ELECTROMAGNETIC FIELD RADIATION FOR FIFTH GENERATION BASE STATION USING MILLIMETER WAVE ANTENNA ARRAY

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ABSTRACT

Pico-cells and indoor base stations in various frequency bands are required as part of the construction of the fifth-generation (5G) network. Electromagnetic fields (EMF) are emitted by these base stations, and there is worry regarding their impact on the human body. The amount of acceptable radiated EMF is measured by specific absorption rate and free space power density as specified by international regulatory bodies. Therefore, the goal of this thesis is to look into the quantity of radiation emitted by antenna arrays in an indoor and hallway environment based on power density. Seven distinct antenna arrays operating at 2.6 GHz and 28 GHz have been devised and constructed using Computer Simulation Technology. In the power density measurement for indoor and hallway environments, the designed antennas are used as a transmitting antenna. The power density values need to verify whether the compliance limits set by the International Commission bodies such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Federal Communication Commission (FCC) bodies are complied with. According to the findings, higher number of the antenna elements would increase the antenna gain and received power, resulting in a higher power density. The gain of the 8×8 antenna array operating at 28 GHz is 23.80 dBi, compared to 17.75 dBi for a 4×4 array. Furthermore, the power density of the 8×8 array is substantially higher than that of the 4×4 array, with the power density of the 8×8 and 4×4 arrays being 6.80×10^{-6} W/m^2 and 2.59×10^{-6} W/m^2 respectively for indoor environments at 1 m distance. The measured power density at 28 GHz was found to be within the ICNIRP and FCC regulation's permissible limits. Comparative test conducted shows that the indoor environments has a higher power density than hallway environment. The measured power density for the 8×8 antenna array at 1 m distance for 28 GHz in the indoor and hallway environments are 6.80×10^{-6} W/m^2 and 6.65×10^{-6} W/m^2 respectively. Based on the allowable power density by ICNIRP and FCC, a compliance distance of 1.37 m was recorded for 8×8 antenna array at maximum power transmission of 30 dBm. This study helps to determine the compliance distances between users and radio base stations in Malaysian indoor and hallway environments.

ABSTRAK

Sel piko dan stesen pangkalan dalaman pelbagai jalur frekuensi diperlukan sebagai sebahagian daripada pembinaan rangkaian generasi kelima (5G). Medan elektromagnetik (EMF) dipancarkan oleh pangkalan ini, dan ada kebimbangan mengenai kesannya terhadap tubuh manusia. Jumlah EMF terpancar yang dapat diterima diukur dengan kadar penyerapan khusus dan ketumpatan kuasa ruang bebas seperti yang ditentukan oleh badan kawal selia antarabangsa. Oleh itu, tujuan tesis ini adalah untuk melihat jumlah radiasi yang dipancarkan oleh tatasusunan antena di persekitaran dalaman dan lorong berdasarkan ketumpatan kuasa. Tujuh tatasusunan antenna berbeza yang beroperasi pada 2.6 GHz dan 28 GHz dirancang dan dibina menggunakan Computer Simulation Technology. Dalam pengukuran ketumpatan kuasa untuk persekitaran dalaman dan lorong, antenna yang direka bentuk digunakan sebagai antenna pemancar. Nilai ketumpatan kuasa perlu mengesahkan sama ada had pematuhan yang ditetapkan oleh badan-badan Suruhanjaya Antarabangsa seperti International Commission on Non-Ionizing Radiation Protection (ICNIRP) dan Federal Communication Commission (FCC) di patuhi. Dari hasil kajian, peningkatan bilangan elemen antena akan meningkatkan gandaan antena dan kuasa yang diterima, menghasilkan ketumpatan kuasa yang lebih tinggi. Hasil pengukuran untuk tatasusunan antena 8×8 yang beroperasi pada 28 GHz adalah 23.80 dBi yang lebih tinggi berbanding tatasusunan 4×4 pada 17.75 dBi. Tambahan pula, ketumpatan kuasa tatasusunan 8×8 jauh lebih tinggi berbanding dengan tatasusunan 4×4 di mana nilai ketumpatan kuasa untuk tatasusunan 8×8 dan 4×4 masing-masing adalah 6.80×10^{-6} W/m^2 dan 2.59×10^{-6} W/m^2 untuk persekitaran dalaman pada jarak 1 m. Ketumpatan kuasa yang diukur pada 28 GHz didapati berada dalam had yang dibenarkan oleh peraturan ICNIRP dan FCC. Ujian perbandingkan yang dijalankan menunjukkan bahawa persekitaram dalaman mempunyai ketumpatan kuasa yang lebih tinggi daripada persekitaran lorong. Ketumpatan kuasa yang telah diukur untuk tatasusunan 8×8 pada jarak 1 m untuk 28 GHz di persekitaran dalaman dan lorong masing-masing adalah 6.80×10^{-6} W/m^2 dan 6.65×10^{-6} W/m^2. Berdasarkan ketumpatan kuasa yang dibenarkan oleh ICNIRP dan FCC, jarak pematuhan 1.37 m direkodkan untuk tatasusunan antenna 8×8 dengan penghantaran kuasa maksimum pada 30 dBm. Kajian ini membantu menentukan jarak pematuhan antara pengguna dan stesen pangkalan radio di persekitaran dalaman dan lorong di Malaysia.

