HIGH GAIN MONOPOLE ANTENNA FOR VHF AND MICROWAVE INTERFEROMETERS

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This Report Is Submitted In Partial Fulfilment Of Requirements For The Bachelor Degree Of Electronic Engineering (Wireless Communication) With Honours

Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer

Universiti Teknikal Malaysia Melaka

June 2017

UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

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ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to my supervisor, Dr. Mohd Riduan bin Ahmad for his support and guidance throughout the project. Without his assistance and dedicated involvement in the project, this thesis would have never been completed.

I would also like to extend my appreciation to all the master‟s students under the same supervior, Dineh Periannan and Muhammad Haziq bin Mohamad Sabri, who have been very helpful. They do not hesitate to share their knowledge.

My sincere appreciation is extended to Muhammad Fikri bin Aziz and Mohamad Azwan bin Zainal‟Abidin for their time and help. Without their help, my five-meter antenna would not have been able to stay upright. Special thanks to Jesmen Yeoh for his assistance in acquiring materials and components needed to construct the antenna.

Finally, I wish to take this opportunity to thank my family and friends for their unconditional support and encouragement. They have given me unlimited motivation to complete this project.

ABSTRACT

Monopole antenna is one of the most widely used antennas around the world owing to the radiation characteristics that it exhibits. Its omnidirectional radiation properties, frequency range, light weight, simple structure, ease of fabrication and low cost make it possible to be used in numerous applications. The only problem is that a simple monopole antenna can only achieve a relatively low gain. This means low sensitivity and low efficiency on the antenna performance. Therefore, a high gain wire monopole antenna is designed and constructed in this project. The antenna is composed of a number of main radiating elements placed collinearly and separated by phasing coils, with a total of four radials made as the virtual grounding. With the aid of CST (Computer Simulation Technology) Microwave Studio, two separate collinear monopole antennas are designed to operate at the VHF and microwave band respectively, one at 60 MHz and another at 1 GHz. Through parametric study, the most satisfactory results are obtained. Simulation results clearly show that the 60 MHz and 1 GHz collinear antennas are able to achieve a gain of 3.238 dB and 10.74 dB respectively. Having a return loss of -26.225 dB and -23.936 dB, both antennas exhibit omnidirectional radiation patterns. Simulations results for farfield radiation patterns and VSWR of both antennas are presented and discussed. The antennas are designed to be used as lightning interferometers. Source of electromagnetic radiation generated from lightning flashes can be detected and located.

Key words: monopole antenna, interferometer, gain, radiation pattern, VSWR (voltage standing wave ratio)

ABSTRAK

Monopole antena adalah salah satu antena yang paling banyak digunakan di seluruh dunia disebabkan ciri-ciri yang dipamerkan olehnya. Radiasi yang bercorak omnidirectional, struktur yang mudah dan ringan, kemudahan fabrikasi dan kos yang rendah menyebabkan monopole antena banyak digunakan dalam pelbagai aplikasi. Satu-satunya masalah yang dihadapi ialah monopole antena hanya boleh mencapai nilai kuasa gandaan yang agak rendah. Ini bermakna sensitiviti dan kecekapan prestasi antena yang rendah. Oleh itu, monopole antena yang mempunyai nilai kuasa gandaan yang tinggi telah direka dan dibina dalam projek ini. Antena tersebut terdiri daripada beberapa elemen utama yang disusun dalam garisan lurus dan dipisahkan oleh gegelung, dan sebanyak empat „radials‟ dipasang sebagai „virtual ground‟. Dengan menggunakan CST (Computer Simulation Technology) Microwave Studio, dua monopole antena yang berasingan telah direka untuk beroperasi pada VHF dan gelombang mikro, satu pada 60 MHz dan satu lagi pada 1 GHz. Melalui kajian parametrik, prestasi antena yang paling memuaskan dapat diperoleh. Keputusan simulasi jelas menunjukkan bahawa monopole antena 60 MHz dan 1 GHz masing-masing mampu mencapai nilai kuasa gandaan sebanyak 3.238 dB dan 10.74 dB. Dengan „return loss; sebanyak -26,225 dB dan -23.936 dB, kedua-dua antena mempamerkan radiasi yang bercorak omnidirectional. Corak radiasi dan VSWR bagi kedua-dua antena dibentangkan dan dibincangkan. Antena dalam projek ini direka dan digunakan sebagai „interferometer‟. Sumber radiasi elektromagnetik yang dihasilkan daripada kilat dapat dikesan.

