CHAPTER 1

INTRODUCTION

1.1 Background

There have been dynamic research activities around the world in advancing the next-generation 5G wireless networks. More than five billion devices demand wireless connections that run voice, data, and other applications in todays wireless networks [6]. With the rapid development of mobile communications, data transmission rate has become one of the critical factors for smartphone applications. Its no wonder that a much higher data rate and a more stable signal quality will be required in 5G communication [7]. In early 2012, International Telecommunications Union-Recommendation (ITU-R) has started to develop International Mobile Telecommunication-2020 (IMT-2020) and to set up the next technology standard. ITU-R also defines the future challenges of 5G in three possible main scenarios [8], i.e., (i) enhanced mobile broadband, (ii) massive machine type communications and (iii) ultra-reliable and low latency communications.

The significant growth in the customers demand for wireless communication using handsets has created the need for important developments of antenna design as a basic part of any wireless systems [9] especially for 5G communication. There have been two major trends in the antenna design. One is that antennas for mobile device requires small size, built-in, and multi band operation with a nice appearance. Moreover, it needs to fulfill various standardizations and requirements, depending on the function and complexity of the system, its service areas, the quality and quantity of data to be transmitted, and so forth [10]. In addition, using high frequency in mmWave band is a need for designing antenna to achieve higher gain to overcome the path loss[11] due to the atmospheric absorption[12] of electromagnetic waves at higher frequencies[13]. The much higher gain that is needed to compensate the higher signal attenuation at mmWave frequencies introduces the concept of antenna arrays for cellular phones[14]

Many research communities have developed antenna designs for 5G technologies in the future that work on mmWave as in studies [6][15][16][17] using 28 GHz frequencies as antenna working frequency. In addition, the use of higher frequency range (mmWave bands) brings its own challenges to designing antennas on base stations and mobile devices cause the antenna size will become smaller and fabrication become challenging [18].

The continuous growth of wireless mobile services has forced the worldwide mobile headset manufacturers to consider the mutual interactions between the mobile device and the human body. While part of the electromagnetic wave radiated by the antenna is absorbed by the human head, some mobile handset antenna characteristics, such as radiation pattern, radiation efficiency, bandwidth, and return loss are altered due to the proximity of the human head. The mutual effects of the human head and the antenna have been introduced by many research works [12].Another important issue to designing antennas for a mobile phone is the reduction of specific absorption rate (SAR) values

which could be caused by radio frequency radiation from multiple radio and antennas in the mobile phone. The SAR should be as low as possible, especially when antenna in contact with the human brain [10]. In study [6][15][16][17][18][12] used frequency 28 GHz as 5G working frequency using microstrip antenna [6][15], but in research [15] has been done in the form of single antenna prototype by seeing the effect of antenna dimension to antenna working frequency. The use of this microstrip antenna is not enough because bandwidth of the antenna is still narrow [6]. In[13][19] used a single element microstrip antenna with a directional radiation pattern and low gain.Directional radiation pattern requires the use of a beam steering as in the study[11] using ten slot-loop antenna elements, while in [17] using a vivaldi array antenna, but the antenna-able coverage in two studies is $\pm 70^{\circ}$ so it is not capable to reach a wide range. In the other side, in [[17]] explain about beam steering function but the phase difference is only given to the port of each antenna without using the smart antenna as beamforming technique. Therefore, used 4×4 butler matrik [20][21][22][5] at mmWave[23][24] with some advantages such as easy implementation, simple, minimal cost[20], the loss involved is very small[25].

In research [16] used the type of slot antenna array to be applied on 5G,but the bandwidth of this working frequency is still narrow. Open type of antenna that support 5G requirment is a vivaldi antenna , this antenna called Tapered Slot Antenna (TSA) which created by Gibson in 1979 [26], the shape of the TSA cause the antenna to have a wide bandwidth and be able to emit a symmetrical radiation pattern [3].

