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DESIGN 60-GHz BAND ANTENNA FOR 5G COMMUNICATION SYSTEM

NUR NAIMAH BINTI HASBULLAH

Thesis submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Engineering Technology (Electrical) with Hons

Faculty of Electrical and Electronic Engineering Technology

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ABSTRAK

Penuai tenaga frekuensi radio (FR) adalah teknologi yang muncul dan sangat menjanjikan yang menawarkan cara baru untuk menghidupkan peranti penggunaan rendah. Penyelidikan keupayaan daya penuai tenaga sangat penting, dan untuk alas an ini, alat simulasi penuai tenaga diperkenalkan. Makalah ini menyajikan reka bentuk antenna patch microstrip, penapis jalur lebar dan penerus untuk aplikasi tanpa wayar 5G yang beroperasi pada 60GHz. Antenna adalah reka bentuk dan simulasi dan analisi dilakukan pada High Frequency Structure Simulator (HFSS). Sementara itu, penyaring dan penyearah jalur lebar adalah reka bentuk dan simulasi dan analisi dilakukan pada perisian Advanced Design System (ADS). Hasil menunjukkan bahawa litar yang direka mampu menghasilkan voltan yang menghampiri 2V. Arus terus pada frekuensi 60GHz dengan sumber kuasa 200mW.Manakala ini juga menyajikan perkembangan pengambilan tenaga RF dengan menggabungkan semua komponen untuk aplikasi tanpa wayar 5G yang beroperasi pada frekuensi jalur 60GHz. Model fizikal terdiri daripada antenna, penapis jalur-jalur, garis microstrip yang sepadan, dan diode Schottky yang dirancang menggunakan perisian High Frequency Structure Simulator (HFSS) dan Advanced Design System (ADS). Perisian merancang litar elektronik gelombang mikro. Schottky diode dan kapasitors digunakan untuk pembetulan. Penuaian tenaga melalui sumber alam sekitar. Secara theory, diode Schottky boleh menghasilkan keluaran yang berganda dari bekalan kuasa input bergantung pada peringkat yang digunakan. Semakin tinggi frekuensi, semakin tinggi leluaran voltan dapat dihasilkan.

ABSTRACT

Radio frequency (RF) energy harvesters are an emerging and much promising technology that offers a new way to power low consumption devices. The investigation of the power capabilities of an energy harvester is essential, and for this reason, a simulation tool of an energy harvester is introduced. This paper presents the design of a microstrip patch antenna, a bandpass filter and a rectifier for 5G wireless application operating at 60GHz. The antenna is design and simulated and the analysis were carried out on High Frequency Structure Simulator (HFSS). Meanwhile The bandpass filter and rectifier are design and simulated and the analysis were carried out on Advanced Design System (ADS) software. The simulation results show that the proposed circuit able to produce approaching 2V DC output voltage at frequency at 60GHz with an input power of 200mW. This paper also presents the development of RF energy harvesting via combining all the component for 5G wireless application operating at 60GHz band frequency. The physical model comprises of antenna, a band- pass filter, a matching microstrip line, and a Schottky diode are designed using lumped components was designed and developed using the software High Frequency Structure Simulator (HFSS) and Advanced Design System (ADS). ADS software for designing microwave electronic circuits. Schottky diode and capacitors is used for rectification. The energy harvesting via environmental source. In theory, it can produce multiple outputs from the input power supply, depending on the stage used. The higher the frequency, the higher the output that can be produced. In addition, the amount of frequency can be obtained based on the size and range of the frequency.

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ADS	Advanced Design Systems
BSs	Base Stations
DC	Direct Current
RF	Radio Frequency
Wi Fi	Wireless Fidelity
5G	Fifth Generation

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CHAPTER 1

INTRODUCTION

1.1 Project Background

As people's awareness of sustainability continues to increase, e-waste is now regarded as an extremely serious problem. It is estimated that tens of billions of disposable and rechargeable dry batteries are used every year and then discarded (Ladan et al., 2014). The recent interest in green electronics has aroused research interest in electronic products, which not only involves low power consumption, but also involves the design of devices in which batteries will not be discarded soon. Such equipment will have to rely on existing natural resources or environmental energy (in some form) to operate, and some form of circuit will be required to capture this environmental energy and convert it into a DC voltage that can power and operate the equipment, so it needs Avoid using batteries for disposal.

Due to the large number of communication channels, television channels, etc., a large amount of power is currently used in the transmission of electromagnetic waves. Therefore, it makes sense to utilize this existing energy and collect this power for remote personal applications. Such as charging a mobile phone or camera. In addition, industrial applications of standalone devices (such as wireless sensor nodes located in hard-to-reach places) can now work on their own without manual intervention to replace or recharge batteries (Guo et al., 2009). When there are many such devices, the recovery of RF energy can greatly reduce costs and make the solution more environmentally friendly.

Furthermore, in 5G cellular networks, presence of wide-band communication signals offer opportunity to harvest RF energy. 5G operates in the frequency range of 600 MHz to 300 GHz (Orfanidis, 2008). In addition, due to the increase in bandwidth, it will improve the user experience by upgrading the current service data rate, user coverage and device battery life. It is also the reason why this project focus on 60GHz band frequency. In this project we investigate on compact 60GHz band antenna for harvesting ambient RF energy to power electronic device at a random location for 5G operation.

This paper proposed for designing a compact 60GHz band antenna will design for harvesting ambient RF energy to power electronic device at a random location for 5G operation.

1.2 Problem Statement

Due to the increasing use of wireless technologies (including WiMAX, WLAN, RFI, cellular phones, 3G, 4G, digital television (DTV), GSM, radio and microwave ovens), there is a large amount of electromagnetic energy in the environment. The power level of the common environmental RF source is the FM broadcast system, cell tower transmission, TV transmission, Wi-Fi, AM transmission, and mobile phones (Yang et al., 2016). Different RF energy can be divided into three categories, namely, intended energy, expected environmental energy and unknown environmental energy. RF energy harvesting or RF energy cleaning can be used to directly power a batteryless system and activate the battery. It can also be used for remote battery charging of mobile phones, powering wireless sensor networks (WSN) and waking up sensors in sleep mode (Shire et al., 2017). This can be done by converting the EM waves in the environment into a usable DC voltage with the help of a rectenna with antenna, integrated filter and rectifier (Shi et al., 2019).

Besides, the 60-GHz band is one potential solution to provide up to multi-Gb/s wireless connectivity. The band promise to be widely used for personal area network applications because it will be 40-100 times faster than today's wireless LAN systems. The 60 GHz frequency band has many advantages over lower frequency bands(Rao & Fapojuwo, 2014). One of the reasons for increasing craze in the availability of huge bandwidth is that it provides continuous and less restricted bandwidth in terms of power limit. With the huge potentials of capacity and flexibility 60 GHz bandwidth became a good candidate for 5G communication systems addition it can eliminate the problem of low received power density at a reception point due to its energy spreading by the distance from the source because receiving power depends on transmit power, then high power base station such as 60GHz frequency or millimetre wave radio is a good candidate for the energy harvesting application (Ullah et al., 2020).

By referring both statements above, we can develop a 60GHz band RF energy harvesting system for 5G operation which more efficient. However, in order to achieve such development, a compact 60GHz band antenna and a 60GHz filter with matching circuit are required to be design for harvesting ambient RF energy to power an electronic device.

1.3 Objective

The main aim of this project is to design a 60GHz band antenna for 5G communication system which will create the opportunity to harvest energyy everywhere in the network's coverage. To accomplish this, the following objectives must be achieved:

i. To design an antenna and band-pass filter for 5G operation.

ii. To develop antenna integrated band-pass filter for 5G operation (60GHz band frequency).

iii. To evaluate the performance of the antenna integrated filter for energy harvesting system.

1.4 Scope of Project

The scope is the most important element in ensuring that projects are completed according to scope. Therefore, to produce a good project, the scope is set so that it does not stray from the objectives. The product been designed that can solve the problem in question, among them are:

1) This study focuses on designing a 60GHz energy harvesting system for 5G operation.

