GRAPHENE ANTENNA DESIGN AND CHARACTERISATION FOR FIFTH GENERATION APPLICATIONS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Electrical Engineering
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MAY 2020

DEDICATION

I dedicate this thesis to all my family members

Especially my parents, Mr. Sa'don and Mrs. Sarah, my husband, Mr. Aniq, my son, Firas and my siblings, you all are my inspiration

I could not accomplished this doctoral journey without your prayer, support, understanding and contribution of time, May Allah Bless all of you

Thank you, Allah for giving me the strength to continue on this challenging journey

ACKNOWLEDGEMENT

From the starting of this research work until preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In the beginning, I wish to express my sincere appreciation to my main supervisor, Associate Professor Dr. Mohd Haizal bin Jamaluddin, for valuable advice and support this research. He has delivered very well guidance, finance, discussions, and constructive critics throughout this research until finding the results. Then, I would like to acknowledge my external supervisor, who is my former main supervisor, Associate Professor Dr. Muhammad Ramlee bin Kamarudin, who guide and give me a chance in the title's selection for my doctorate study. His support, finance, encouragement, knowledge, motivation and comment are very helpful. He also has struggled in searching and contacting with persons who work in graphene field. I am also very thankful to my co-supervisor Dr. Fauzan bin Ahmad for the knowledge and support in the part of graphene and facilities. Without his precious support and interest, this graphene research work could not be continued.

I am also indebted to Kementerian Pengajian Tinggi Malaysa for funding my Ph.D study through MyBrain15-MyPhD. Then, Perpustakaan Sultanah Zanariah at Universiti Teknologi Malaysia also deserve special thanks for their assistance in supplying the relevant literatures especially through e-journal.

My sincere appreciation also extends to all my colleagues for their views and tips which are useful indeed, and thanks for the fun-time together. Not forget to the fellow friends and staffs at Wireless Communication Centre, Material Science Laboratory and Malaysia-Japan International Institute of Technology at Universiti Teknologi Malaysia, and Institut Teknologi Maju at Universiti Putra Malaysia who gave me access to the laboratory and research facilities, besides provided assistance at various occasions.

Last but not the least, I would like to thank my family: my parents, my husband, my son and my siblings for supporting me spiritually throughout this study and my life.

ABSTRACT

The incoming fifth generation (5G) technology requires antennas with a greater capacity, wider wireless spectrum utilisation, high gain, and beam steering ability. This is due to the cramped spectrum utilisation in the previous generation. As a matter of fact, conventional antennas are unable to serve the new frequency due to the limitations in fabrication and installation mainly for smaller sizes. The use of graphene material promises antennas with smaller sizes and thinner dimensions, yet capable of emitting higher frequencies. Graphene is a unique material that can display tuning characteristics. This characteristic originates from its surface complex conductivity, which is controlled by a chemical potential. Most characteristics of tunable graphene antenna have been studied on terahertz frequency range, thus making it difficult to be realised practically. Besides, the standard antenna that uses switching components may have trouble during installation, and size consuming as it can be seen in the reconfigurable antenna. Due to that, another study to produce graphene with excellent properties is vital for the advancement of wireless communication system. In this thesis, graphene antennas for fifth generation applications are conducted in three parts of studies. In the first part, the graphene antenna properties are studied in different curing temperatures and times. The curing temperatures are 250°C, 300°C, and 350°C, then each temperature is set with curing times of 20 minutes, 30 minutes, 1 hour, 2 hours, and 3 hours to manufacture graphene based antenna with different properties. The proposed graphene based antenna properties are then respectively investigated using performance network analyser (PNA), vector network analyser (VNA), field-emission scanning electron microscope (FESEM), and Raman spectroscopy. From analyses on the dielectric, conductivity and characterisation on graphene's physique, the antenna properties exhibit a tunability through its resonance frequency and main beam direction of the radiation pattern by the variation obtained in curing temperature and time. In the same time, the gain of the antennas can also be varied. The second part is the study of graphene antennas at a frequency of 15 GHz in both single and array elements. The high-frequency antenna contributes to a large bandwidth and is excited by coplanar waveguide for easy fabrication on one surface via screen printing method. The defected ground structure is applied in an array element to improve the radiation and increase the gain. The results show that the printed graphene antenna for single element produces an impedance bandwidth, gain, and efficiency of 48.63%, 2.99 dBi, and 67.44%, respectively. Meanwhile, the array element produces slightly better efficiency (72.98%), approximately the same impedance bandwidth as the single element (48.98%), but higher gain (8.41 dBi). Moreover, it provides a beam width of 21.2° with scanning beam capability from 0° up to 39.05°. The last part is a tunable antenna based on graphene operating at microwave frequency range is proposed. The antenna is designed and fabricated at 15 GHz with a gate electrode placed behind it. They are connected to external direct current (DC) bias during the measurement. The biasing is applied from 0 V to 30 V. The result shows that the resonance frequency is tuned to 20 MHz and reflection coefficient magnitude improves by 1.24 dB. Following this, an analytical calculation on chemical potential is also derived to enhance the graphene tunability. It is shown that at least 2.85 kV of the gate voltage is needed to vary the chemical potential and less than 0.29 μm of dielectric thickness is suitable for tuning purpose with a given condition. Based on the three parts of studies on antenna design and characterisation, graphene can be a good alternative material for future communication. It is due to the exhibited performances are comparable with conventional material and could act beyond the common antenna properties under the influence of tunability, which is owned by graphene.