Kata kunci projeck: „monopole antenna‟, „interferometer‟, nilai kuasa gandaan, corak radiasi, „VSWR (voltage standing wave ratio)‟

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CHAPTER 1

INTRODUCTION

1.1 Background

Lightning is a common natural phenomenon known by every man living on earth. It often occurs during thunderstorms due to electrical discharge, either between a cloud and the ground, between two clouds, or between different regions of a cloud.

While lightning is one of the most wonderful displays in nature, it can be disastrous if strikes at the wrong places. Lightning generates electromagnetic radiation in a tremendous amount over a very big frequency spectrum, from as low as a few kHz to GHz. It is enough to kill a grown man in a few seconds.

Interferometry is a system used to locate the position of electromagnetic radiation generated from lightning. With the angular locations of the lightning known, it is possible for imaging lightning discharge progression and for people to avoid thunderstorms.

The most basic interferometry system consists of two antennas placed on the ground separated by a distance d. However, only a one-dimensional location of lightning source can be obtained. To achieve a higher accuracy two-dimensional position, a third antenna is added to the system. With this, a more precise azimuth and elevation angle of the lightning source can be determined.

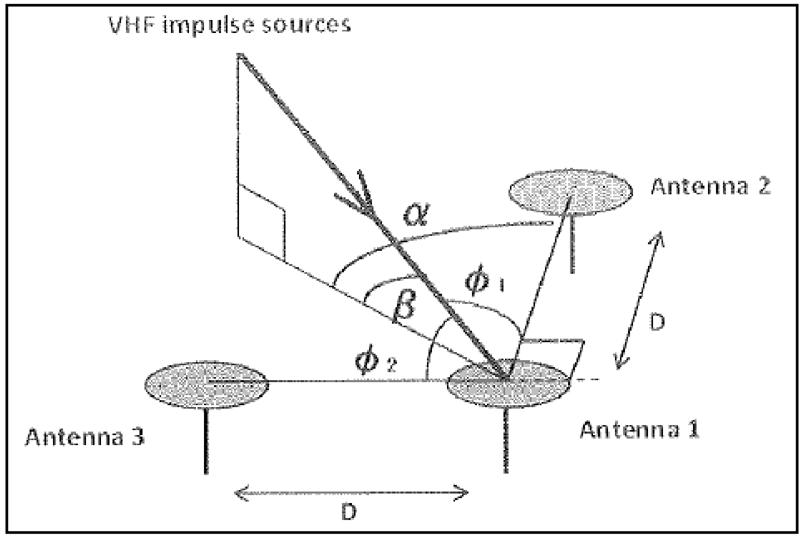

Figure 1-1 Antenna Arrangement of Interferometer for Two-Dimensional Mapping [1]

In this project, a high gain monopole antenna for microwave interferometry is designed, simulated and constructed. In practice, a wide use has been made of the quarter-wavelength monopole antenna. It consists of a main radiating element of a quarter wavelength long mounted on a ground plane or radials and fed by a coaxial line. A quarter-wavelength monopole antenna typically exhibits an omnidirectional radiation pattern with a unity gain [2].

To increase and achieve a minimum gain of 10 dB, the collinear monopole antenna configuration is used. More than one radiating elements are stacked together in a line and separated by phasing coils. There is a significant improvement on the antenna gain. With this, lightning can be detected more easily hence proper lightning discharge progression imaging can be done.

1.2 Problem Statement

Gain is one of the most important measures of an antenna‟s performance as a transmitting system. It is a very common problem for all types of antenna to have low gain. Low gain means low sensitivity and shorter range of antenna operation. In other words, a higher antenna gain is essential for reliable signal reception and transmission. Constructing a monopole antenna with high gain is the ultimate target of this project.

Wavelength is inversely proportional with frequency hence antennas tend to be bulky and heavy at lower frequencies. For instance, a basic quarter wavelength monopole antenna at the operating frequency of 60 MHz is as long as 1.25 meters but only exhibits a low gain of approximately 1 dB. The antenna will probably need to be much longer than 10 meters if it is to achieve a higher gain. Placing the tall antenna vertically on the ground in the open will expose the antenna to extreme weathers. It will eventually succumb to strong wind and heavy rain and might not be able to perform at its best condition. It should be shielded by a protective jacket or made of strong rigid materials so as to prevent it from corroding.