2) Design and simulate the 60GHz antenna using HFSS software

3) Utilizing a MATLAB suitable software to calculate the parameter of antenna and filter.

4) Design and simulate the 60GHz band pass filter using simulation software Advance Design System.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, will discuss about 5G technology and what makes it special, the importance of 60 GHz, the wireless power transfer techniques and some related works. The related work divided into three section, antenna, filter and energy harvesting. Some examples of the hardware and software that are used in this project will also been mentioned in this chapter. This chapter show some previous work, journals and researches include energy harvesting, components of circuit and software that can be contribute an idea to completing this project.

2.2 5G Technology

5G networks will be able to achieve very high data rates, depending on the environment and the number of users. Specifically, for users in indoor environments, 5G can provide 1 Gb/s data rate services. In an outdoor environment with many users, the data rate will be reduced, up to tens of Mb/s. In addition, such a high data rate should be achieved within 95% coverage (Q. (Clara) Li et al., 2014). As the 5G spectrum will utilize frequencies in the millimeter wave bandwidth, the network capacity will increase significantly. The total bandwidth of the new 5G bandwidth is expected to be 10 GHz. The entire spectrum will provide a higher quality of service than the current 4G network (R.E Hattachi 2015).

2.2.1 5G Communication

5G will also be more energy efficient. Energy efficiency refers to the energy in the entire network, which is defined by the number of bits that can be transmitted per joule of energy. This will be achieved through deliberate network design and device connectivity, thereby extending battery life. In 5G, the device battery life of smartphones will be extended to 3 days, and the battery life of low-power devices will be extended 10 times (Zungeru et al., 2016). Even for low-cost machine-to-machine communication equipment, it can be expected to reach a service life of 15 years. For sensors and wearable devices in 5G, their batteries need to run for years without charging. The sensor cost is extremely low and consumes very little energy to maintain a long battery life (Osseiran et al., 2016).

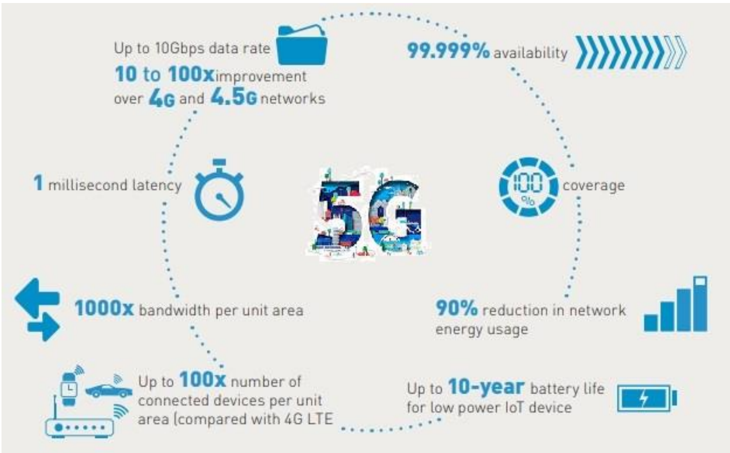

Figure 2.1: 5G Technologies requirement

2.2.2 5G Applications

For smart grids, we need to collect data in central stations with critical communication systems. Applications include smart management of power transmission from the distribution grid to the end of the grid. In addition, remote management of stations can improve the efficiency of the entire grid (Al-Areqi et al., 2017). Great changes will take place in the application of power grids, hospitals, industry and transportation. In addition, it will introduce ideas and concepts such as smart cities, smart cars, mobile healthcare and smart grids (Poornalakshmi et al., 2019).

2.2.3 5G Energy Harvesting

5G will handle large amounts of data traffic through a very dense network architecture. As a result of this processing, huge data traffic and maintenance architecture will also lead to a significant increase in energy consumption, resulting in a larger carbon footprint in the mobile communications industry (Naveed Ahmad Chunghtai, 2018).

The 2% of global carbon dioxide emissions come from the information and communication technology (ICT) industry. Of this 2% share, mobile communications account for about 15% to 20%. In mobile communications, only the operation of the base station consumes 80% of energy consumption. In order to alleviate the huge energy consumption problem in 5G networks, academia and industry are paying attention to energy harvesting technology. Energy harvesting is the process of generating energy from surrounding environmental sources (J.B,Rao and A.O. Fapojuwo, 2014). Figure 2.2 shows the ambient energy source in environment.

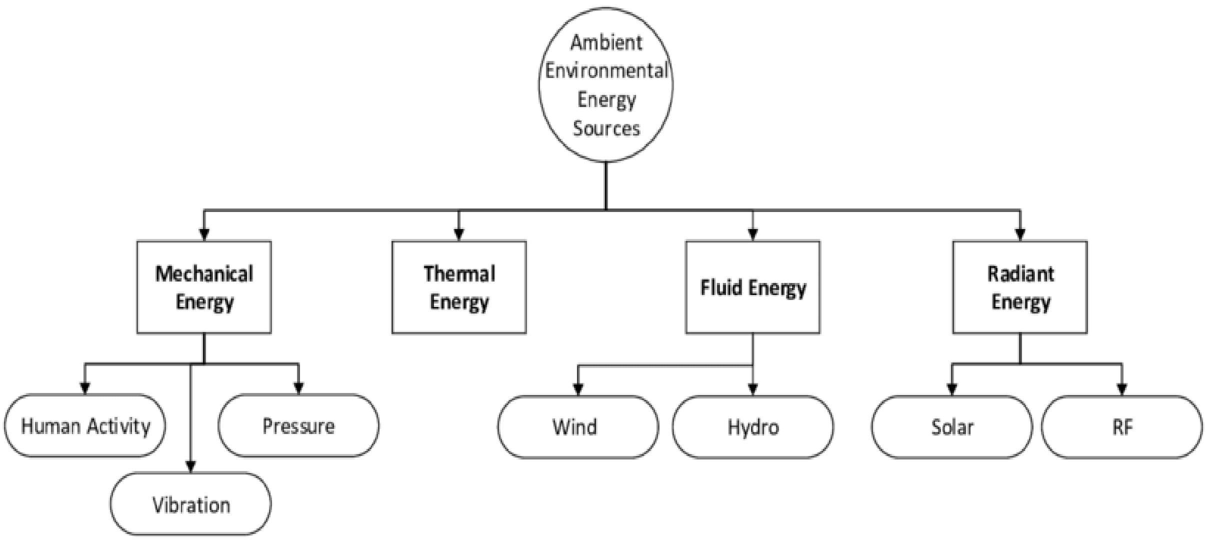

Figure 2.2: Ambient energy source in environment

2.3 Energy Harvesting

Energy harvesting network not only focuses on improving energy efficiency, but also reduces the dependence of system energy on the grid. Energy harvesting in 5G cellular networks has several potential advantages. In order to alleviate the huge energy consumption problem in 5G networks, academia and industry are paying attention to energy harvesting technology. Energy harvesting is the process of generating energy from surrounding environmental sources (Efthymakis, 2018). As a result of this processing, huge data traffic and maintenance architecture will also lead to a significant increase in energy consumption, resulting in a larger carbon footprint in the mobile communications industry (Rao & Fapojuwo, 2014).