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LIST OF ABBREVIATIONS

1G	-	First Generation
2G	-	Second Generation
3G	-	Third Generation
4G	-	Fourth Generation
5G	-	Fifth Generation
BS	-	Base Station
BTS	-	Base Transceiver Station
CDMA	-	Code Division Multiple Access
CST	-	Computer Simulation Technology
dB	-	Decibel
DC	-	Direct Current
DPC	-	Dynamic Power Control
DTA	-	Datacom Analyzer
DTX	-	Discontinuous Transmission
DXF	-	Drawing Exchange Format
EIRP	-	Equivalent Isotropic Radiated Power
EMF	-	Electromagnetic Field
FCC	-	Federal Communication Commissions
FDTD	-	Finite Difference Time Domain
GSM	-	Global System for Mobile
H_2O	-	Chemical Formula for Water
HPBW	-	Half Power Beamwidth
IARC	-	International Agency for Research on Cancer
IC5G	-	Innovation Centre 5G
ICNIRP	-	International Commission on Non-Ionizing Radiation Protectio
IEEE	-	Institute of Electricals and Electronic Engineers
IMT	-	International Mobile Telecommunication
IoT	-	Internet of Thing
ISI	-	Inter Symbol Interference
LAN	-	Local Area Network

LTE - Long Term Evolution
M2M - Mobile to Mobile
MIMO - Multiple Input Multiple Output
MmWave - Millimeter Wave
MoM - Method of Moment
MPE - Maximum Permissible Exposure
NBM - Narda Broadband Field Meter
O_2 - Oxygen
OMT - Operation and Maintenance
PCB - Printed Circuit Board
PD - Power Density
RBS - Radio Base Station
RF - Radio Frequency
SAR - Specific Absorption Rate
SINR - Signal to Interference Noise Ratio
SMA - Sub Miniature Version
UMTS - Universal Mobile Telecommunication Services
UV - Ultraviolet
VNA - Vector Network Analyzer
VSWR - Voltage Standing Wave Ration
WCC - Wireless Communication Center
Wi-Fi - Wireless Fidelity
WiMax - Worldwide Interoperability for Microwave Access
WHO - World Health Organization

LIST OF SYMBOLS

ρ - Density
$\bar{P}$ - Power Density
Re - Real Part
$\bar{E}$ - Electric Field
$\overline{H}$ - Magnetic Field
P_r - Receiving Power
P_d - Receiving Power Density
P_t - Transmitted Power
p_e - Effective Radiated Power
g_{a1} - Transmitting Antenna Gain
g_{c1} - Transmitting Line Loss
g_{a2} - Receiving Antenna Gain
g_{c2} - Receiving Line Loss
R - Range Between Two Antennas
λ - Wavelength
P_d - Power Density
π - Pi
P - Power
G - Gain
d_F - Minimum distance of farfield
D - Diameter
f - Frequency
t - Time
c - Speed of light
f_o - Operating frequency
ε - Dielectric Constant
W - Width of Patch
L - Length of the Patch
W_g - Width of the ground plane

L_g - Length of the ground plane

ε_{reff} - Effective Dielectric Constant

L_{eff} - Effective Length

ΔL - Length Extension

W_0 - Width of Microstrip Line

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

The wireless industry is currently facing a tremendous growth of mobile data traffic demands due to the increasing use of smart phones along with new applications such as real-time conferencing, high-definition video streaming and online gaming. According to the recent forecast in [1], the fifth Generation (5G) connection is expected to generate three-fold more data traffic than the fourth Generation (4G) connection by 2023. In addition, mobile-to-mobile (M2M) and Internet of Things (IoT) are estimated to further raise the data traffic, where these technologies will grow from 33% in 2018 to 50% by 2023. Therefore, mobile network operators need to prepare a sufficient network capacity to successfully support the traffic demands in 5G networks.

The concept of small cells, which reduces the cell size and increases frequency reuse, has attracted significant attention from both the wireless industry and academia as a promising solution to enhance the network capacity. However, the current operating frequency, particularly in the microwave band, is becoming increasingly congested, which limits the improvement of 4G cellular networks. Another potential solution for increasing the network capacity is by utilizing a higher fraction of frequency spectrum, such as millimeter wave (mmWave) bands. Although, the amalgam of these two feature, i.e., small cells and mmWave spectrum, will bring substantial benefits in the 5G networks [2], the ubiquitous wireless system raises the level of electromagnetic field (EMF) exposure to humans in the surrounding area. Hence, there is an increasing concern about the potential adverse health effects caused by the exposure of EMF on humans [3][4].