Apart from that, cost is also a concern. Up until now, a 60 MHz antenna for lightning interferometry does not yet exist. Meanwhile, an antenna for commercial use at the same frequency costs more than RM 10,000. It is not very likely that people are able to afford to purchase one at this price. Monopole antenna designed in this project costs at most only a few hundred ringgits. It is cheap and affordable.

1.3 Objectives

The objectives of this project are as follows:

a) To design, simulate and construct 60 MHz and 1 GHz high gain wire monopole antenna for VHF and microwave interferometer.
b) To design a wire monopole antenna that is less costly.
c) To analyse the performance of the designed antennas.

1.4 Scope of Work

The scope for this project can be classified into three parts. The first part involves simulation of the 60 MHz and 1 GHz monopole antennas in CST (Computer Simulation Technology). By performing parameter sweep, the most optimum design of the monopole antenna is selected. The performance is further improved with slight modifications until the gain reaches at least 10 dB.

The second part of this project deals with acquiring components and materials needed for the antenna construction. Due to the reason that the 1 GHz filter is unavailable at the moment, only the 60 MHz antenna is constructed and tested. The results obtained are then analyzed.

Lastly, a complete comparison was done on the simulated and measured results. The comparison is analyzed in detail.

1.5 Thesis Structure

This thesis is organized into five main chapters. The five chapters include introduction to the project, literature review of past researches, methodology, results and discussion and lastly, conclusion and future work.

The first chapter gives a general overview and explanation of the conducted project. This includes the application of the designed antenna, problem statements, objectives and scope of the project. Detailed explanations will be covered in the following chapters.

The second chapter provides a review of previous researches on lightning, interferometry system and also various configurations of high gain monopole antennas. A critical review is then made based on the performances of each antenna designs. From there, the project is continued with the most suitable design, with some modifications to fulfil the desired antenna specifications and performance.

In the third chapter, a detailed explanation on the antenna design is included. Antenna design and simulation are done using CST (Computer Simulation Technology) Microwave Studio. The materials and dimensions used are clearly specified in this chapter. From designing to constructing the antenna, each process is described.

The result obtained from both simulation and measurement is analyzed. The fourth chapter covers the result analysis based on the S-parameter plots, radiation patterns, polar plots and also results obtained from oscilloscope.

Lastly, in the fifth chapter, a conclusion is made. Future works that can possibly bring the performance of high gain monopole antenna to the next level are included in this chapter before the thesis comes to an end.

CHAPTER 2

LITERATURE REVIEW

2.1 Types of Lightning Flashes

Lightning flashes can be classified into two main types, namely cloud-to-ground (CG) and cloud-to-cloud flashes which can be further divided into intra-cloud and inter-cloud flashes (IC).

Cloud-to-cloud flashes occur between cloud or clouds. They are discharge of lightning between clouds without any discharge channel coming in contact with the ground. Intra-cloud flashes occur when there are two oppositely charged portions in the same cloud. Inter-cloud flashes are less common compared to intra-cloud flashes. They happen only between oppositely charged portions of different clouds.

Cloud-to-ground flashes occur between the cloud and the ground. In fact, it has been identified that there are a total of four different types of lightning discharges between the cloud and the earth surface, namely downward negative lightning, upward negative lightning, downward positive lightning and upward positive lightning. Through observation, it was found that 90% of cloud-to-ground lightning are downward negative flashes. The remaining 10% are downward positive flashes [3][4].