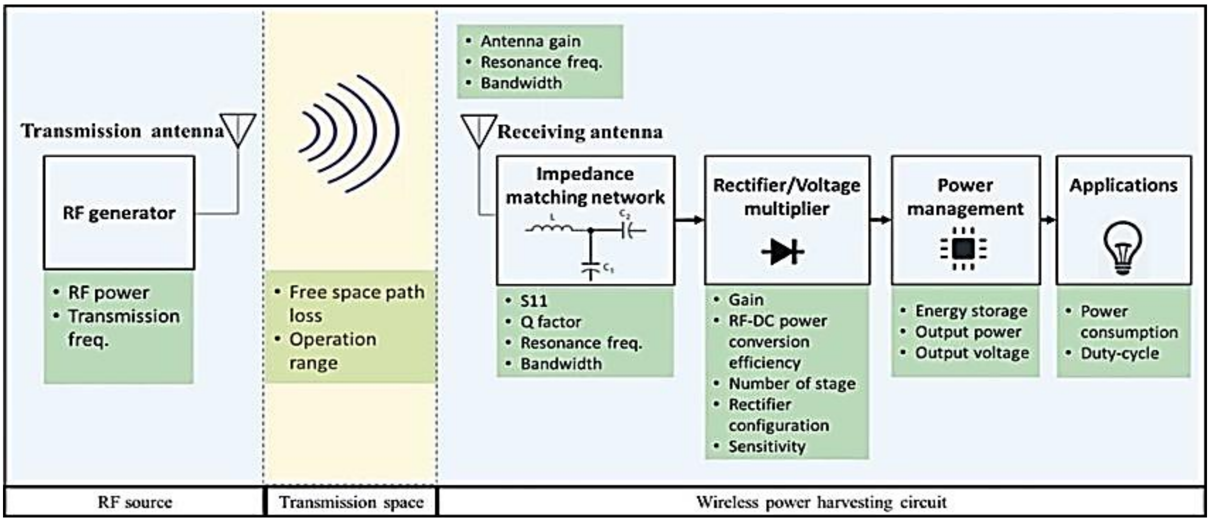

Figure 2.3: Block diagram of RF harvesting system

2.3.1 Types of Energy Harvesting

Energy harvesting can be divided into large-scale and small-scale. The collection of energy from the human body and the collection of energy from surrounding radio frequency sources are both small-scale collections.Radio frequency energy harvesting, antenna works as a transducers, rectifier circuit used to convert to electromagnetic energy AC to DC signal and converted signal is store or deliver to the load. (Adam et al., 2017). This energy that is wasted can be harvested to generate electricity. An energy harvester comprises of transducer to extract the energy, energy converter to transform the energy, energy converter to transform the energy into other energy and an energy storage or load for keeping and utilize the energy. It is used for energy generation (Girish Kumar, 2010).

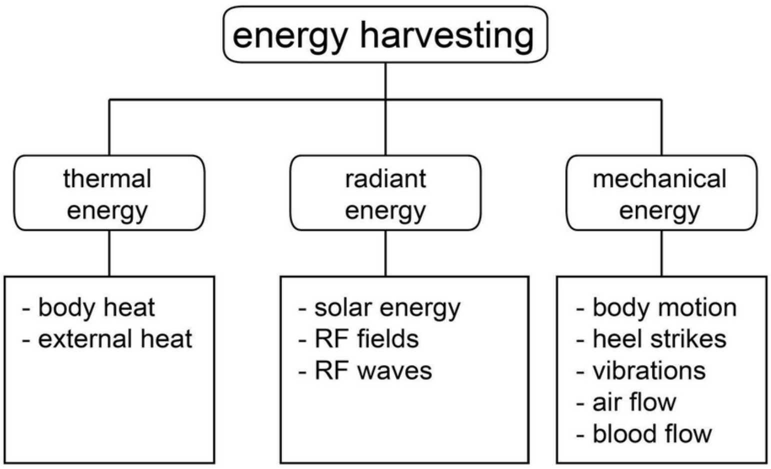

Figure 2.4: Types of energy harvesting

2.3.2 Advantages of Energy Harvesting

Energy harvesting can provide sustainable energy for equipment obtained from nature or man-made itself. There are many sources of energy harvesting, one of which is radio frequency (RF)(Ulukus et al., 2015). In order to generate DC power, the receiver antenna will detect radio frequency, and the signal will be sent through a matching network and sent to the rectifier to convert RF into DC power. The important part of the system is the radio frequency energy, the rectenna and the matching network or circuit. This energy is collected from ambient radio frequencies that may generate continuous energy.

2.3.3 Comparison of energy harvesting sources

The energy used in energy harvesting is solar energy, human body heat, radio frequency energy, radio frequency waves, external heat, moving objects and vibration. For the classification energy it is radiant for the radio frequency waves, radio frequency energy and solar power. Other than that, for the body heat and external it is thermal. Then, the mechanical energy are used to vibration and motion body (Han et al., 2013).

Table 2.1: Comparison of energy harvesting (Zungeru et al., 2016)

Energy source	Classification Energy	Power Density	Weakness	Strength
Solar Power	Radiant energy	100mW/cm^3	Require exposure to light, and low efficiency if device	Can use limit
RF waves	Radiant energy	0.02µW/cm^2 at 5km from AM radio	Low efficiency inside a building	Can used without limit
RF energy	Radiant Energy	40µW/cm^2 at 10m	Low efficiency if out of line of sight	Can use without limit
Body Heat	Thermal Energy	60µW/cm^2 at 5°C	Available only when temperature difference is high	Easy to build using thermocouple
External heat	Thermal Energy	135µW/cm^2 at 10°C	Available only when temperature difference is high	Easy to build using thermocouple
Motion Body	Mechanical	800µW/cm^2	Motion	High power density is not limited to internal and external
Vibration	Mechanical	4µW/cm^2	Has to exist at surrounding	High power density is not limited to internal and external

2.4 RF energy harvesting system

The radio frequency energy harvesting system converts radio frequency energy into direct current energy, so it is also called radio frequency to direct current converter. RF signals for wireless communication systems will be the most suitable energy source because heat, light and vibration are not always available everywhere. Therefore, it involves converting the environmental energy present in the air into electrical energy. This technology uses power regulation, batteries or intermediate stages of storage batteries to protect the energy collected from the environment. Electromagnetic energy exists in the form of alternating magnetic fields around AC power lines or radio waves emitted by nearby transmitters (Mavaddat et al., 2015).

2.4.1 Types of RF Energy Harvesting

Electromagnetic energy exists in the form of alternating magnetic fields around AC power lines or radio waves from nearby transmitters. There are two types of energy harvesting applications for near field and far field. Firstly, far field devices are the wearable rectenna well suited for energy harvesting for ultrahigh frequency band and a tetra band genetic based rectenna designed to harvest from the global system for mobile communications and Wi-Fi RF sources (V. Rizzoli, 2010). Besides that, there are two examples of devices operating in the near-field devices of the source are reported. The one is a harvester optimized for power generation from spurious emissions of compact fluorescent lamp. Other than that, the near field link optimized for powering IMDs. For both cases it is a wireless power transfer is implemented by inductive coupling (S. Riviere, 2010).

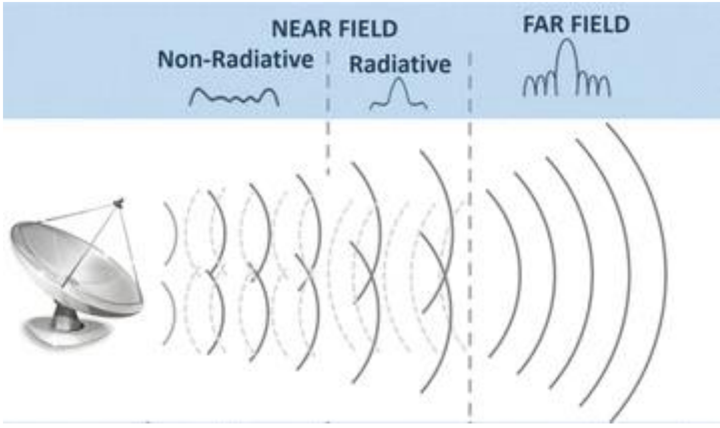

Figure 2.5: Distribution of near field and far field regions

2.4.2 RF Energy Harvesting Components

Rectenna is a combination between antenna and rectifier circuit. These two parts are very important because the function of the rectifier antenna is to receive the RF signal and convert it to DC through the rectifier and enhance it according to the number of n stage to transfer it into the load. Received power of RF signal is described by Friis transmission in Equation (1).

$$P_R = P_T G_T G_R \left(\frac{C}{4\pi r f}\right)^2 \quad (1)$$

Where PR is the received power in dBm, PT is the transmitted power in dBm, GT is the transmit antenna gain, GR is the receive antenna gain, C is the speed of light, f is the operating frequency, and r is the distance between the transmitter and the receiver antenna. Despite different operating frequencies and transmit powers, almost same received power was obtained at the same distance for three systems (Sojan, S., & Kulkarni, R. 2016).

