AN ULTRA-WIDEBAND ANTENNA WITH TRIPLE BAND-NOTCHED CHARACTERISTICS FOR WEARABLE APPLICATION

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ABSTRACT

This work presents a compact UWB antenna with triple band-notched at WiMAX (3.2 – 3.7 GHz), C-band (3.7 – 4.2 GHz) and WLAN (5.15 – 5.35 GHz) for wearable applications. The UWB antenna is fabricated on two different flexible substrates which are thin FR-4 and Rogers Duroid RO3003^{TM}. The two substrates are selected so that the performance of the lossy material (thin FR-4) and the low-loss material (RO3003^{TM}) can be compared. In order to reduce the complexity, only two slots are introduced on the radiating patch instead of three slots to reject each narrowband frequency. In this case, one slot rejects a combination of WiMAX and C-band and the other slot rejects the WLAN frequency band. The UWB antenna on the thin FR-4 has an overall size of 21×16 mm^2, whereas the UWB antenna on RO3003^{TM} substrate is 19×14 mm^2, both of which are very compact and thus, suitable for wearable applications without causing discomfort when worn on body. Although the antennas are small in size, their performance is not compromised. The UWB antenna with the thin FR-4 has the frequency range from 2.51 GHz to 12.09 GHz, maximum radiation efficiency of 100% and maximum gain of 4 dBi. Meanwhile, the UWB antenna with RO3003^{TM} has the frequency range from 2.83 GHz to 10.78 GHz, maximum radiation efficiency of 80% and maximum gain of 4 dBi. Nevertheless, both antennas are able to reject the WiMAX and C-band as well as the WLAN band. The simulated Specific Absorption Rate (SAR) results show that both antennas comply with the SAR limit Federal Communication Commission (FCC) and International Commission of Non-Ionizing Radiation Protections (ICNIRP) standards for 1 mW input power. Bending investigations performed on different diameters of Styrofoam cylinders shows that the frequency range and the notch bands are not very much affected. Therefore, it is safe to conclude that the triple band notched UWB antennas in this work are suitable to be used for wearable applications.

ABSTRAK

Kajian ini membentangkan antena ultra jalur lebar (UWB) bersaiz kecil dengan takukan tiga jalur pada frekuensi WiMAX (3.2 – 3.7 GHz), jalur-C (3.7 – 4.2 GHz) and WLAN (5.15 – 5.35 GHz) untuk penggunaan aplikasi boleh pakai. Antena UWB ini direka menggunakan dua substratum anjal berbeza iaitu FR-4 nipis serta Rogers Duroid RO3003^{TM}. Kedua-dua substratum dipilih supaya prestasi bahan yang mempunyai kehilangan tinggi (FR-4 nipis) dan bahan kehilangan rendah (RO3003^{TM}) boleh dibandingkan. Untuk mengurangkan kerumitan, hanya dua lubang alur direka bentuk pada tampalan antenna untuk menolak ketiga-tiga jalur frekuensi. Dalam kerja ini, satu lubang alur menolak gabungan frekuensi WiMAX dan jalur-C, dan lubang alur yang lain menolak jalur frekuensi WLAN. Perbandingan menunjukkan bahawa antena UWB dengan substratum RO3003^{TM} mempunyai dimensi yang lebih kecil iaitu 19 × 14 mm^2 berbanding dengan FR-4 nipis yang mempunyai dimensi 21 × 16 mm^2 di mana kedua-duanya sangat kecil. Oleh itu, kedua-dua antenna sesuai bagi aplikasi boleh pakai tanpa menyebabkan ketidakselesaan apabila dipakai pada badan. Walaupun dimensi kedua-dua antena adalah kecil, prestasinya tidak terjejas. Antena UWB dengan FR-4 nipis mempunyai julat frekuensi operasi daripada 2.51 GHz hingga 12.09 GHz dengan kecekapan sinaran berbagai hingga 100% dan gandaan sebanyak 4 dBi. Manakala, antena UWB dengan RO3003^{TM} mempunyai julat frekuensi operasi daripada 2.83 GHz hingga 10.78 GHz, kecekapan sinaran berbagai sebanyak 80% dan gandaan maksimum 4 dBi. Namun begitu, kedua-dua antena mampu menolak jalur WiMAX, jalur-C serta jalur WLAN. Hasil penyelakuan Kadar Penyerapan Tentu (SAR) menunjukkan bahawa kedua-dua antena mematuhi had SAR ditetapkan oleh Suruhanjaya Komunikasi Persekutuan (FCC) dan piawaian Suruhanjaya Perlindungan Sinaran Tidak Pengionan Antarabangsa (ICNIRP) untuk kuasa input 1 mW. Kajian kekuatan lenturan menggunakan gabus silinder dengan garis pusat berbeza menunjukkan bahawa julat frekuensi dan jalur-jalur takuk antena tidak terlalu terjejas. Oleh itu, boleh disimpulkan bahawa kedua-dua antena UWB dengan takukan tiga jalur dalam kerja ini sesuai digunakan dalam aplikasi boleh pakai.