This thesis proposes vivaldi array antenna for 5G mobile communication with swiched-beam technique called butler matrix with dimension of 4×4 at 28 GHz frequency. Designed and simulated butler matrix-array antennas are further designed using mobile phone modelling so that it can be evaluated and analysis of antenna array-butler matrix performance by using four scenario from CTIA among others are (i)free space, (ii)talking position, (iii)talking position with hand and(iv) browsing mode. In consequence, this thesis focus on the design of vivaldi array antenna integrated butler matrix with high gain, radiation patterns that vary according to the selection of input ports with Specific Absorption Rate (SAR) value according to with IEEE C95.1-2005 standards on SAR Limit.

1.2 Problem Identification

One of the challenges in making a 5G antenna is to design a high gain antenna to avoid high pathloss due to the atmospheric absorption of electromagnet waves at higher frequencies[13][12][11]. The much higher gain that is needed to compensate the higher signal attenuation at mmWave introduces the concept of antenna arrays for cellular phones[14]. But on the other side, the use of antenna arrays to increase the antenna gain causes the antenna radiation pattern to be directional thus requiring the use of beam steering on the antenna [27][17]. The use of beam steering to overcome this problem is not effective, in [11] [17] it is evidenced by the coverage area of 70° that is not full coverage due to the use of an array antenna only on one side of the antenna. To overcome this uncovered area, there are required design antenna put in the left, right

and top side on device.

There are two ways to steering beam using smart antenna system such adaptive array system and switched-beam [24][21][25]. An adaptive array uses adaptive algorithm and digital signal processing to steer the beam automatically to the desired direction with better signal to interference ratio but it is high cost due to the complexity of implementation, while switched beam antenna is less cost and simple[21] to be implemented to achieve most of the features of adaptive array including capability to steer the antenna beam [24]

Butler matrix is one of the well-known beam forming network can be used in switched-beam smart antenna system [22]. It is plays an important role in the transmitter and receiver for 5G communication[23] with some advantages such as easy implementation, simple, minimal cost[20], the loss involved is very small[25]

As indicated by [12] while part of the electromagnetic wave radiated by the antenna is absorbed by the human head, mobile headset antenna characteristics, such as radiation pattern, radiation efficiency, bandwidth, and return loss are altered due to the proximity of the human head. To solve this problem, antenna designed with respect to SAR limit according to IEEE C95.1-2005 [1].

This study was conducted on the basis of research [17][12] on the design of vivaldi antennas which integrated with 4×4 butler matrix [24][5] at mmWave[23]. The working frequency of this 5G antenna is 28GHz [6][15][17][12]. The impact of the human body becomes one of the indicators in antenna performance. The use of vivaldi antenna array with butler matrix on mobile phone is expected to be new innovation in 5G mobile communication.

1.3 Objective

The objective of this research is to increase the performance of antenna at mmWave 5G using vivaldi array antennas collected together with 4×4 butler matrix which both of them allotted into sub array-butler matrix. Integration of sub array-butler matrix is put on top side, left side and right side resulting in a wide beam range of antenna, due to overcome narrow beam caused of antenna array. it is also able to work with a small SAR (Specific Absorption Rate) value according to IEEE C95.1-2005 standard on "SAR Limit "Thus meeting the 5G standard for mobile communications and safe for humans. With the evaluation of antenna performance in terms of modelling the mobile phone and systems such are hand and head of human are expected to maximize and find out the best design of the antenna and know the impact of human's body and device against the antenna.

This research is expected to support Fifth Generation technology especially in the field of design annotation on 5G and become the foundation as the next research especially the use of vivaldi antenna and butler matrix as switched multi-beam technique on Fifth Generation Network by influencing Telkom University and researcher from other institution which is developing or researching similar.

1.4 Scope of Work

In this research, the system is limited by several constraints, including :

1. The use of vivaldi antennas as antennas used in mobile terminals using Rogers RT5880 material with a thickness of 0.254 mm and relative permittivity (ϵ_r) of 2.2. The antenna integrate with butler matrix placed on the mobile terminal and works at a frequency of 28 GHz.