2.5 Rectifier

A bridge rectifier is used to design a rectifier system that can achieve better RF to DC conversion. By using Schottky diodes, this energy is converted to direct current. The antenna of the energy harvesting system is considered to operate at 2.5 GHz with an output impedance of 50 ohm. The input impedance of the rectifier should match the output impedance of the antenna to maximize power transmission. For simple rectifier systems, it is very effective for designing RF energy harvesting systems (Kundu (Datta) et al., 2017).

2.5.1 Rectifier Circuit

There are two major configuration of energy harvesting from Radio Frequency. The Villard voltage doubler it is also known as Cockcroft Walton voltage multiplier and second is Dickson voltage but it is different in performance (Kimura & Tsunemitsu, 2019). The matching task is much simple in Dickson topology because it is applied a parallel capacitor in each stage. The conversion from RF to DC is the key to the energy harvesting from electromagnetic radiation. There is different block in RF to DC converter as main and important one which is the rectifier (Säily et al., 2011).

2.5.2 Comparison of Rectifier

Basic rectifier, voltage doubler and voltage multiplier configuration circuit. The Dickson topology is used because the capacitors in each stage are configured in parallel(Aishah et al., 2017). There are various literatures describing the types of voltage multipliers and showing a comparison of rectifiers.

Table 2.2 Comparison of rectifier

Type of Rectifier	Structure	Rectifier Topology
Basic rectifier	A diode in series with the load. The capacitor acts as a filter to smooth the ripple in the output. Usually called single stage	Half wave rectifier, full wave rectifier
Voltage doubler	Use two stages to approximately double the DC voltage	Villard circuit, Greinacher circuit, bridge circuit, Dickson charge pump voltage doubler
Voltage multiplier	Converts RF energy into DC voltage using network of capacitors and diodes	Villard cascade voltage multiplier, Dickson multiplier, cockroft walton voltage multiplier

2.6 Advanced Design System (ADS)

Advanced Design System is the world's leading electronic design automation software for RF, microwave and high-speed digital applications. ADS lead the most innovative and powerful integrated circuit 3DEM thermal simulation technology used by leading companies in the wireless, high-speed networking, defense aerospace, automotive and alternative energy industries. For 5G, IoT, Gigabit data link, radar, satellite and high-speed switch mode power supply design, Keysight ADS provides an integrated simulation and verification environment that can be designed to meet the latest wireless, high-speed digital and military requirements High-performance hardware standards (Microwave Journal, 2016).

CHAPTER 3

METHODOLOGY

3.0 Introduction

Methodology is a system composed of a wide range of principles or rules, from which specific methods or processes can be derived to explain or solve. It will include a detailed description of the steps to make the project successful. The project starts with the development of the project workflow, and the literature review of the project can be completed on time, the plan must be implemented, and it must also serve as a guide for the project work plan. This method is used to achieve the project goals to be achieved, and the problem statement is studied and determined in detail.

3.1 Flowchart of Methodology

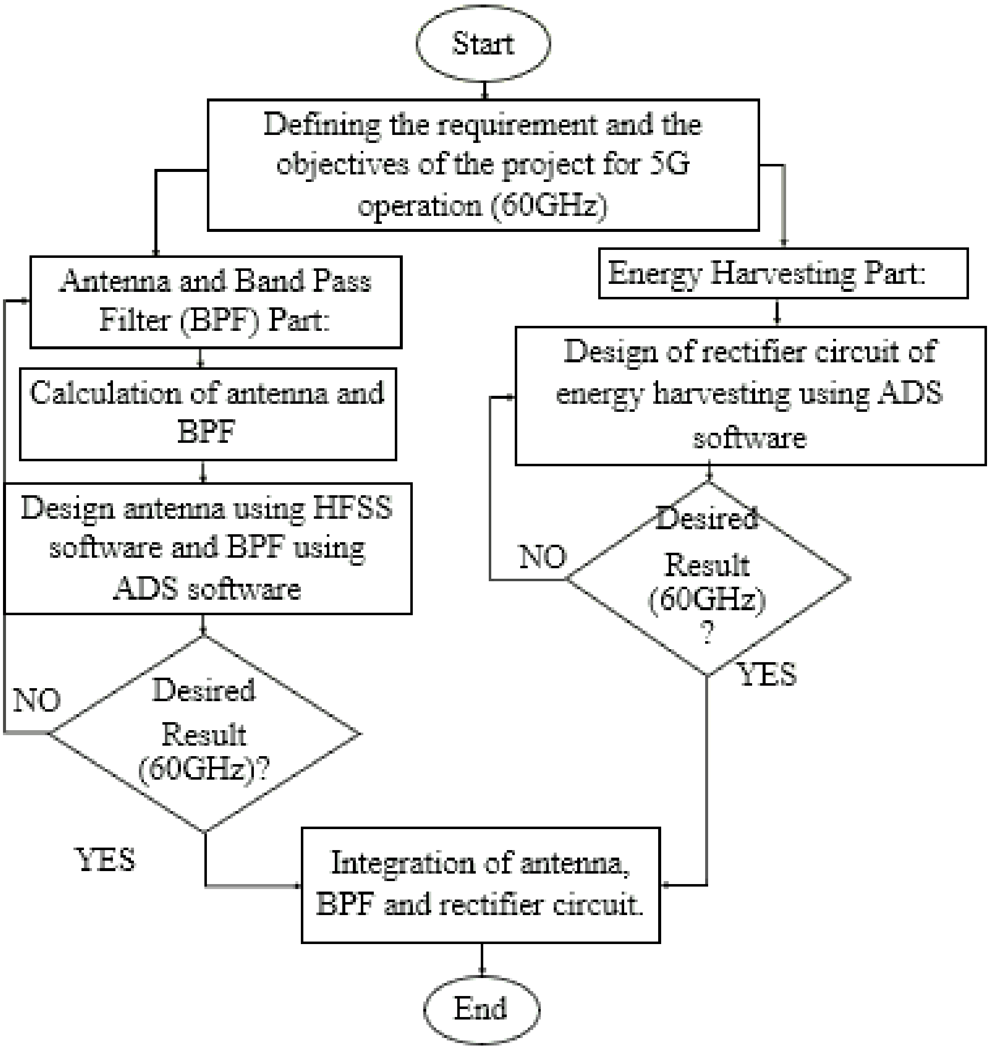

Figure 3.1: Flowchart of the project

Figure 3.1 shows the project flow from start to finish. This project it is combined with three parts, it is antenna, band pass filter and energy harvesting. Firstly, it defined the requirement and the objectives of the project for 5G operation (60GHz).