Mobile phones emit radio-frequency energy in a form of non-ionizing radiation. Such radiation is considered carcinogenic to humans and it is categorized under Group 2B by the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) in 2011[5]. The emission from mobile phones can lead to harmful effects due to the proximity between the antennas and parts of the human body such as the head. Human organs or tissues can absorb the energy from the EMF radiation, which subsequently causes biological effects. The biological effects can be classified into thermal and non-thermal effects. The former effect may lead to tissue heating, which can cause injury and brain damage. In addition, concerns on EMF exposure also come from base station (BS) as nowadays the BSs are deployed close to or in the surrounding residential areas. Following this, there are a number of local and international EMF radiation exposure limits, compliance tests and guidelines proposed by relevant regulatory organizations.

Specific Absorption Rate (SAR) is a metric that is currently utilised to regulate the safety limit for mobile phone EMF radiation. SAR refers to a metric for evaluating the EMF exposure at the area close to the antenna, which is also known as near-field region. Such metric measures the amount of radiation that is absorbed by a human head when using a cellular phone. In general, the high SAR indicates that the human is exposed to a relatively large amount of EMF. Another way to evaluate the EMF radiation exposure level on humans is by using power density, where such measurement metric has been used as a guideline for the network operator in the base station deployment [6][7].

With the recent migration of mobile telecommunication technology to 4G (LTE 2.6 GHz), and in the near future to 5G where frequencies in the mmWave bands of 28 GHz and 38 GHz may be employed for high-speed mobile communications, it is imperative that studies should be done at these frequencies to see its radiation impact on humans. Thus far, all studies have been mostly concentrated at the two most common frequencies of 900 MHz and 1800 MHz. This makes this research timely, and relevant.

SAR, is used to measure the rate of absorbed energy inside the human body. It also requires either advanced numerical simulations or costly measurement systems. As for the power density, it is the power per unit area normal to the direction of propagation. At frequency from 10 MHz to 10 GHz, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) basic restrictions are provided in terms of SAR. Basic restrictions are given in terms of free space power density for higher frequencies between 10 GHz to 300 GHz.

Research works that are involved in the studies of the transmit power of mobile communication systems, reduction of EMF radiation, and potential health hazards are listed and discussed [8]. They include the low EMF exposure future networks (LEXNET) [9], international EMF project, greentouch, as well as energy aware radio and network tecHnologies (EARTH) [10]. These projects comprise network operators, industrial partners, universities and research centers. Their objective includes reduction of energy consumption, reduction of EMF radiation exposure, development of international acceptable standards and improvement in energy efficiency. Following this, guidelines on the limits of EMF exposure from mobile phones, BSs, and other sources of EMF radiation exposure have been provided in[11][12]. These guidelines are based on epidemiological and laboratory studies. They state the maximum admissible exposure of people to EMF waves not less than 300 GHz.

The guidelines can be applied to both public and occupational exposure. The term public exposure can be referred to as the members of the public of all ages who are unaware of such exposures. Therefore, they practice fewer precautions to reduce the EMF exposure. Occupational exposure, on the other hand, can be referred to as the EMF exposure of adults who are not only aware and trained of the potential hazards, but also have taken the needed precautions.

Numerous techniques have been suggested to reduce the EMF radiation for the 5G communication system, such as power control, SAR shielding, beamforming [13][14], and massive MIMO [15][16]. Compliance assessment method dedicated for 5G radio BS is currently an active research area for all telecommunication systems that emit RF EMF to ensure that such systems follow the relevant regulatory exposure limits. Currently, the compliance assessment method for 5G radio BS is an active research area. Therefore, this research provides an overview of some of the impacts of the EMF emission, effects of the radio BS in indoor environment, as well as compliance test for the 5G communication systems. The future direction and open issues were discussed for EMF assessment and compliance test.

1.2 Problem Statement

The effect of mobile radiation known as non-ionizing radiation on human health has recently been a subject of great interest and study as a result of the increase in mobile phone usage throughout the world. Studies have shown that there is supporting evidence of biological effects caused by radiation radio base stations [17][18]. With the migration to 5G communications technology, the antennas deployed at the radio base station will have different configurations, such as steerable with narrow beams and operating at high frequencies. In order to increase the coverage, base station antenna need to be designed with the 5G requirement to obtain the narrower beamwidth and the value of gain of the antenna has to be more than 12 dB [19]. An antenna array can be deployed to obtain narrow beamwidth and targeted gain. The main challenge of using antenna array is how antenna specifications can be achieved using limited antenna sizes.