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LIST OF SYMBOLS AND ABBREVIATIONS

BAN	-	Body Area Network
CST MWS$^{®}$	-	CST Microwave Studio$^{®}$
EBG	-	Electromagnetic Band Gap
ECSRR	-	Complementary Split Ring Resonator
EIRP		Effective Isotropic Radiated Power
FCC	-	Federal Communication Commission
FR-4	-	Flame Resistant 4
ICNIRP	-	International Commission of Non-Ionizing Radiation Protections
PCB	-	Printed Circuit Board
PDMS	-	Polydimethylsiloxane
RO3003^{TM}	-	Rogers Duroid 3003
SAR	-	Specific Absorption Rate
UWB	-	Ultra-Wideband
UWB-FR4	-	Fundamental UWB antenna with FR-4
UWB-FN-FR4	-	UWB antenna with first and second notch bands with FR-4
UWB-SN-FR4	-	UWB antenna with third notch band with FR-4
UWB-TN-FR4	-	UWB antenna with triple notch bands with FR-4
UWB-RO	-	Fundamental UWB antenna with RO3003^{TM}
UWB-FN-RO	-	UWB antenna with first and second notch bands with RO3003^{TM}
UWB-SN- RO	-	UWB antenna with third notch band with RO3003^{TM}
UWB-TN- RO	-	UWB antenna with triple notch bands with RO3003^{TM}
VSWR	-	Voltage Standing Wave Ratio
WBAN	-	Wireless Body Area Network

WiMAX	-	Wireless Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In February 2002, Federal Communication Commission (FCC) in the United States has licensed the Ultra-Wideband (UWB) frequency spectrum to operate between the frequency range from 3.1 GHz to 10.6 GHz for commercial use with an Effective Isotropic Radiated Power (EIRP) to be less than -41.4 dBm/MHz [1]. This emission limit is set so that the antenna can produce a lower permittable Specific Absorption Rate (SAR). SAR is an established mechanism for measuring the electromagnetic energy absorbed by biological tissue when exposed to radiated electromagnetic energy [2]. The SAR limit set by the FCC is 1.6 W/kg averaged over 1 g of actual tissue while the SAR limit recommended by the International Commission on Non-Ionising Radiation Protection (ICNIRP) is 2.0 W/kg averaged over 10 g of actual tissue [3].

Applications based on UWB technology have achieved considerable development due to their appealing characteristics, such as low power consumption, high speed transmission rate and ability to prepare for short range wireless communication links that use low-cost and low-energy transmitter or receiver; Wearable Body Area Network (WBAN) is among the most attractive application [4]. A wearable antenna is a key component for the WBAN network as it is responsible for transmitting and receiving the signal between the implantable device (such as pacemakers, heart rate monitors, and respiratory monitor) and wearable network [5], [6]. Furthermore, the wearable antenna is critical for a proper operation of the WBAN system as it can be placed on a human body and thus, the influence of the human on the characteristics of the antenna should be taken into account during the initial design stage [7].