3.2 Flowchart of Energy Harvesting

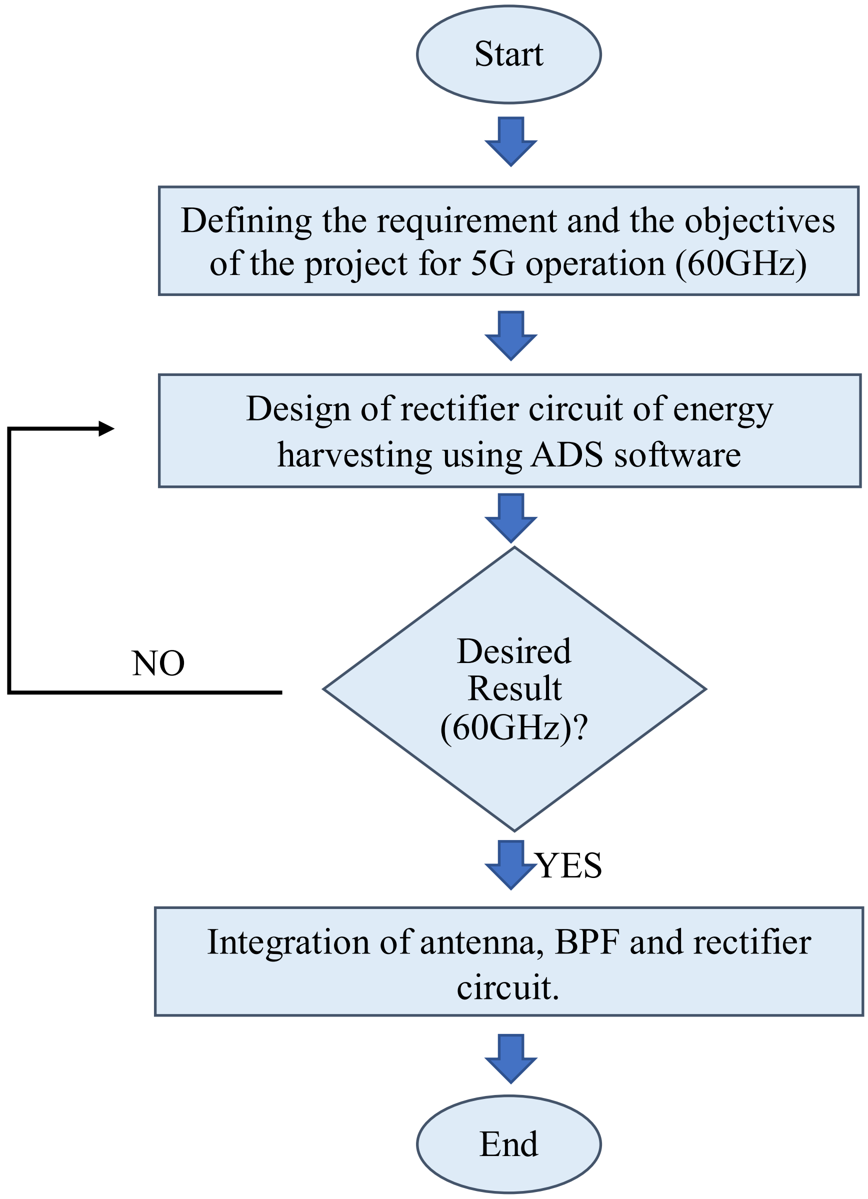

Figure 3.2: Flowchart of the energy harvesting mechanism

Figure 3.2 shows the flow of the beginning project until end. Firstly, find the resource literature review on energy harvesting system and the components, then design of the rectifier circuit for 5G operation using ADS software after design must simulated to get the result achievable then after get a good result, and design of the rectifier circuit.

3.2.1 Block Diagram

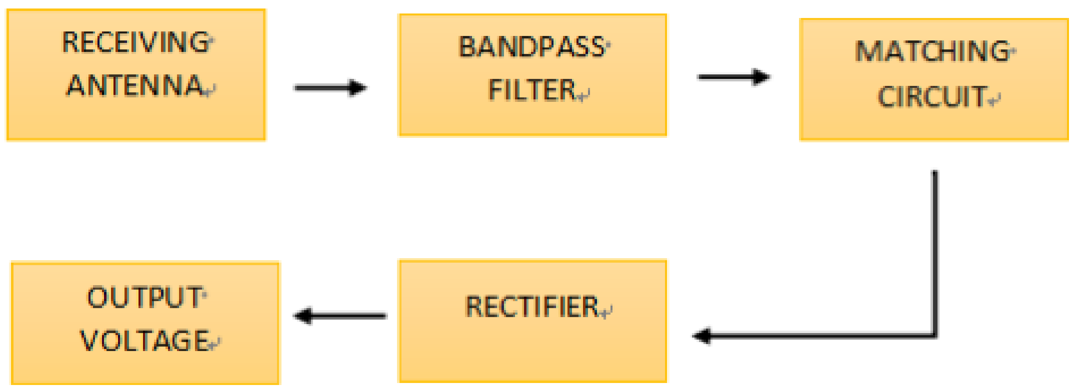

Figure 3.3: Project Block Diagram

According to the block diagram, the antenna receives radio frequency (RF) energy and will pass through a band-pass filter to eliminate unwanted frequencies, and then for the matching network will match the output impedance of the antenna with the rest of the circuit. In order to achieve the best signal transmission from the antenna to the load. Finally, the rectifier will rectify the frequency and convert it to a DC voltage.

3.3 Conceptual Diagram RF to DC

The radio frequency source, define as transmission antenna from radio frequency source such as satellite, mobile phone in the range spectrum of 58 GHz to 62 GHz. Next, part of transmission space has a free space loss and receiving antenna catch-up the free space loss. Lastly, wireless power harvesting begins with receiving signal from antenna. This antenna is responsible for collecting the incident RF from the radiating source and then feeds through the band pass filter to the rectifier circuit to achieve DC power.

3.4 System Developing Process

In order to develop this system, it is mainly divided into three parts, namely the antenna part, the band pass filter and the rectifier as the DC conversion circuit. The Microstrip 16 array patch antenna has been selected for application in the company. The third part is about the rectifier from RF to DC. This is the rectifier, also known as the circuit design RF to DC for 5G operation. In order to design the rectifier circuit, Advanced Design System (ADS) software has been used to simulate the rectifier circuit. The components that have been used are capacitors, inductors and diodes.

3.4.1 Voltage Multiplier

If a complex voltage multiplier is used, design a simple single voltage multiplier to avoid power loss. A voltage multiplier is a circuit that converts it into a DC power source when AC power is supplied. In this project, Advanced Design System (ADS) software has been used to run the simulation as shown in Figure 3.4.

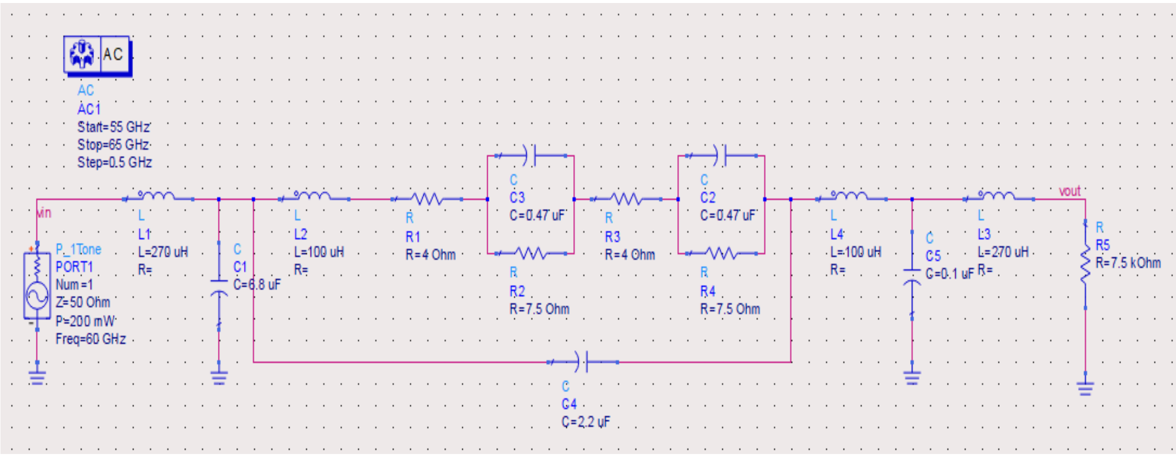

Figure 3.4: Design of rectifier circuit for 5G operation by using ADS Software

3.4.2 Impedance Matching Circuit

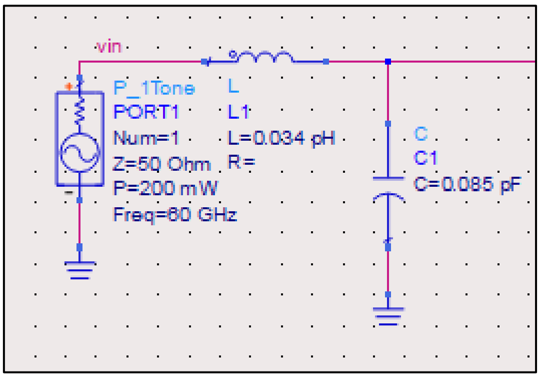

Figure 3.5: Impedance Matching Circuit

The matching circuits used for energy harvesting and data reception are different. As shown in Figure 3.4, for data reception, the load of the antenna is the front-end RF source. The target reference for this design is 58 GHz to 62 GHz. The millimeter wave usually has an input source power of 200mW when operating in 5G. In order to maximize the energy conversion efficiency, otherwise the input impedance of the receiving antenna and the output impedance of the receiving circuit should be the same, otherwise, part of the wireless energy received by the antenna will be reflected back to the environment.

