VERY HIGH FREQUENCY (VHF) INTERFEROMETER

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To my family for supportimg me with love and their dedicated partnership .

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ABSTRACT

A lightning interferometer is an instrument which can determines the direction of arrival of radiation. Such intruments have been studied and used for several decades. Since lightning is abundantly identified with measurable data, absence of such data prevents the research progress. In this project, a Very High Frequency (VHF) Interferometer is developed which is capable of locating the VHF radiation sources of a lightning flash by correlating the signal that received at two or more antennas. In order to best utilize the additional data, cross correlation algorithm is used to process the signals. This algorithm can locate the entire duration of a lightning flash and then azimuth and elevation angle are also calculated to determine the direction of lightning stroke. This interferometer system also can act as a earlier warning system as it detect the first cloud flashes and a forecast can be made before cloud-to-ground flashes occur. Therefore, this interferometer system is useful for the public citizens in protecting themselves from lightning strikes.

ABSTRAK

Interferometer kilat merupakan instrumen yang boleh menentukan arah kedatangan sinaran. Alatan tersebut telah dikaji dan digunakan untuk beberapa dekad. Memandangkan kilat banyaknya dikenal pasti dengan data yang boleh diukur, ketiadaan data seperti ini menghalang kemajuan penyelidikan. Dalam projek ini, Kekerapan Sangat Tinggi (VHF) Interferometer dibangunkan yang mampu mencari yang sumber radiasi VHF daripada kilat dengan menghubungkaitkan isyarat yang diterima pada dua atau lebih antena. Dalam usaha terbaik menggunakan data tambahan, algoritma korelasi silang digunakan untuk memproses isyarat. Algoritma ini boleh mengesan keseluruhan tempoh kilat dan kemudian azimuth dan sudut ketinggian juga dikira untuk menentukan arah strok kilat. Sistem interferometer juga boleh bertindak sebagai sistem amaran awal kerana ia mengesan berkelip awan pertama dan ramalan boleh dibuat sebelum berkelip awan ke tanah berlaku. Oleh itu, sistem interferometer ini amat berguna untuk rakyat awam dalam melindungi diri mereka daripada kilat.

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LIST OF ABBREVIATIONS

VHF	Very High Frequency
ELF	Extremely Low Frequency
VLF	Very Low Frequency
LF	Low Frequency
UHF	Ultra High Frequency
SHF	Super High Frequency
CG	Cloud-to-Ground
CC	Cloud-to-Cloud
IC	Intra-cloud
BFB	Bolts from the blue
TOA	Time of arrival
MDF	Magnetic direction finding
DOA	Direction of arrival
2-D	Two dimensional
3-D	Three dimensional
DC	Direct current
SCOT	Smoothed coherence window

CHAPTER I

INTRODUCTION

This chapter described about the background of the project. In addition, the problem statement and objectives of this project will be briefly explained in this chapter. The scope and structure of report will also be included in this section.

1.1 Project Background

Lightning is a natural phenomenon that is of incredible worry to humankind and industry because it can cause harm to both human lives and properties. The lightning discharges produce electromagnetic radiation over a broadband frequency range, from extremely low frequency/very low frequency (ELF/VLF) up to very high frequency/ultra high frequency/super high frequency (VHF/UHF/SHF). Lightning discharges such as cloud-to-ground (CG) and cloud-to-cloud (CC) flashes which happen for one or two seconds are the natural phenomenon. The causes for VLF/LF and VHF/UHF waves are totally not the same. The VLF/LF electromagnetic waves are mainly emitted during lightning return strokes (RSs), while VHF/UHF are radiated during the progressions of breakdowns like stepped leaders. Since it is known that VHF radiation (30-300 MHz) is produced by smaller-scale breakdown activity itself, it can be used to map the locations of lightning flashes [1].

Previous work on the lightning locating system includes the studies using various detection techniques such as time of arrival (TOA) system to measure the arrival times of impulsive VHF events [2 - 4], magnetic direction finding (MDF) system to measure the electromagnetic fields radiated by a lightning flash [5], and interferometric techniques to determine the direction of arrival of radiation [6 - 8]. Thus, this project focuses on implementation of interferometry technique to locate VHF pulses emitted by lightning discharges. Interferometer systems receive the VHF pulses at a pairs of closely spaced antennas and acquire one- or two-dimensional directions of arrival of the lightning radiation sources. The signals that obtain from pairs of antennas are correlated to exactly measure the phase or time difference of arrival of the two VHF signals [9]. Estimations along two orthogonal baselines can be utilized to decide the spherical angles of sources and consequently their azimuth and elevation angles. With the data found, a VHF lightning mapping will produced by using interferometer technique which can determine the direction of the radiation.