ABSTRAK

Teknologi generasi kelima (5G) yang akan datang memerlukan antena dengan lebih kapasiti, penggunaan spektrum tanpa wayar yang lebih luas, gandaan yang tinggi, dan kebolehan pengemudian alur. Ini disebabkan oleh penggunaan spektrum yang sempit pada generasi terdahulu. Sebagai hakikatnya, antena konvensional tidak mampu untuk menyediakan frekuensi baru disebabkan oleh batasan fabrikasi dan pemasangan terutamanya untuk saiz yang lebih kecil. Penggunaan bahan graphene menjanjikan antena dengan ukuran yang lebih kecil dan dimensi yang lebih nipis, namun mampu memancarkan frekuensi yang lebih tinggi. Graphene adalah satu bahan unik yang boleh memaparkan ciri penalaan. Ciri ini berasal dari kekonduksian kompleks permukaannya, yang dikawal oleh potensi kimia. Kebanyakan ciri antena graphene boleh tala telah dikaji pada julat frekuensi terahertz, oleh itu menjadikannya sukar untuk direalisasikan secara praktikal. Di samping itu, antena piawai yang menggunakan komponen pensuisan mungkin mengalami masalah semasa pemasangan, dan mengambil saiz seperti yang boleh dilihat dalam antena boleh konfigurasi semula. Oleh sebab itu, satu lagi kajian untuk menghasilkan graphene dengan sifat yang sangat baik adalah penting untuk kemajuan sistem komunikasi tanpa wayar. Dalam tesis ini, antena graphene untuk aplikasi generasi kelima dikendalikan kepada tiga bahagian kajian. Pada bahagian pertama, sifat antena graphene dikaji pada suhu dan masa pengawetan berbeza. Suhu pengawetan adalah 250°C, 300°C, dan 350°C, kemudian setiap suhu ditetapkan dengan masa pengawetan selama 20 minit, 30 minit, 1 jam, 2 jam, dan 3 jam untuk menghasilkan antena berasaskan graphene dengan ciri yang berbeza. Ciri antena berasaskan graphene yang dicadangkan kemudiannya masing-masing disiasat menggunakan penganalisis rangkaian prestasi (PNA), penganalisis rangkaian vektor (VNA), mikroskop elektron pengimbasan pemancaran medan (FESEM), dan spektroskopi Raman. Dari analisis dielektrik, kekonduksian dan pencirian pada sifat graphene, sifat antena menunjukkan keupayaan boleh tala melalui frekuensi resonans dan arah alur utama pola sinaran dengan perubahan yang diperolehi di dalam suhu dan masa pengawetan. Pada masa yang sama, gandaan antena juga boleh diubah. Bahagian kedua ialah kajian terhadap antena graphene pada frekuensi 15 GHz dalam kedua-dua elemen tunggal dan tatasusunan. Antena frekuensi tinggi menyumbang kepada lebar jalur yang besar dan diuja oleh pandu gelombang sesatah untuk lebih memudahkan fabrikasi pada satu permukaan melalui teknik percetakan skrin. Struktur pembumian cacat digunakan dalam elemen tatasusunan untuk memperbaiki radiasi dan meningkatkan gandaan. Keputusan menunjukkan bahawa antena graphene yang dicetak untuk elemen tunggal menghasilkan lebar jalur galangan, gandaan, dan kecekapan masing-masing sebanyak 48.63%, 2.99 dBi dan 67.44%. Sementara itu, elemen tatasusunan menghasilkan kecekapan yang sedikit lebih baik (72.98%), kira-kira lebar jalur galangan yang sama seperti elemen tunggal (48.98%), tetapi gandaan