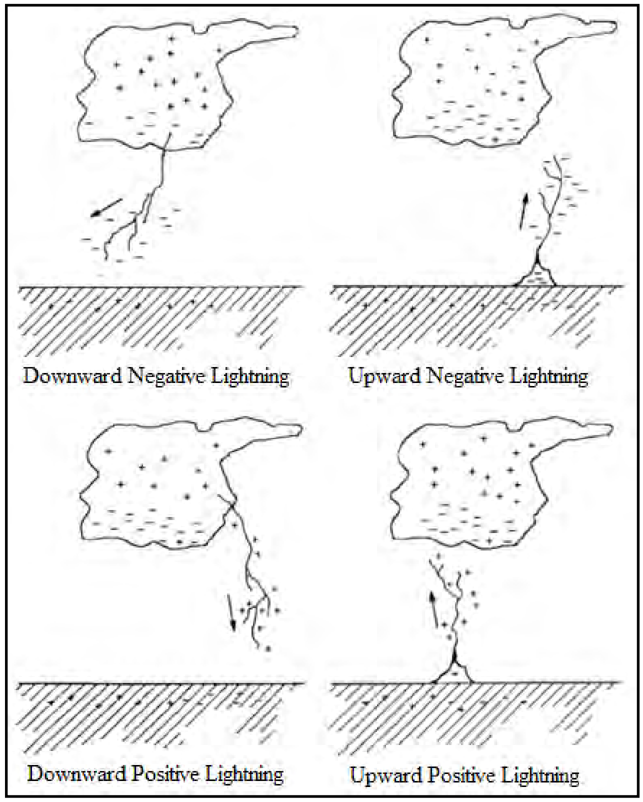

Figure 2-1 Types of Lightning Discharges between Cloud and Ground [4]

2.2 Mechanism of Lightning

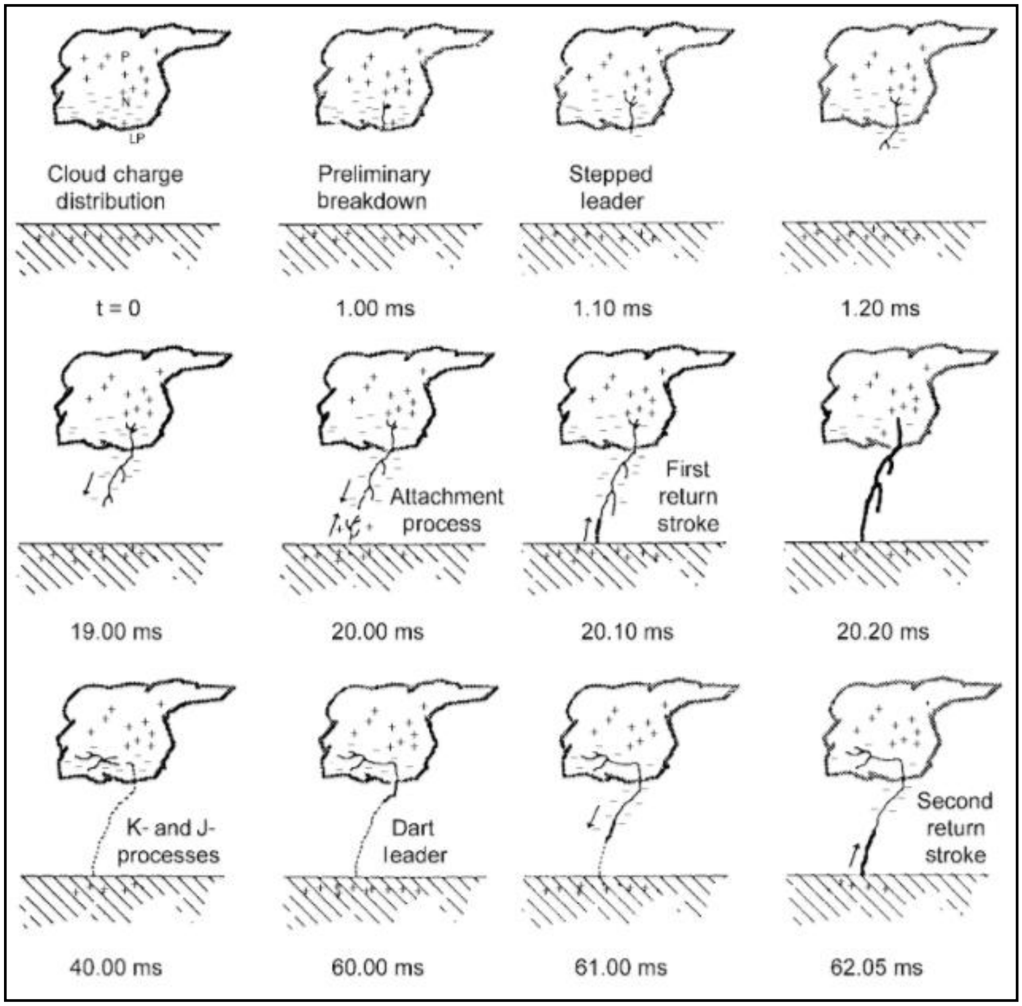

Figure 2-2 Discharge Process in a Negative Cloud-to-Ground Lightning Flash [4]

It has been known for a long time that lightning is an electrical discharge originates in charged storm clouds. Before going into the mechanism of lightning strikes, it is important to understand the polarization of positive and negative charges within a cloud.