The matching network connection selected for this experiment is the L matching network. The matching network consists of a capacitor which has a value of 0.08 pF and an inductor of 0.03 pH. This matching network is to ensure that there is maximum power dissipated from the antenna to the rectifier circuit. At least value of inductor chosen together with a least value of capacitor. This is to make it as an impedance matching network. In DC frameworks with absolutely resistive sources and loads are reactance.

3.4.3 Combination of Diode

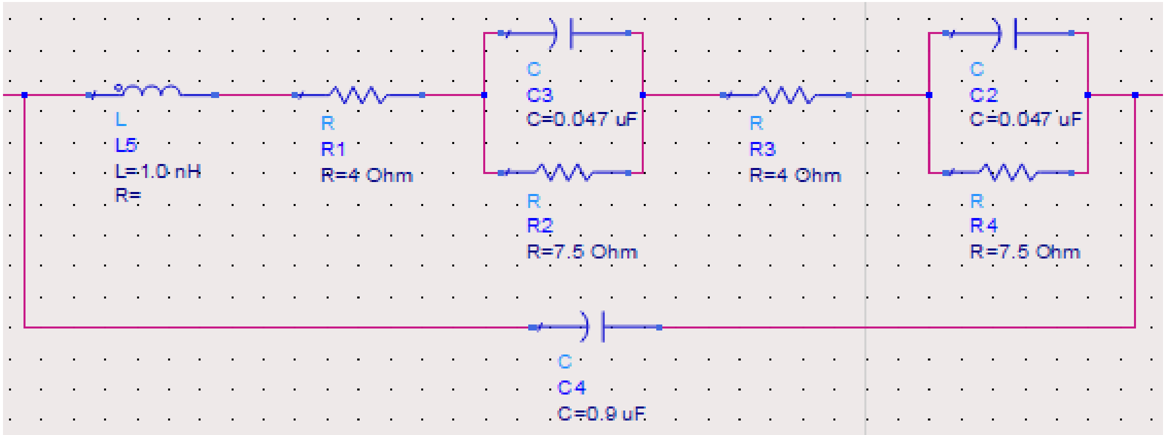

Figure 3.6: Combination of Diode in Rectifier Circuit

The combination of Schottky diode which is resistor and capacitor. The value of resistor that has been used is equally 4 Ohm and value of capacitor has been used is equally 0.04µF. Utilizing just capacitors and diodes, these voltages can venture up generally low voltages to amazingly high values output voltage, while in the meantime being far lighter and less expensive than transformers.

3.4.4 Direct Current Voltage Output

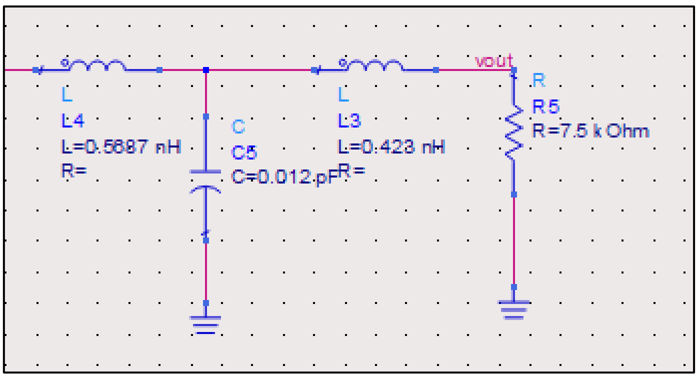

Figure 3.7: Direct Current Voltage Output

For the rectifier circuit which is radio frequency to direct current (DC), Band Pass filter converts the captured RF energy from the antenna and supplies DC output voltage.

3.5 Selection of Materials

3.5.1 Capacitor

Figure 3.8: Capacitor

The capacitor is used in the rectifier circuit to store energy and obtain a constant DC signal, but in fact the fluctuating DC is small, rather than pulsating DC. DC ripple means that the voltage across the load is changing or changing over time. For the capacitor value, 6.8uF, 2.2uF and 0.1uF were selected for the rectifier circuit.

3.5.2 Diode

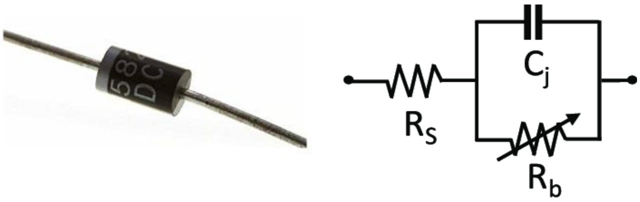

Figure 3.9: Equivalent Schottky Diode

The combination resistor and capacitor which is schottky diodes are capable of achieving high switching speeds because of two basic principles. The schottky diode can improve the signal and become increase multiple voltage output supply.

3.5.3 Inductor

Figure 3.10: Inductor

A filter is a device that allows the DC component of the load to pass and blocks the AC component output by the rectifier. The characteristic of the inductor is to allow only the DC component to pass and block the AC signal. For the design circuit, adjust the inductance value to 1.0nH, 0.42nH and 0.57nH are suitable for the design circuit.

3.6 Rectifier circuit energy harvesting

The simulated of the DC output voltage at source RF, and different frequency which is 58 GHz to 62 GHz.

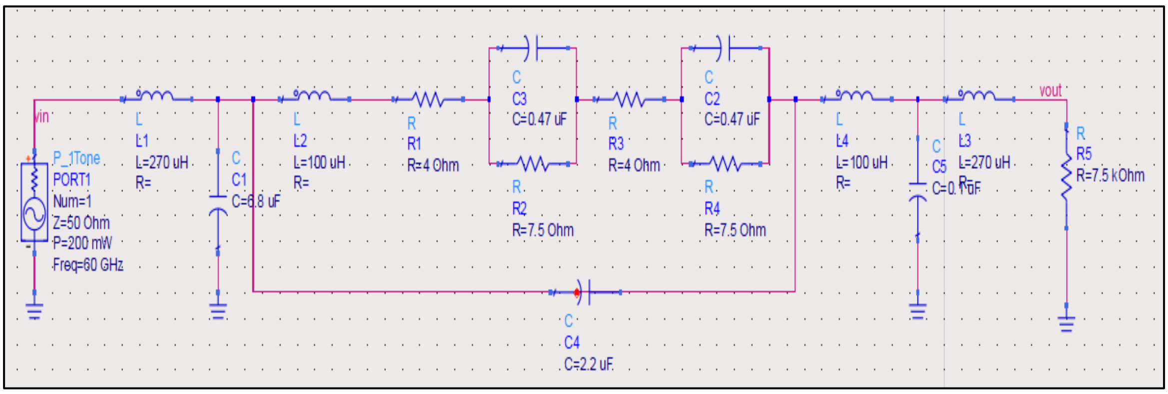

Figure 3.11: Simulation using source RF to DC at power 200mW

The rectifier circuit energy harvesting from RF to DC is new design and the process was relatively simple. The RF to DC integrated circuit is able to capture energy from the movement of those charge carries. The energy is stored temporarily in a capacitor, Schottky diode and then used to create a desired potential difference at the load.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the simulated results of the rectifier circuit are discussed in detail. This chapter also discusses of simulation result RF to DC.

4.2 Simulation of Radio Frequency to Direct Current

The result of the DC output voltage at source RF, and different frequency which is 58 GHz to 62 GHz.