yang lebih tinggi (8.41 dBi). Selain itu, ia memberikan lebar alur 21.2° dengan kemampuan pengimbasan alur dari 0° sehingga 39.05°. Bahagian terakhir ialah antena boleh tala berasaskan graphene beroperasi pada julat frekuensi gelombang mikro dicadangkan. Antena direka bentuk dan difabrikasi pada 15 GHz dengan elektrod get yang diletakkan di belakangnya. Ia disambungkan pada pincangan arus terus (DC) luaran semasa pengukuran. Pincangan digunakan dari 0 V hingga 30 V. Hasilnya menunjukkan bahawa frekuensi resonans ditala kira-kira 20 MHz dan magnitud pekali pantulan meningkat 1.24 dB. Berikutan itu, pengiraan analisis ke atas potensi kimia juga diterbitkan untuk meningkatkan keupayaan boleh tala graphene. Ia menunjukkan bahawa sekurang-kurangnya 2.85 kV voltan get diperlukan untuk mengubah potensi kimia dan kurang daripada 0.29 μm ketebalan dielektrik adalah sesuai untuk tujuan penalaan dengan keadaan tertentu. Berdasarkan ketiga-tiga bahagian kajian ke atas reka bentuk dan pencirian, graphene boleh menjadi bahan alternatif yang baik untuk komunikasi masa hadapan. Ini kerana, prestasi yang ditunjukkan adalah sebanding dengan bahan konvensional dan boleh bertindak melangkaui ciri antenna biasa di bawah pengaruh kebolehan boleh tala yang dimiliki oleh graphene.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1G	-	First Generation
SMS	-	Short Message Service
2G	-	Second Generation
3G	-	Third Generation
4G	-	Fourth Generation
LTE-A	-	Long Term Evolution-Advanced
5G	-	Fifth Generation
IoT	-	Internet of Thing
M2M	-	Machine-to-Machine
Gbps	-	Gigabits per second
GHz	-	Gigahertz
mm-Wave	-	Millimeter-Wave
WRC	-	World Radio Conference
IMT	-	International Mobile Telecommunications
dBi	-	Decibels Relative to Isotropic
mm		millimeter
SLL	-	Side Lobe Level
PCBs	-	Printed Circuit Boards
RFIC	-	Radio Frequency Integrated Circuit
DC	-	Direct Current
THz	-	Terahertz
CPW	-	Coplanar Waveguide
DGS	-	Defected Ground Structure
Mbps	-	Megabits per second
ms	-	milliseconds
Tbps	-	Terabits per second
MMC	-	Massive Machine Communication
$Mn_{0.2}Zn_{0.8}Fe_2O_4$		Manganese Zinc Ferrite
MDC	-	Microwave Dielectric Ceramic
MPA	-	Microstrip Patch Antenna

PET	-	Polyethylene Terephthalate
RDR	-	Rectangular Dielectric Resonator
PLDPA	-	Printed Log-Periodic Dipole Array
CGEs	-	Gradual Corrugated Edges
MDs	-	Metal Directors
AVA	-	Antipodal Vivaldi Antenna
3D	-	Three-Dimensional
dB	-	Decibels
SIC	-	Substrate Integrated Cavity
HPBW	-	Half-Power Beamwidth
CR	-	Coupling Reduce
SIW	-	Substrate Integrated Waveguide
EBG	-	Electronic Band Gap
FR-4	-	Flame Retardant-4
AoA	-	Angle of Arrival
UWB	-	Ultra-Wideband
CNT	-	Carbon Nanotube
2D	-	Two-dimensional
0D	-	Zero-dimensional
1D	-	One-dimensional
3D	-	Three-dimensional
m/s	-	meter per second
$cm^2V^{-1}s^{-1}$	-	square centimeter per Volt per second
RF	-	Radio Frequency
SEM	-	Scanning Electron Microscopy
TEM	-	Transmission Electron Microscopy
AFM	-	Atomic Force Microscopy
S	-	Siemens
SI	-	International System of Units
S/m	-	Siemens per meter
eV	-	electron Volt
K	-	Kelvin
ps	-	picosecond