1.2 Problem Statement

Recently, there have been a ton of enthusiasm on lightning related research. Many studies have been carried out for better understanding about the lightning phenomenon such as cloud-to-cloud, cloud-to-air and cloud-to-ground flash. Since lightning is abundantly identified with measurable data, absence of such data prevents the research progress. A better comprehension of the lightning breakdown process can be done by carried out the studies on lightning discharge processes in various meteorological conditions. Nevertheless, there are just a couple of estimations done in equatorial areas. The characterization of lightning discharges in equatorial areas is hence should have been studied in detail.

Besides, the lightning strike also gives a big influence in our daily life such as it will cause harm to human and animal lives, destroy the building and other electrical equipment. Thus, a system that can detect and locate the lightning strike is very useful. This is because the first located lightning events are cloud flashes. With the capability to detect these first cloud flashes, a forecast can be made and some prevention can be done before the more dangerous cloud-to-ground flashes occur. Therefore, a lightning detector which is able to detect the lightning strike distance will be the useful for the public citizens in protecting themselves from lightning strikes.

1.3 Objective of the Research

The purpose of this study is to design and develop the lightning location system. The following objectives of project had been determined as:

i. To design and develop the VHF antenna system based on interferometer technique.
ii. To process the analog signals of the captured VHF radiations.
iii. To produce VHF lightning mapping that shows the location of the VHF radiation sources in both azimuthal and elevational.

1.4 Scopes of Work

The design and develop of the VHF antenna system in this project is based on interferometer technique. Besides, MATLAB application is used to process the analog signals of the captured VHF radiations. VHF lightning mapping is produced by using interferometer technique which to determine the position of the radiation.

1.5 Report Structure

The thesis is organized and separated into five major chapters. In chapter 1, the overview of Very High Frequency (VHF) Interferometer is discussed in project background. In addition, the problem statement, objective and scope of project will be outlined clearly in this section. In chapter 2, the past studies related to VHF Interferometer are reviewed and criticized. The background theory of VHF Interferometer will be included in this chapter. In chapter 3, all relevant experiments and techniques used in the project will be discussed in detail. The flowchart for the VHF Interferometer design will be explained in this chapter. In chapter 4, the result of the project will be recorded and interpreted in this section. The obtained and collected data will be analyzed carefully to verify whether the objectives have been achieved. In the last chapter, a conclusion will be drawn from the project. Besides, the recommendation for the future plan which related to the project will be made in this section.

CHAPTER II

LITERATURE REVIEW

This chapter will discuss about the literature review or background studies on topics which are related. The discussions in this chapter are supported by knowledge that refers from books, journals, articles, and papers.

2.1 History of Lightning Interferometry

The very first interferometric study of lightning was reported in 1979 [6]. The operating frequency of this single baseline interferometer over a narrow band centered was 34 MHz. The interferometer manipulated by Warwick was unable to produce images or maps of lightning because of using only single baseline. Rather, as a lightning source cruised by, the fringes recorded by the instrument would move in a sorted out manner. The fringes seen by Warwick were rough when contrasted with maps being delivered by contemporary time of arrival systems in Florida. Figure 2.1 shows the fringes seen by Warwick that include the electric field of a lightning flash and the askew striations in the phase show a moving source [10].

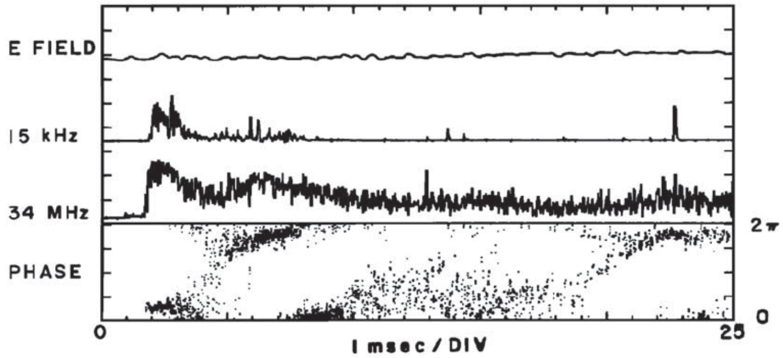

Figure 2.1: First published interferometric observation of lightning [10].

Craig Hayenga who is the student of Warwick, continued operating at 34 MHz but implemented perpendicular crossed baselines. This interferometer could be used to determine the azimuth and elevation angles of lightning sources at VHF frequencies [11]. Figure 2.2 shows the first published 2-D interferometric map of lightning. Azimuth and elevation are represented in degrees and the “R” is the position of the phase reference [10].