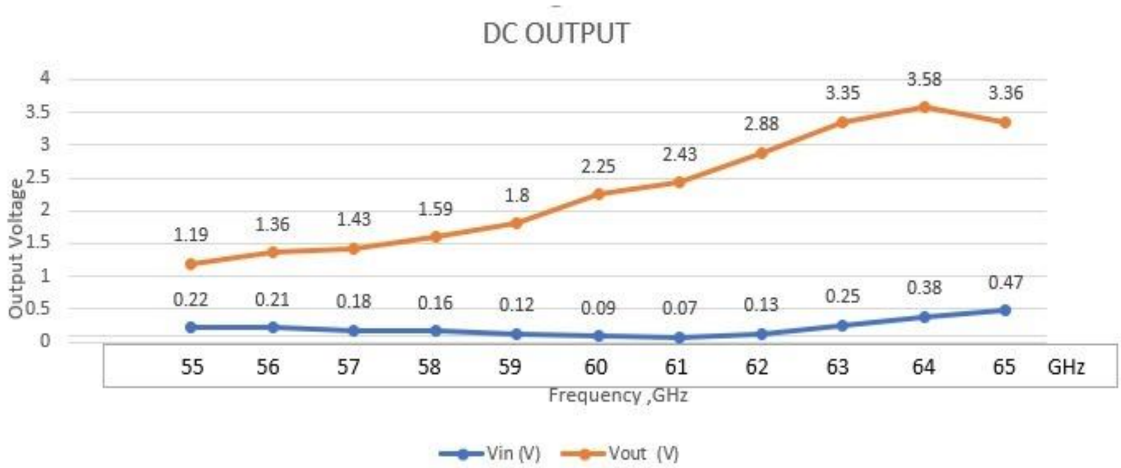

Figure 4.1: Input and output voltage source RF to DC

In this part of energy harvesting, from band pass filter received the radio frequency signal than pass to the rectifier circuit at 58 GHz to 62 GHz that the target benchmark for 5G operating. One of the only RF to DC converters widely available for use was from power. This simulation has created a line of wireless RF energy harvesting that operates in the far fields to provide volt of continuous to charge devices.

Table 4.1: Data Result of input and output voltage

RF signal (DC Input), GHz	Vin (V)	Vout (V)
58	0.16	1.59
59	0.12	1.80
60	0.09	2.25
61	0.07	2.43
62	0.13	2.88

The Table 4.1 and Figure 4.2 shown the design of rectifier circuit for 5G operation using advanced design system (ADS) software is proposed to support the radio frequency energy to direct current supply output voltage. Based on Table 1, result of integration of antenna, BPF and rectifier circuit. simulation shows the input and output voltage give a good result outcome. On 60GHz we get 2.25V and based on the graph, the relationship between input and output voltage are direct proportional with the frequency. The frequency increases the output voltage increase. RF to DC is the new technique to harvest energy the from radio frequency.

Table 4.2: Data Result of input and output current

RF signal, GHz	Iin (A)	Iout (A)
58	0.13	1.25
59	0.11	1.67
60	0.09	2.22
61	0.08	2.86
62	0.07	1.54

The Table 4.2 shown the radio frequency energy to direct current supply output current. The power is 200mW for the 60GHz we get 2.22A for the output and for the input current we get 0.09A. The frequency increases the output and input current also increase.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, energy harvesting method which is RF energy harvesting that designed with a 60GHz antenna integrated with filter and rectifier circuit. Other than that, it is also investigated the challenges that the design of circuits has in 60GHz band frequencies. The RF energy harvesting system focus on 60GHz frequency and can be used for 5G communication operation. The system is suitable for future harvesting method because it focuses on larger frequency and can works with the latest communication system, 5G which has higher bandwidth than 4G. For this RF energy harvesting system, the emphasize about the cost, simplicity and the efficiency. With the development of technology day to day work has been eased for person with energy harvesting.

Otherwise, energy harvesting are promising technologies towards that goals and can helpful in work device application and also rural area. According to the objectives of this project, the construction of this rectifier circuit is as simple as possible. The radio frequency (RF) that is available and can be used as a substitute. It is about the choice of components that will influence the performance and reliability of the device in order to adjust the radio frequency to direct current (DC) supply, and the most important thing is to design a rectifier circuit. The frequency and the Schottky diode captured from the observation would be affected by the output voltage.

Furthermore, the application is widely recommended to the public. It would make it possible for persons to get rid of barriers and constraints in the future by adopting this technology. Cables and batteries used in electrical appliances and adapted to wireless have limitations and restrictions. So, it is also called the science of wireless energy transmission. The finding from this project is to be able harvesting the RF energy and converting into DC voltage to be applied into device for 5G application such as future development, speed, IoT applications and others. Lastly, wireless energy harvesting is a rural area and potential technologies to provide successful solutions for future developments.

5.2 Recommendation

To summarize, to improve this project in future developments, several recommendations have been identified including, the simulation and design of energy harvesting circuit such as rectifier circuit using advanced design system (ADS) software must more research and know the function every component because this software more advantages and important to do the circuit. Secondly, must be investigated the challenges that the design of circuits has in mm-wave frequencies and chosen diode suitable with range frequencies, Schottky diode encouraged which is have fast switching rate and improve increases voltage output. Lastly, to improve design rectifier circuit must add stages voltage multiplier because it will be increased voltage it produces. Future work should focus on future refining the design of the rectifier to allow for more effective signal harvesting, as well as investigating the design using a real source.

REFERENCES

Chris Caroll, “High-Tech Trash,” *National Geographic Magazine*, Jan 2008

T.M. Chiam, et. al, “5.8 GHz Circularly Polarized Rectennas Using Schottky Diode and LTC5535 Rectifier for RF Energy Harvesting.” *2009 Asia Pacific Microwave Conference*, pp. 32-35, 2009

Americas, "5G Spectrum Recommendations," August 2019.

S. Shrestha, S. K. Noh, and D. Y. Choi, “Comparative study of antenna designs for RF energy harvesting,” International Journal of Antennas and Propagation, vol. 2013, Article ID 385260, 10 pages, 2013.

R. E. Hattachi and J. Erfanian, "A Deliverable by the NGMN Alliance NGMN 5G white paper," 17-February-2015.

Adam, I., Yasin, M. N. M., Malek, M. F. A., Rahim, H. A., Shakhirul, M. S., & Razalli, M. S. (2017). Feasibility study on RF energy harvesting in Malaysia. *Advanced Science Letters*, *23*(6), 5034–5038. https://doi.org/10.1166/asl.2017.7304

Aishah, A. S., Beson, M. R. C., Azemi, S. N., & Junid, S. A. A. (2017). 60 GHz Milimeter-Wave Antennas for Point-to-Point 5G Communication System. *MATEC Web of Conferences*, *140*. https://doi.org/10.1051/matecconf/201714001006

Al-Areqi, N. N., Seman, N., & Rahman, T. A. (2017). Design of microstrip parallel-coupled line band pass filters for the application in fifth-generation wireless communication. *Journal of Telecommunication, Electronic and Computer Engineering*, *9*(2–7), 19–23.

Efthymakis, P. (2018). *VCU Scholars Compass A RECTENNA FOR 5G ENERGY HARVESTING*.

Guo, Y. X., Wang, J., Luo, B., & Liao, E. (2009). Development of a 60-GHz bandpass filter and a dipole antenna using wafer transfer technology. *IEEE Electron Device Letters*, *30*(7), 784–786. https://doi.org/10.1109/LED.2009.2022772

Han, B., Vassilaras, S., Papadias, C. B., Soman, R., Kyriakides, M. A., Onoufriou, T., Nielsen, R. H., & Prasad, R. (2013). Harvesting energy from vibrations of the underlying structure. *JVC/Journal of Vibration and Control*, *19*(15), 2255–2269. https://doi.org/10.1177/1077546313501537

Kaviarasu, K., & Ganesh, V. (2015). Design and simulation of a 900 MHz rectifier for Rectenna application. *2015 International Conference on Communication and Signal Processing, ICCSP 2015*, 754–756. https://doi.org/10.1109/ICCSP.2015.7322592

Kimura, Y., & Tsunemitsu, Y. (2019). Analysis of Effective Coverage Area in 60GHz-Band

Millimeter Wave Wireless LAN for High Speed Railway Passenger Car and Indoor Room. *2019 International Symposium on Antennas and Propagation, ISAP 2019 - Proceedings*, 7–9.