V	-	Volt
RFID	-	Radio-Frequency Identification
MHz	-	Megahertz
Ω/sq	-	Ohm per square
FGF	-	Flexible Multi-Layer Graphene Film
PANI	-	Polyaniline
ISM	-	Industrial, Scientific, And Medical
SiO_2	-	Silica / Silicon Dioxide
Si	-	Silicon
Ag	-	Silver
CVD	-	Chemical Vapor Deposition
GSG	-	Ground-Signal-Ground
VNA	-	Vector Network Analyser
MST	-	Modulated Scattering Technique
FLG	-	Few-Layer Graphene
CF	-	Carbon Fiber
wt%	-	Weight percentage
GNPs	-	Graphene Nanoplatelets
PS	-	Polystyrene
GO	-	Graphene Oxide
GF	-	Graphene Film
I_D/I_G	-	The Ratio Between Intensity of D and G Band
RGO	-	Reduced Graphene Oxide
Ti	-	Titanium
Cu	-	Copper
PI	-	Polyimide
IGZO	-	Indium Gallium Zinc Oxide
MWNT	-	Multiwalled CNT
Ω.cm	-	Ohm centimeter
nm	-	nanometer
µm	-	micrometer
kHz	-	kilohertz
CST	-	Computer Simulation Technology

PNA	-	Performance Network Analyser
FESEM	-	Field-Emission Scanning Electron Microscope
CPU	-	Central Processing Unit
RAM	-	Random Access Memory
PC	-	Personal Computer
SMA	-	Sub Miniature Version A
AUT	-	Antenna Under the Test
EBSD	-	Electron Backscatter Diffraction
kV	-	kilovolt
STEM	-	Scanning Transmission Electron Microscopy
TEM mode	-	Transverse Electromagnetic mode
MIC	-	Microwave Integrated Circuit
MMIC	-	Monolithic Microwave Integrated Circuit
PVAL	-	Polyvinyl Alcohol
MV	-	Medium Voltage
cm	-	centimeter

LIST OF SYMBOLS

%	-	Percentage
R_{max}	-	Maximum Data Rate
B	-	Bandwidth
M	-	The Discrete Levels of Signals
S	-	Signal Power
N	-	Noise Power
E	-	Total Field
AF	-	Array Factor
n	-	The Number of Elements
θ_o	-	Angle Observed
d	-	Separation Between Elements / Inter-element Spacing
β	-	Progressive Phase Shift
P_r	-	The Power Delivered to the Receiving Antenna / Received Power of Test Antenna
P_t	-	The Input Power of the Transmitting Antenna
R	-	The Distance Between Two Antennas
G_T	-	The Gain of Transmitting Antenna / Gain of AUT
G_R	-	The Gain of Receiving Antenna
D	-	The Largest Dimension of Antenna
λ	-	The Wavelength
$TE^{y}_{1\delta 3}$	-	Higher Order Mode
$TE^{y}_{1\delta 1}$	-	Fundamental Mode
δ		The Fraction of Half-Cycle of the field variation
°	-	Degree
v_F	-	Fermi Velocity
σ	-	Conductivity
V_g	-	Gate Voltage
ρ	-	Sheet Resistivity / Bulk Resistivity
n	-	Surface Charge Density

ε_o	-	Dielectric Permittivity of Free Space
ε_r	-	Dielectric Constant of Substrate / Relative Complex Permittivity
t_s	-	Substrate Thickness
e	-	Electron Charge
ω	-	Angular Frequency
μ_c	-	Chemical Potential
T	-	Temperature
Γ	-	Scattering Rate
τ	-	Transport Relaxation Time
k_B	-	Boltzmann Constant
$\hbar$	-	Reduced Plank's Constant
π	-	pi
$\pm$	-	Plus-minus
$°C$	-	Degree Celcius
Ω	-	Ohm
mL	-	Milliliter
P_s	-	Received Power of Standard Antenna
G_S	-	Gain of Standard Antenna
e_o	-	Total Antenna Efficiency
e_r	-	Reflection (mismatch) Efficiency
e_{cd}	-	Antenna Radiation Efficiency
Γ_{RL}	-	Voltage Reflection Coefficient
ε'	-	Real Part of Permittivity / Dielectric Constant
ε''	-	Imaginary Part of Permittivity / Dielectric Loss
$tan(\delta)$	-	Loss Tangent
W_p	-	Patch Width
c	-	Velocity of Light
f_o	-	Center Frequency
L_p	-	Patch Length
L_{eff}	-	Effective Length
ΔL	-	Length Extension