2. The size of butler matrix is 4×4 which mean it has 4 input and 4 output. Butler matrix component of this thesis as follows 4 pieces of 90° hybrid, 2 pieces of cross over, 2 pieces of phase shifter with -45° and 2 pieces of path connecting butler matrix-antenna.

3. Does not discuss electronics circuits on mobile phone modelled.

4. The final configuration of the antennas-butler matrix puts in mobile terminal is tested by modelling the cellular phone also human body such as head and hand in which the antenna is mounted. This performance is evaluated by return loss, radiation pattern, current distribution, radiation efficiency, total efficiency and SAR value. The overall performance of the antenna uses 4 scenarios from CTIA.

1.5 Hypothesis

The proposed vivaldi array antenna which integrates with 4×4 butler matrix are capable to steer antenna beam in a specific direction in one plane [28][20][24][25]. Butler matrix with phase shifter of 45° which produces phase difference at output port respectively with value of phase difference equal to ±45°, ±-135°, ± 135°, ± -45° [5][24] with phase error ≤10°.

By using butler matrix-array antenna, it is expected to create antenna which can change the desired direction along with switching input ports on the butler matrix. The butler matrix placement on the left, right and top sides is expected to provide wide beam range antennas.

The whole of this integration is able to change the radiation pattern as wide as it could even though using beamforming technique, high gain [11][13][14], work an 28 GHz frequency [6][17][15][12] and also and the overal of antenna performance satisfies the basic parameters of the antenna such as return loss, VSWR, return loss, gain, etc [4].

The array antenna-butler matrix [14] that has been placed on the mobile phone tested using four modelling scenarios of CTIA (Cellular Telecommunications and Internet Association) [29] is expected to have a small SAR (Specific Absorption Rate) value [12] [30] in accordance with IEEE C95.1-2005 standards on SAR Limit [1] so that it is not harmful to humans.

1.6 Research Method

This thesis is divided into 5 work packages (wp) to make efficient and high quality results.

1. Wp1: Study literature
   In this wp, this thesis studies the theories needed to design antenna for mobile terminal according for 5G application from textbooks, journals, conference papers, or thesis or dissertation books.

2. WP2: Design of Butler Matrix
   Designing element butler matrix consisting of 90° hybrid, cross over, phase shifter and path connecting butler matrix to antenna. Parameters which determine whether or not the butler matrix is seen from return loss, isolation, insertion loss, phase output, power flow, etc.

3. WP3: Design of single and array antenna
   Single antenna design and optimization is performed to obtain the best performing antenna in terms of return loss, VSWR, bandwidth, radiation pattern and gain. While array antenna is using single element antenna with distance about $\frac{\lambda}{2}$.

4. WP4: Integration of butler matrix-array antenna and placed on mobile phone
   Butler matrix-array antenna which has been designed then placed on the side of the mobile phone in the upper, left and right side. Then evaluated the resulting performance.

5. WP5: Performance evaluations
   The performances of final configuration antenna are evaluated based of CTIA (Cellular Telecommunications and Internet Association) proposed model in terms of: (i)free space, (ii) talking position, (iii) talking position with hand and head and (iv) browsing mode.

1.7 Thesis Organization

In general, the overal of Thesis is divided into five chapter's discussion. the explanation is as follows :

- CHAPTER 1 INTRODUCTION
  This chapter consist of background, problem definition and objective, scope of work, hypothesis, research methodology and writing systematic.

- CHAPTER 2 REVIEW OF LITERATURE AND STUDIES
  This chapter contains the basic concepts and theories related to this research .

- CHAPTER 3 EXPERIMENTAL DESIGN AND SIMULATION
  This chapter consist of flowchart system as follow design of butler matrix with

it's component, design of single-array antenna, integration butler matrix-antenna, mobile phone modelling and other stage of this research flow.

- CHAPTER 4 RESULT AND ANALYSIS
  This chapter consist of simulation result of the antenna and analysis the result of simulation. The simulation of the system is run based on the scenarios that has been design to analyze the proposed system in high mobility condition.
- CHAPTER 5 CONCLUSION AND ADVICES
  This chapter consist of the conclusion of this research and the advice to develop the research.