time, especially those with short transit trips. Nevertheless, this process is essential because security rules are significant to prevent weapons, such as bombs and handguns, from being carried onto the airplane [3].

Despite the low-resolution display of two-dimensional (2D) images, X-ray poses health risks due to its high ionising radiation towards human tissues [1]. Meanwhile, terahertz radar offers high-resolution images, but its high cost and short distance limit its application at the airports [2].

Airway companies have taken measures by increasing scanner accuracy and time efficiency through enforcement of baggage-screening procedure, but often at the cost of increased waiting time and ticket price [4]. The highlighted concerns had motivated the researcher to develop a modern radar system in the attempt of overcoming these issues that have always remained top security priority. The key solution is by using MWI based UWB system for indoor security purposes [2], which refers to one of the most sought topics in the radar-imaging field. The details of standardisation and regulations of the UWB technology are presented in the next sections.

1.2 UWB standard and regulation

UWB communication uses very narrow RF pulses between the receiver and the transmitter for communication purposes. Short-duration pulses generate extensive bandwidth and have many other advantages, thus are the building blocks for wireless communication. There are many types of waveband signals in a UWB, such as
REFERENCES


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