ε_{eff}	-	Effective Dielectric Constant
D_{cpw}	-	Distance of Separation Between the Two Ground Planes of Waveguide
$s1$	-	Slot Width Between Ground Plane and Feedline
W_f	-	Feedline Width / Center Strip Conductor Width
Z_o	-	Characteristic Impedance
W_s	-	Substrate Width
L_s	-	Substrate Length
θ_c	-	Angle of Chamfer Structure
L_f	-	Feedline Length
W_g	-	Ground Plane Width Between Slot and Feedline
L_g	-	CPW Length
$s2$	-	Side Slot
$s3$	-	Top Slot
t_g	-	Graphene Thickness
L_c	-	Length of Cut
W_d	-	Slot Width
L_d	-	Slot Length
S_{11}	-	Reflection Coefficient Magnitude
ε_s	-	Static Permittivity
ε_∞	-	Relative Dielectric Permittivity
$\tau(T)$	-	Temperature Relaxation Time
E_a	-	Activation Energy
τ_o	-	Prefactor
R_c	-	Gas Constant
$\sigma(T)$	-	Temperature-Dependent Electrical Conductivity
RL	-	Return Loss
Z_{in}	-	Normalised Input Impedance
f	-	Microwave Frequency
μ_r	-	Relative Permeability
R_o	-	Resistance
R_s	-	Sheet Resistance

t	-	The Thickness of Resistor
l	-	The Length of Resistor
w	-	The Width of Resistor

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless communication technology evolves in every ten years. The evolution occurs to serve the improvement service for current requirement so that interaction between people can be implemented properly from time to time. Historically, wireless communication technology has started in 1981 with analogue system. At the moment, the phone only limited for voice communication [1] and this era is known as the first generation (1G). Then in 1992, a digital system was introduced where users can start employ short message service (SMS) text messaging [2]. The existed system is categorised as second generation (2G). Next, in year 2001, the third generation (3G) has started by expanding digital technology through multimedia transmission [3] in mobile phone, laptop and computers. The multimedia consists of high-speed internet access, highly-improved video and audio streaming capabilities [1]. While in 2011 until recent, fourth generation (4G) has taken place to provide high bandwidth access and it is recognised as Long Term Evolution-Advanced (LTE-A) [1], [4]. The 4G LTE technology has become the world information, social media and news can be reached instantly, able facilitating our daily work and life [5] likes online shopping, learning, meeting or even handling business, home work, leisure, and transportation [6] with just in our fingertips by simply using smart phones.

In the coming of 2020 and beyond, the researchers and scientists anticipate that fifth generation (5G) comes with greater capacity and implement new spectrum [7]. The 5G is depicted that it will involve new complementary technologies such as machine-type communication or known as Internet of Thing (IoT), beamforming, front and backhaul, hot spots and small cells [8]. As reported in [9], it states that 5G will support stringent latency, reliability, wide range of data rates, and network scalability and flexibility. Thus, there are a huge number of antenna devices will be installed in the extending of 5G technology [10] likes on-body [11], building or any constructions [6], electrical appliances [12], and private or public transport [13]. Based on these scenarios, the 5G antenna in mobile terminal should have good properties for supporting this new features such as high gain [14], antenna array [15], multiple antenna [16], switched antenna [16], beam-forming [17], and high-directivity beam steering [12]. Figure 1.1 shows the communication evolution from 1G to 5G.