There are concerns of many users with the increase in the number of mmWave 5G base stations for users due to smaller coverage area per base station, will cause health risks and hazards for the human body [20]. Power density measurements can be conducted to provide safety and assurance to users and the community, by determining compliance distances. This compliance distance is crucial to ensure that there are rules and regulations that can be used by public and occupational worker when they are exposed to the radio base station or antenna. The compliance distance estimated in [21] applies only to radiation measurements from the outdoor base station cell tower. Compliance distances from various types of base stations such as indoor lower power base stations need to be carried out.

1.3 Objectives

This study embarks on the following objectives:

i. To design and analysis the performance of mm-wave antenna arrays for 5G base station applications.
ii. To measure and analyse power density in different propagation environments using the proposed antenna.
iii. To propose the compliance distance for different antenna configuration with low power base station.

1.4 Scope of Work

The main scope of this research work comprises the design and fabrication of antenna arrays, measurement and analysis of electromagnetic field radiation from 5G base station using the proposed antenna. The designed microstrip patch antenna arrays must meet the requirements of the 5G communications system in terms of gain and beamwidth.

The microstrip antenna arrays are designed and simulated using CST software. The square patch antenna is designed as a single element first, the same design is used duplicated to create the array. FR4 substrate is used for the antenna design operating at 2.6 GHz, while Rogers 5880 Duroid substrate is used for the microstrip patch antenna with 2.2 dielectric constant of 2.2 for the 28 GHz operating frequency. The proposed microstrip patch antenna designs are fabricated and tested in the WCC laboratory.

Farfield measurements of the proposed microstrip patch antenna array has been performed in the anechoic chamber in UTM Johor Bharu. This measurement is crucial because it contributes towards the measurement of the return loss and radiation pattern of the designed antenna. Finally, power density measurements with different transmitting power for two environments, indoor and hallway are performed at

Innovation Center for 5G (IC5G) UTM Kuala Lumpur. The designed antennas is used as a transmitting antenna connected to a signal generator. The horn antenna is used as the receiving antenna and is connected to the spectrum analyser to measure the received power in dBm. The power density is determined from the received power and compared with the ICNIRP standard value.

1.5 Thesis Outlines

The thesis consists of six chapters. In Chapter 1, the overview of the whole project is discussed, which includes the research background, problem statement, objectives of the research, scope of the research, and thesis outlines.

Chapter 2 presents the basic principle and requirement of array antenna used at radio base station for 5G. This chapter presents a literature review on array antennas that have been used for radio base station application. The principles of EMF radiation, as well as the effects of EMF radiation on the human body are also presented in this chapter. An overview of wireless telecommunication systems operating on mmWave frequency is presented to relate the challenges of array antenna implementation to radio base station applications. This chapter also presents the safety guidelines and regulations of EMF radiation proposed by international standard bodies such as the FCC and ICNIRP.

Chapter 3 elaborates the research methodology starting with the presentation of the research flow charts. The flow chart outlines the main research activities followed from the beginning to end. Design parameters and specifications are introduced as a guide to achieve the desired results. In addition, all design equations are presented, fabrication and measurement procedures are all presented.

The antenna design is presented in Chapter 4. This chapter presents the design of the antenna arrays, 2×2, 4×4 and 8×8, elaborates on design, simulation and fabrication of the proposed antennas. The simulation and measurements result for all proposed antennas are compared and discussed. All parametric studies done to optimize the design are analysed and presented.

Chapter 5 presents the EMF measurement for two environments, indoor and hallway for frequencies of 2.6 GHz and 28 GHz. From the received power, the power density for both environments can be determined. Finally, this chapter presents the estimation of compliance distance from the received power and power density.

Finally, Chapter 6 concludes the significant results and contribution achieved in this research. Further research directions and recommendation are presented as a continuation for further developments in the research topic.

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APPENDIX C

LIST OF PUBLICATIONS

Indexed Journal

1. **Ibrahim, N.A**., Tharek, A.R., and Elijah, O. (2017). Recent Trend in Electromagnetic Radiation and Compliance Assessment for 5G Communication. *International Journal of Electrical and Computer Engineering (IJECE), 7*(2), 912-918. **(Indexed by SCOPUS)**
2. **Ibrahim, N.A**., Tharek, A.R., Ngah, R., Aziz, O.A., and Elijah, O. (2020). Power Density Of Rectangular Microstrip Patch Antenna Arrays for 5G Indoor Base Station. *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS), 19*(3), 1367-1374. **(Indexed by SCOPUS)**

Indexed Conference Proceedings

1. **Ibrahim, N.A**., Tharek, A.R., and Elijah, O. (2017). EMF Radiation Effects from 5x5 Dipole Array Antenna Towards Human Body for 5G Communication. *In Asian Simulation Conference, Springer.* (pp. 483-493). **(Indexed by SCOPUS)**