An important consideration for UWB antennas is the strong interference from the existing wireless network technologies, for instance, Wireless Interoperability for Microwave Access (WiMAX) between 3.2 GHz to 3.7 GHz and C-band between 3.7 GHz to 4.2 GHz [8]–[10]. Besides, according to the IEEE 802.11a standard, for an UWB antenna to work in wearable and indoor applications, it should avoid the higher frequency band from 5.15 GHz to 5.35 GHz which is assigned for Wireless Local Area Network (WLAN) [11]. These three bands may cause interference and hence, reducing the performance of UWB antenna. As a result, it is appropriate notch the unwanted frequency bands that are susceptible to strong interference within the UWB frequency range.

1.2 Problem Statement

Electromagnetic (EM) interference with other existing wireless systems, radiation pattern deterioration under bending conditions [12], and the need for a compact antenna size are all challenges for Ultra-Wideband (UWB) antennas for wearable devices. Despite having a wide frequency range, UWB devices suffer from the consequences of having to share the spectrum with licensed and unlicensed wireless communication bands within the UWB bandwidth, such as World Interoperability for Microwave Access (WiMAX) service, Wireless Local Area Network (WLAN) IEEE802.11a and C-band operating in the 3.2 GHz to 3.6 GHz, 3.7 GHz to 4.2 GHz and 5.15 GHz to 5.35 GHz [13], [14]. Furthermore, EM interference from the strong narrow band signals within the UWB frequency band may overload the receiver. The narrow band signals are received as interfering noise by UWB receivers and have the potential to degrade the overall performance of UWB communication systems through data loss, signal interruption, and device failure [15]. Bandpass filters may be used to suppress the dispensable bands, but extra devices added to the system might lead to a rise in terms of cost, complexity, size and insertion losses [16].

Hence, a highly miniaturized UWB antenna with a triple band-notch characteristics is proposed in this work to alleviate the potential EM interference arises from the narrow band applications. The band-notched operations are achieved by etching slots in the rectangular metal radiating patch [17]. It has been realised that by adjusting the total length of the slot to be approximately quarter or half-wavelength of the desired notched frequency, destructive interference can occur, rendering the antenna non-responsive at that frequency [18]. The designed antenna is compact in terms of the size which is 21 × 16 mm^2 and is fabricated on a thin FR-4 substrate material to ensure flexibility. In addition, for comparison purposes, the UWB antenna with a triple band-notch is also fabricated on another flexible substrate material, Rogers Duroid 3003 (RO3003^{TM}) with the size of 19 × 14 mm^2. The performance of the UWB antenna in bending condition is investigated to ensure that it is suitable for wearable applications. In addition, the Specific Absorption Rate (SAR) imposed by the UWB antenna on the human body is assessed to ensure that the SAR results lie well within the FCC and ICNIRP regulated limits.

1.3 Objectives

The objectives of this work are as follows:

i. To design, simulate and fabricate an UWB antenna with a triple notch band on Rogers Duroid 3003 and thin FR-4 substrate materials.

ii. To measure and analyze the linear characteristics of fabricated wearable UWB antenna with triple notch bands.

iii. To evaluate the performance of the antenna in bending condition and examine the SAR limits to ensure the antenna is suitable for wearable applications.

1.4 Scopes

The specification of the UWB antenna design in this work is listed in Table 1.1.

Table 1.1: Specification of the UWB antenna design

UWB antenna frequency range	The frequency range of the UWB antenna is from 3.1 GHz to 10.6 GHz.
Notched frequency bands	WiMAX (3.2 GHz – 3.7 GHz), C-band (3.7 GHz - 4.2 GHz) and WLAN (5.15 GHz – 5.35 GHz)
SAR simulation	The simulation of the antenna towards human body is conducted to determine the maximum SAR value that the human body tissue can tolerate and at the same time, obeys the limits as stipulated by the FCC and ICNIRP.
Antenna fabrication	The antenna is fabricated on a thin FR-4 substrate with a dielectric constant, ε_r of 4.5, loss tangent, tan δ of 0.019 and board thickness, *h* of 0.5 mm and Rogers

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APPENDIX F

VITA

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