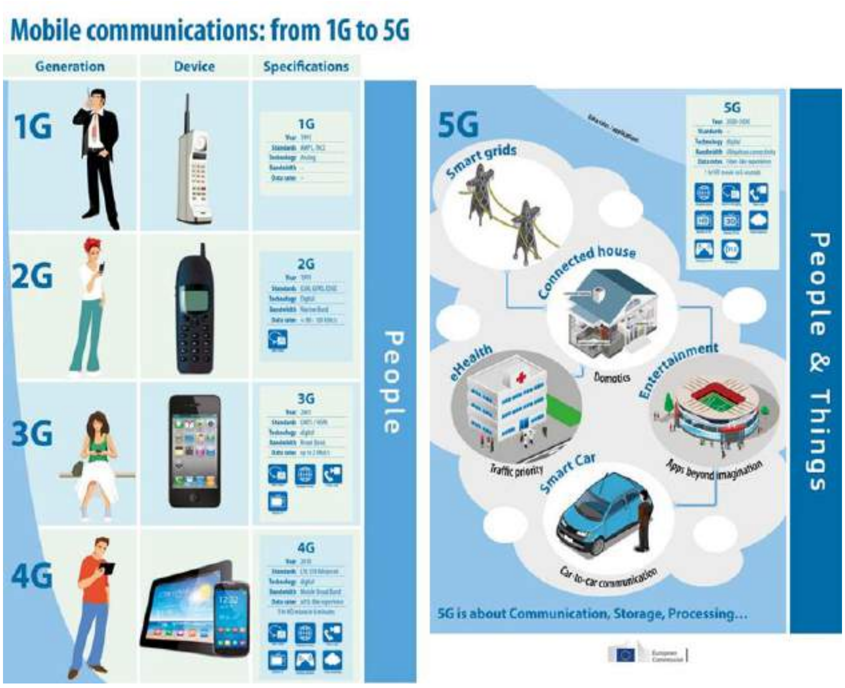

Figure 1.1 The service provided by 1G to 4G is limited for people whereas 5G covers people and things [18]

Therefore, in the 5G antenna design, it is not enough to utilise conventional materials at all kind of 5G applications. It is because some applications appropriate to certain materials in order to keep the aesthetic value, comfortability, and quality. These scenarios become a big challenge in the antenna design. Accordingly, it is time for researchers and scientists in the antenna field to make a paradigm shift. The antenna design is not just made by common conductive and substrate, but can be developed from others potential materials which benefits in the antenna performance as will be introduced in this work that is graphene.

1.2 Problem Statement

With the development of wireless communication technology towards 5G by 2020, the total of device will become larger and could hit up to ten or hundreds billions [4]. This fact is supported by [19] where the huge number is came from machine-to-machine (M2M) applications. That means, the mobile phone that subscribes mobile broadband every year can reach more than one hundred fold. The rise number of machine as a result of people desire the Internet access for immediate communication and access information [10]. Hence, this situation bring to a limit which make the current communication unable to support the mobile data traffic.

The first problem is identified that the [12] predicted the data traffic will go beyond 17 exabytes (17 x 1018 bytes) per month with combining mobile phones, laptops, tablets, and M2M. While in [7] mentioned that the heavy data is coming from video where mobile users start watching television programs and movies through streaming video. Due to that, the mobile traffic will reach 291.8 exabytes in a year by 2019 [7], [20]. The forecast will become worst as the available frequency spectrum allocated, that is lower than 3 GHz has been fully utilised [19]. The same limitation was also presented in [21] where the frequency below 6 GHz is extremely crowded with mobile systems, broadcasting and satellite. This situation brings the spectrum enter the maximum usage [11] thus make the lower frequency unable to serve high bandwidth anymore [10], [14].

Based on this limitation, the demand on higher capacity can be solved by providing broad range of frequency or large bandwidth in order to provide high data rate service [21]. The data rate must exceed 1 Gbps [1], [8], [11], [12] and could reach 50 Gbps [22] which means the possible bandwidth is 1 GHz [7], [12], [22]. Due to cramped utilisation at low frequency, a new frequency spectrum need to be explored and proposed for the future communication. It is supported by [22] where the greater bandwidth can be obtained at higher frequency which able to support higher speed. Several high frequencies have been proposed. Samsung's technology has designed frequency near to millimeter wave (mm-Wave) which range from 30 GHz to 300 GHz [11]. Whilst the other researchers has proposed several tens of gigahertz (GHz), such as 28 GHz and 38 GHz [1], [12], [23], [24], free licensed of 60 GHz [14], and E band; 71 GHz to 76 GHz, 81 GHz to 86 GHz and 92 GHz to 95 GHz [7], [12], [15], [25]. Besides that, the World Radio Conference, Geneva in 2019 (WRC 19) has regulated that 24.5 GHz to 86 GHz can be used for future development of International Mobile Telecommunication (IMT) [26]. Since all the spectrum is not defined yet, thus the frequency that can be considered is band above 6 GHz as stated in the Office of Communications (Ofcom), United Kingdom [22]. However, this work considers frequency in between 6 GHz to 20 GHz because it is not explored as much as mm-Wave, while equipment and facilities in this frequency can be obtained easily.