All lightning begins with the presence of charged clouds. These clouds have positive charges accumulated at the upper portion and negative charges at the lower portion. Clouds contain suspended water droplets and ice particles that are constantly moving in a turbulent way. When water droplets or moisture evaporate from the surface of the earth and rise upwards, water particles in the clouds experience greater friction. The clouds become even more polarized. This can be explained by the mechanism of polarization of charges within a storm cloud that involves freezing.

When coming in contact with the low temperature at high altitude, the rising moisture freezes and forms a tightly packed central region of a cluster of moisture. The frozen central portion of the moisture acquires negative charges while the outer layer moisture acquires positive charges. Continuing to rise upwards, the moisture cluster collides with water droplets within the cloud. This causes the outer positive charge layer of moisture to be ripped off by the air current and brought upwards to reside with all the positive charges at the upper side of charged cloud. The remaining negatively charged frozen moisture is left to sink to the bottom. This way, the clouds become further polarised.

At one point, static charge within the cloud becomes so strong that the electric field developed is capable of ionizing the surrounding air, creating a pool of free moving electrons and positive ions. This conductive layer of ionised air makes the perfect environment for a transfer of charges between cloud and ground or between clouds.

For a cloud-to-ground flash, a bolt of lightning starts with the development of a route between the cloud and the earth. This route is known as the step leader. Through the step leader, electrons at the bottom of a cloud begin their way towards the ground where trees and buildings have positive charges. As the electrons get closer to the ground, positive charges covering the earth surface are attracted upwards and hence creating a streamer. The streamer continues to rice until it connects with the step leader. At this point, a complete roadway from the cloud to the earth is fully constructed. The lightning closely follows.

The transfer of charges at such high speed heats up the air surrounding the lightning pathway and causes the air to expand in an aggressive manner. This in turn creates a shockwave which is then heard as a deafening thunder. The same process can happen between different clouds or within the same cloud [4].

2.3 Antenna Fundamental Parameters

The performance of an antenna is determined based on various parameters. These include radiation pattern, radiation power density, beamwidth, directivity, efficiency, gain and bandwidth. The parameters are interrelated but not all of them are needed to determine an antenna‟s overall performance. As follows are several important parameters necessary to analyze

2.3.1 Gain

Gain of an antenna is defined as the ratio of intensity in a given direction to the radiation intensity that would be obtained if the power received by the antenna were radiated isotropically. The radiation intensity corresponding to the isotropically radiated power is equal to the power received by the antenna divided by 4π. This can be expressed in the following equation [5].

$$Gain = 4\pi \frac{radiation\ \ intensity}{total\ \ received\ \ power} = 4\pi \frac{U(\theta,\emptyset)}{P_{in}} \qquad (2.1)$$

Relative gain is used in most cases. It is defined as the ratio of the power gain in a given direction to the power gain of a reference antenna in its referenced direction. The reference antenna should be an antenna whose gain is known, such as a dipole or a horn antenna. In most cases, it is a lossless isotropic source.

To put it in a simpler way, as the gain increases, the direction of radiation becomes more focused. The radiation pattern is compressed, hence it extended outwards.

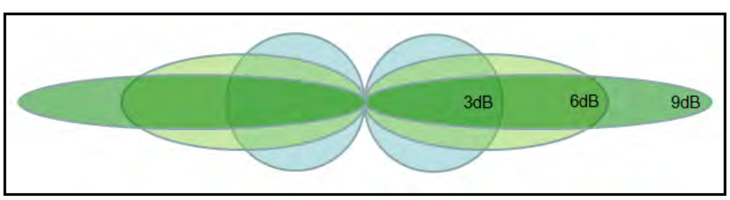

Figure 2-3 Relation between Gain and Radiation Pattern