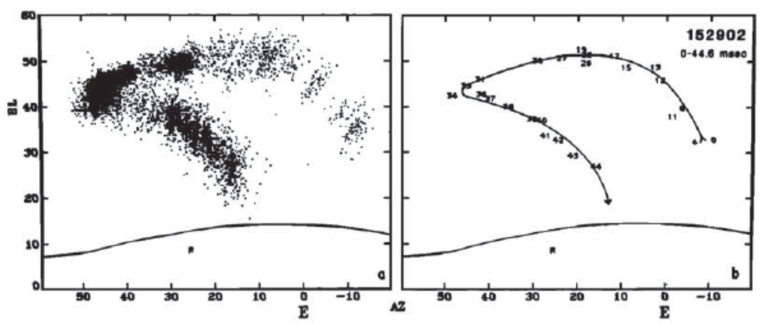

Figure 2.2: First published 2-D interferometric map of lightning [10].

Rhodes et al. [12] and Shao et al. [13] have built up this technique promote and have utilized single-station interferometers to enhance our comprehension of the development of both intra-cloud (IC) and cloud-to-ground (CG) lightning. It is conceivable to get 3D locations utilizing interferometry by determining an elevation angle utilizing particular antenna arrangements [14, 15].

The source location is then gotten by figuring the triangulation of the azimuth as well as elevation from no less than 2 sensors [16]. For such systems, the normal separation between sensors is in the scope of 50-150 km, and they are made out of no less than 3 sensors. Suppose that the source does not move notably in azimuth for a given duration, these systems can exploit the various periods of the signal to decide a standard time difference over the entire integration period (as phase difference). Richard et al. built up a business variant of this system working in 2 dimensions that can locate both IC and CG flashes [17, 18]. Their sensor incorporates over a 100 µSec period, bringing about azimuth errors in the scope of 0.3 – 1.0 degrees.

Most of the interferometric systems are work over very narrow frequency bands which is from few hundred kHz to few MHz in VHF/UHF bands, since this enables the system to have high sensitivity in particular band of operation. Even so, it also makes the system performance influenced by local broadband, and places a particular constraint in the spacing of the antenna array components to prevent arrival-time (phase) ambiguity [15]. However, work by Shao et al. [19] and later free work in Japan [20, 21] exhibit a pattern towards utilizing broadband interferometry. This pattern is made conceivable by the arrival of affordable broadband RF and digital signal processing electronics.

2.2 Terminology and Definitions

2.2.1 Tri-Polar Charge Structure

The cloud should first physically isolate charge to create lightning when forming thundercloud. This process is compelled by the updrafts of the storm as various kinds of water particles such as water, ice and graupel collide and rebound off each other. This process repeatedly and produces a tri-polar charge structure in the cloud as shown in Figure 2.3. At the base of the cloud, there is the smaller lower positive charge layer, in the center is the main negative charge layer, and at the top is upper positive charge layer. The electrons are drawn down from the air over the cloud because of the net positive charge on top of the cloud to produce a screening layer. This will causes the DC electric field to rapidly drop to 0 over the cloud [10].

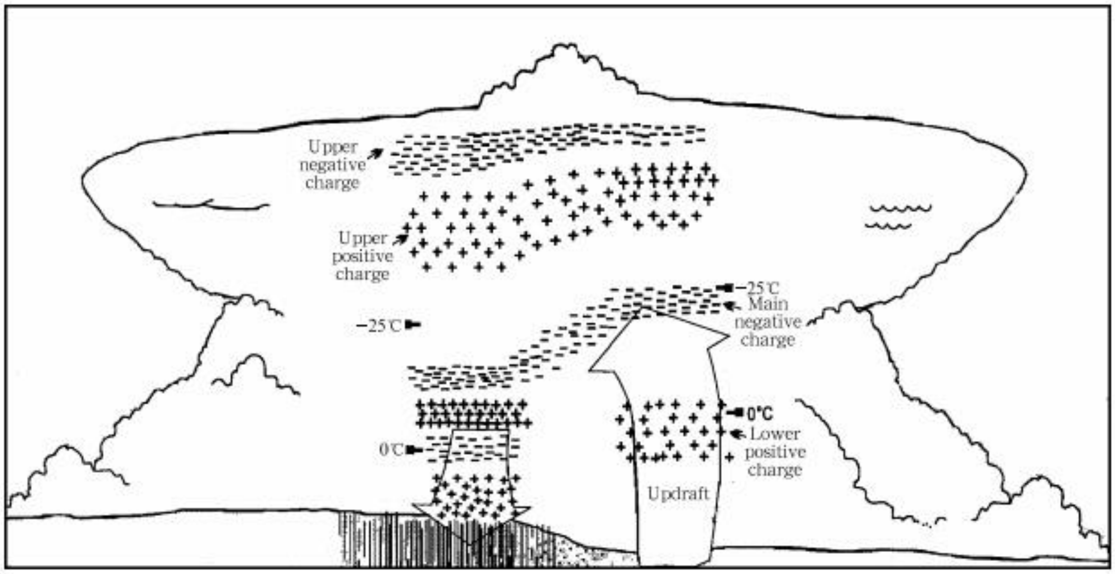

Figure 2.3: Tri-polar charge of the cloud [22].