The second problem is, the conventional indoor antenna commonly has omnidirectional radiation in between -8 dBi to 0 dBi [14]. The gain is too low in order to support the forthcoming 5G system which involves an indoor communication within 80 % compared to outdoor in about 20 % [10], [25], [27]. While that, mm-Wave will experience some disturbances compared to lower frequency because, the signal becomes weak during penetration on solid material or building wall [1], absorbed or scattered by gases, rain, foliage [11], and flora [27]. The path loss also will affect the data rate, spectral efficiency, and energy [10]. In conjunction, the lower frequency band resulting larger antenna size, if the antenna array is designed at this frequency for solving the interference or increasing gain. The antenna will be bulky and not practical for current devices. Furthermore, a very high frequency will face a challenge in manufacturing antenna [8] since the antenna size is inversely proportional to the operating frequency. Due to that, a conventional material and fabrication method used in common antenna also has limitation to manufacture a smaller antenna size which has gap of 0.1 mm.

Related to the problem above, the indoor communication requires higher penetration of radiation. A signal can penetrate with higher gain by implementing antenna array [11] and considering the beam steering and narrow beam [14]. Thus, the gain should be achieved by mobile terminal is near to 12 dBi [28]. In the antenna array design, the isolation for each S-parameter between antenna elements and radiation pattern must be obtained properly in order to obtain high gain. Thus, a technique of mutual coupling reduction can be implemented to reduce side lobe level (SLL) and improve gain. In the production of antenna either single element or array, this study will integrate with alternative materials, graphene as conducting element. It is due to the difference application commonly requires particular material mainly to save cost, besides being flexible, easy, fast, suitable for small size production, and lightweight. Some devices may even be down-scaled [29] in size because of the higher frequency spectrum utilisation. Thus graphene is one of the alternative selection since it has an advantage to produce small dimension which means can be fabricated from nanometers to centimeters [30], [31], and promising candidates to decrease the antenna size [32]. In addition, graphene also can produce broad bandwidth to solve the first problem aforementioned.

The third problem is spotted on multifunctional and multipurpose devices in future communication. The feature is important since the current environment forces people to perform many types of communication and execute many tasks simultaneously involving an antenna which is adaptive with any situation or frequency needed. Due to that, a combination antenna from several frequencies will enlarge the antenna size. In addition, the thickness of cellular phone printed circuit boards (PCBs) are not more than 1 mm thus any increase in the PCB thickness is directly related to rise the production costs and size of the design in the fiercely competitive consumer electronics arena [14]. The difficulties may occurred because the communication device, installation and maintenance should be cheap and reduce cost [12].

Accordingly, a tunable antenna is suitable because its performance is the same as that of a multiple antenna. Since it can cover multiple operating frequencies, then it tends to reduce the system size and number of components [33] besides to serve the device into compact size [34], additional functionalities and attractive features [35], respectively. Tunable antennas commonly implement switches [33], [36]–[43] for varying operating frequency. However, the switches installation possibly disrupt the antenna performance. The other method that presents the same effect employs the implementation of certain materials, where they can be in the form of substrate, radiating or receiving element or additional antenna layer [34], [35], [44], [45]. Thus it is appropriate to envisage the radio frequency integrated circuit (RFIC) with material likes silicon, semiconductors or any material embedded [14], [46]–[48] by a direct current (DC) biasing exhibit switching characteristics. It is applicable because graphene also has tunable properties [49]. This effect is caused by its surface complex conductivity, which is controlled via chemical doping by changing the gate voltage applied [49], [50].