Kundu (Datta), P., Acharjee, J., & Mandal, K. (2017). Design of an Efficient Rectifier Circuit for RF Energy Harvesting System. *International Journal of Advanced Engineering and Management*, *2*(4), 94. https://doi.org/10.24999/ijoaem/02040024

Ladan, S., Guntupalli, A. B., & Wu, K. (2014). A high-efficiency 24 GHz rectenna development towards millimeter-wave energy harvesting and wireless power transmission. *IEEE Transactions on Circuits and Systems I: Regular Papers*, *61*(12), 3358–3366. https://doi.org/10.1109/TCSI.2014.2338616

Li, P. F., Liao, S., Xue, Q., & Qu, S. W. (2020). 60 GHz Dual-Polarized High-Gain Planar Aperture Antenna Array Based on LTCC. *IEEE Transactions on Antennas and Propagation*, *68*(4), 2883–2894. https://doi.org/10.1109/TAP.2019.2957095

Li, Q. (Clara), Huaning Niu, A., Papathanassiou, (Tolis), & Wu, and G. (2014). 5G Network Capacity. *IEEE Vehicular Technology Magazine*, *March*, 71–78.

Mavaddat, A., Armaki, S. H. M., & Erfanian, A. R. (2015). Millimeter-wave energy harvesting using 4 × 4 microstrip patch antenna array. *IEEE Antennas and Wireless Propagation Letters*, *14*, 515–518. https://doi.org/10.1109/LAWP.2014.2370103

NGMN Alliance. (2015). 5G White Paper. *A Deliverable by the NGMN Alliance*, 124. https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0_01.pdf

Orfanidis, S. J. (2008). Waves and Antennas Electromagnetic. *Media*, *2*, 525–570. http://www.ece.rutgers.edu/~orfanidi/ewa/

Osseiran, A., Monserrat, J. F., & Marsch, P. (2016). 5G mobile and wireless communications technology. In *5G Mobile and Wireless Communications Technology* (Issue June). https://doi.org/10.1017/CBO9781316417744

Poornalakshmi, M., Pavithra, T., & Introduction, I. (2019). *DESIGN OF LOW COST RECTENNA FOR WIRELESS ENERGY HARVESTING ABSTRACT : C =*. 66–71.

Rao, J. B., & Fapojuwo, A. O. (2014). A survey of energy efficient resource management techniques for multicell cellular networks. *IEEE Communications Surveys and Tutorials*, *16*(1), 154–180. https://doi.org/10.1109/SURV.2013.042313.00226

Säily, J., Lamminen, a, & Francey, J. (2011). Low cost high gain antenna arrays for 60 GHz millimetre wave identification (MMID). *… ESA Workshop on Millimetre Wave …*, *Mmid*. http://www.4taconic.com/dielctrc/pdf/technicalarticles--high_gain_antenna_mmid.pdf

Shakib, M. N., Moghavvemi, M., & Mahadi, W. N. L. (2016). Optimization of planar monopole wideband antenna for wireless communication system. *PLoS ONE*, *11*(12), 1–15. https://doi.org/10.1371/journal.pone.0168013

Shi, C., Cui, J., Sheng, W., & Han, Y. (2019). A 60GHz Wideband Antenna Array Based on Metasurface with Gap Waveguide (GWG) Divider. *2019 49th European Microwave Conference, EuMC 2019*, *1*, 666–669. https://doi.org/10.23919/EuMC.2019.8910778

Shire, A. M., Abdullah, N., & Mohd, E. (2017). Design of rectenna for wireless energy harvesting. *Proceedings - 14th IEEE Student Conference on Research and Development: Advancing Technology for Humanity, SCOReD 2016*, 8–11. https://doi.org/10.1109/SCORED.2016.7810060

To, S., & By, P. (2010). *REPORT ON Secretary , DOT , Delhi Prepared By*. *December*, 1–50.

Ullah, S., Yeo, W. H., Kim, H., & Yoo, H. (2020). Development of 60-GHz millimeter wave, electromagnetic bandgap ground planes for multiple-input multiple-output antenna applications. *Scientific Reports*, *10*(1), 1–12. https://doi.org/10.1038/s41598-020-65622-9

Ulukus, S., Yener, A., Erkip, E., Simeone, O., Zorzi, M., Grover, P., & Huang, K. (2015). Energy Harvesting Wireless Communications: A Review of Recent Advances. *IEEE Journal on Selected Areas in Communications*, *33*(3), 360–381. https://doi.org/10.1109/JSAC.2015.2391531

Yang, W., Ma, K., Yeo, K. S., & Lim, W. M. (2016). A Compact High-Performance Patch Antenna Array for 60-GHz Applications. *IEEE Antennas and Wireless Propagation Letters*, *15*(January), 313–316. https://doi.org/10.1109/LAWP.2015.2443054

Z.Zakaria, N. A. Zainudin, M. N. Husain, M. Z. Abidin, A. Aziz, M. A. Mutalib, and A.R. Othman.(2013). "Current Developments of RF Eergy Harvesting System for Wireless Sensor Networks," Adv. Inf. Sci. Serv. Sci., vol. 5, no. June 2013, pp. 328-338, 2013.

Zungeru, A. M., Ang, L. M., Prabaharan, S. R. S., & Seng, K. P. (2016). Radio frequency energy harvesting and management for wireless sensor networks. *Green Mobile Devices and Networks: Energy Optimization and Scavenging Techniques*, *April*, 341–367. https://doi.org/10.1201/b10081-17

APPENDICES

Appendix A Design and Prototype rectifier circuit for 5G operation

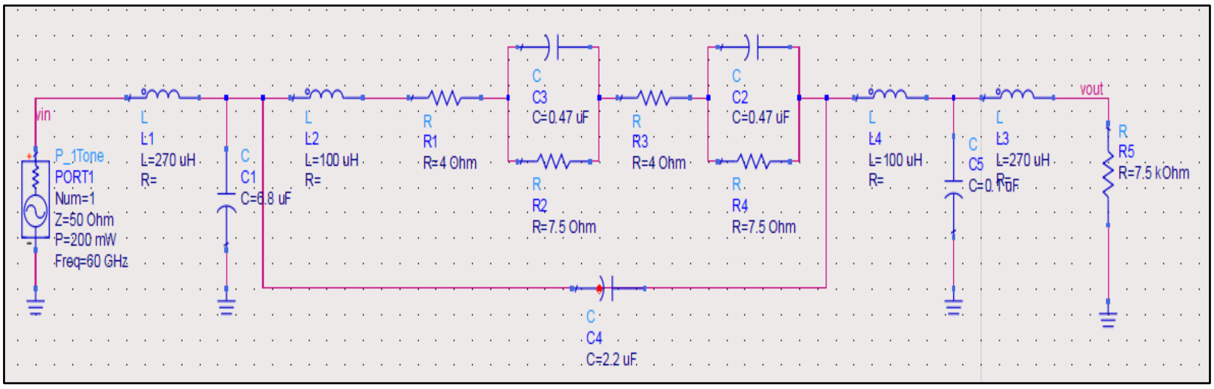

Figure 1: Design of rectifier circuit

Figure 2: Prototype components of rectifier circuit

Appendix B Gantt chart project planning SDP 2

Table 1: Gantt chart project planning SDP 2

ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
SDP 2 BRIEFING	■													
BUY MATERIAL		■	■	■	■	■								
TESTING		■	■	■	■	■	■							
DATA COLLECTION					■	■	■	■	■					
LOGBOOK, AND TECHNICAL REPORT										■	■	■	■	
PRESENTATION WITH SV												■	■	
PRESENTATION WITH PANEL														■
SUBMIT FULL REPORT PROJECT														■