2.2.2 Streamers and Leaders

A streamer is a cold plasma which happens every time when an electric field surpasses the breakdown field of air. Streamers can divided into two categories which is negative streamers and positive streamers. Negative streamers is those when electrons are stream out of while positive streamers are those when electrons are stream into.

A leader is a hot, conducting filamentary plasma which is produced when numerous streamers join together on small region of air. Normally, a leader happens when the temperature of air is high enough (around 1500K) that make the electrons stripped from air molecules through thermal processes. Leaders also can divided into two categories which is those carrying negative charge (colored blue in Figure 2.5), and those carrying positive charge (colored red in Figure 2.5) [10, 23].

2.2.3 Intra-cloud, Cloud-to-ground, and Bolt from the Blue Flashes

There are three general types of lightning flashes which are intra-cloud (IC), cloud-to-ground (CG) and bolts from the blue (BFB) as shown in Figure 2.5 [10].

Figure 2.4: Three general types of lightning flashes [10].

IC flashes are the flashes that occurred inside the thundercloud. This kind of flashes are involved in most of the lightning in the world. Figure 5 shows the flash which starts between the main negative and upper positive charge layers is the most common type of IC flash.

CG flashes are the flashes that touch the ground and can classified into two main types: –CG flashes which transfer negative charge to ground, and +CG flashes which transfer positive charge to ground. Figure 5 shows the most well-known type of –CG flash which starts between the lower positive and main negative charge layers.

BFB flashes are CG flashes which typically occur at the back side of the thundercloud. These flashes can travels over a long distance, more than 20 km, in clear air away from thundercloud and then strikes to the ground.

2.2.4 Azimuth, Elevation, and Altitude

The azimuth angle is the angle clockwise from North while the spherical azimuthal angle is the angle counter clockwise from East. The elevation angle is the angle increasing from the horizon while the spherical polar angle is the angle increasing from the zenith. The vertical distance over the sea level is referred as altitude [10].

2.2.5 Phase Fitting and Cross Correlation

There are two main computational techniques that related to lightning interferometers. The first one is phase fitting which fits a linear pattern to the phase difference versus frequency. The other one is cross correlation which is mathematically well defined. Eventually, both computational techniques are used to calculate the time delay between antennas in the interferometer array. However, there are slight difference in calculations which can make the final solutions is not precisely same [10].

2.3 Cross Correlation Technique

The cross correlation technique is used to determine the direction of the VHF source and this technique covers the 'classic' approach to take two crossed baselines which is forming of three antennas. A few past studies that related to the ideas of cross correlation technique are carried out to produce maps of lightning [24 - 26].

2.3.1 Basic Algorithm

From Figure 2.6, for a remote VHF signal reaching at two antennas which spaced by a distance d, the time difference of arrival T_d and the phase difference $\Delta\Phi$ are identified with each other and to the angle of incident radiation α as indicated by

$$d\cos\alpha = cT_d = \left(\frac{\Delta\Phi}{2\pi}\right)\lambda \tag{2.1}$$

where λ is the wavelength of the radiation and c is the speed of light in air. The direction cosine,$\cos\alpha$ of the source from can be determined by identified the time difference of arrival T_d or the phase difference $\Delta\Phi$ [9].

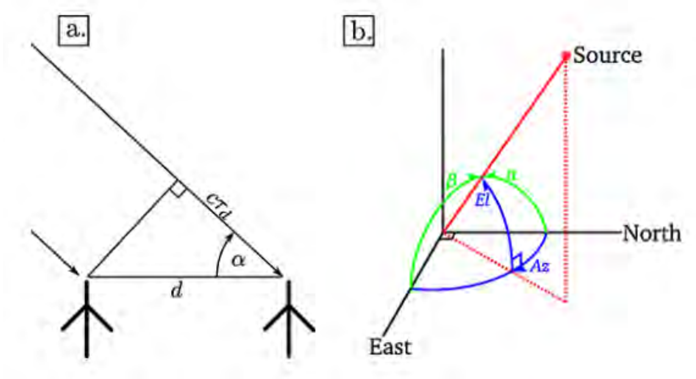

Figure 2.5: Basic geometry of interferometer measurements [9].

For sources that arrived at two baselines interferometer, two angles are needed to indicate the direction and required extra calculation for their determinations as shown in Figure 2.7.