However, several problems are pointed out on graphene where it exhibits big shifted resonance frequency during measurement, broad bandwidth, and unstable radiation pattern due to losses on graphene conductivity and uncontrolled graphene properties that are obtained after curing process. Then, a small changes of resonance frequency and return loss at microwave range [51], [52] are exhibited if tunability is studied. Applying a high voltage to tune the resonance frequency or using a tiny substrate based on the surface charge density equation [53] can solve the limitation, theoretically. Different responses at frequency range near to 1 terahertz (THz) [54] indicate a definite change of tuning due to the high dependence on chemical potential at THz range [55], which means the conductivity of graphene varies smoothly when a chemical potential is changed. Thus, nano-size antenna should be produced for obtaining THz range but it only can be achieved with the support of adequate facilities.

With these deficiencies, there is an alternative method to investigate the characteristics of graphene and at the same time to study the tunability of graphene antenna that is through the disturbance by external energy, or temperature exposure. Since graphene that used in this study have to go through curing process, so it is suitable to use temperature as the factor of change. Temperature also is one of the variable which can modify the conductivity of graphene besides using chemical potential [56]. With the effect of temperature on graphene, the carbon structure of graphene can be changed then affected the electrical properties which directly tune the antenna properties likes resonance frequency [57], [58], reflection coefficient magnitude [59], and radiation pattern if it is in a form of antenna. This mechanism can be an alternative way to be integrated in communication device for future technology.

1.3 Objectives

The objectives of the research are :

(a) To investigate the characteristics of graphene antenna in term of electrical and physical properties

(b) To design, fabricate and test the performance of graphene antenna for single and array element to achieve 5G antenna requirement

(c) To analyse the tunable properties of graphene antenna

1.4 Scopes

The scopes of the research are :

(a) The graphene antenna is investigated in a range of temperature and time exposed. The investigation covers the same fifteen single antennas that classified into three curing temperature; 250°C, 300°C and 350°C. Each curing temperature has the curing time at 20 minutes, 30 minutes, 1 hour, 2 hours and 3 hours. The antenna properties are studied in the variation of curing temperature and time. The change of relative complex permittivity and structure of graphene are recorded for supporting the study.

(b) The single element and phased array of graphene antenna are studied at frequency of 15 GHz using of coplanar waveguide (CPW). The requirement for 5G antenna covers resonance frequency, reflection coefficient magnitude, bandwidth, percentage of impedance bandwidth, radiation pattern, gain and total efficiency. The array antenna studies are limited to four elements due to availability of a four port-external power divider. The defected ground structure (DGS) is implemented as the mutual coupling reduction and beam steering ability is examined in simulation only.

(c) Tunable antenna is analysed using a single element. The antenna operates at the same frequency of 15 GHz. A gate electrode is placed at the back side of antenna for biasing purpose. The biasing analysed covers from 0 V to 30 V and the tunable properties is observed at the resonance frequency and reflection coefficient magnitude. Then, an analytic calculation is suggested for the possibility value for tuning to be happened.

1.5 Thesis Organisation

This thesis is distributed into seven chapters. Chapter 1 has introduced the background and evolution of 5G, the problem and proposed solution for antenna in 5G including the objectives and scopes of the thesis. Chapter 2 presents the literature review of 5G and graphene. The 5G covers definition, requirement and 5G antenna properties such as bandwidth improvement, gain enhancement, mutual coupling reduction, and beam scanning which are reviewed from the previous study. The graphene part touches graphene definition, graphene structure, electronic properties, tunable characteristics, graphene surface conductivity, and opportunity of graphene in 5G applications. The graphene antenna which is graphene patch antenna, and tunable graphene antenna are reviewed from the previous work. The relation of graphene between temperature and microwave absorption is carried out together with previous study on graphene affected by temperature.

Chapter 3 explains the methodology of this research. This chapter contains the antenna specification, flow chart, research methodology, antenna design and estimation, simulation tools, fabrication process, and measurement process. Chapter 4 discusses the properties of 5G antenna made by graphene in single and array element. This chapter contains antenna design and estimation, design evolution, parametric studies, investigation of graphene antenna properties in a range of curing temperature and time with the justification of dielectric, conductivity, surface morphology, and carbon structure, and measurement result for single element. While array element analyses mutual coupling reduction, inter-element spacing, measurement results, and beam scanning performance.

Next, in Chapter 5, the study presents tunable graphene antenna using DC voltage. Then a calculation is derived to analyse the possible value that can show tunability using provided antenna specification. Finally, Chapter 6 concludes the findings of all this research, highlights the contribution, and recommendation for future work.

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