DISERTASI

A NEW IMPLEMENTATION OF INTERFEROMETRY LIGHTNING LOCATION SYSTEM AND INDIRECT LIGHTNING CURRENT MEASUREMENT IN INDONESIA

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DISERTASI

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DISSERTATION

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DOCTORAL PROGRAM IN ENGINEERING SCIENCES
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DISSERTATION APPROVAL PAGE

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Dengan ini menyatakan bahwa disertasi saya dengan judul "A New Implementation Of Interferometry Lightning Location System And Indirect Lightning Current Measurement In Indonesia", bebas dari fabrikasi, falsifikasi, plagiat, kepengarangan yang tidak sah dan konflik kepentingan dan pengajuan jamak, seperti yang tercantum dalam Peraturan Menteri Pendidikan, Kebudayaan, Riset, dan Teknologi Republik Indonesia Nomor 39 Tahun 2021.

Bilamana ditemukan ketidak sesuaian dengan hal-hal di atas, maka saya bersedia menerima sanksi akademik dari Universitas Sriwijaya sesuai dengan aturan yang berlaku.

Demikian pernyataan ini dibuat dengan sesungguhnya dan dengan sebenar-benarnya.

Palembang, 10 Juni 2025

Yang menyatakan

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PREFACE

First and foremost, I would like to express my deepest gratitude to Allah The Almighty, whose grace and guidance have enabled me to complete this dissertation. This work, entitled “A NEW IMPLEMENTATION OF INTERFEROMETRY LIGHTNING LOCATION SYSTEM AND INDIRECT LIGHTNING CURRENT MEASUREMENT IN INDONESIA”, has been written as a requirement to obtain the degree of Doctor in Engineering Science at the Doctoral Program in Engineering Science.

This dissertation was motivated by a desire to contribute to the understanding of lightning characteristics and the development of a locally adaptable lightning location system using the interferometry method. The research aims to design a system capable of capturing electromagnetic field data, estimating lightning peak currents, identifying strike locations, and analyzing lightning discharge behavior on a microsecond scale, specifically within the geographical context of Palembang, Indonesia.

This research has resulted in several important academic contributions. Three scientific publications have been produced: two papers presented in international seminar proceedings, and one published in a reputable international journal. Additional outputs include a presentation at a four-nation symposium involving Indonesia, Malaysia, Thailand, and India, as well as a research talk attended by researchers and students from Indonesia, Malaysia, and Japan, all of whom share a strong interest in lightning research.

I hope this dissertation will serve as a meaningful contribution to the field of atmospheric and electrical engineering, and provide a foundation for future innovations in lightning observation and safety systems.

Palembang, May 2025

The Author

This dissertation is dedicated to :

My lovely husband, Arvin

whose unwavering love, quiet strength,

and constant support have been the foundation of my every step.

You stood beside me through sleepless nights and silent battles,

believing in me even when I faltered.

And to my beloved children,

Hafidz, Faiz and Fakhir

whose laughter lit the darkest days

and whose innocence reminded me why this journey matters.

May this work one day inspire you to chase your dreams with courage and heart.

With all my heart, this work is for all of you.

"And among His Signs—

*He shows you **lightning**,*

(In it there is) hope and fear,

And He brings down rain from the heavens,

Then He bestows life to earth after it is dead—

Indeed, in that are Signs for a people who reason."

(Nobel Qur'an 30:24)

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My sincere gratitude also goes to the Rector of Universitas Muhammadiyah Palembang, Prof. Dr. Abid Jazuli, S.E., M.M., for the material support that enabled me to visit and learn directly at the "headquarters" of the THOR research group in Melaka.

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I would also like to express my sincere appreciation to the Ministry of Higher Education, Research, and Technology of the Republic of Indonesia for the financial support provided at the beginning of my doctoral studies. This support laid the essential foundation for the academic journey I have undertaken, and I am truly grateful for the opportunity it afforded me to pursue this research.

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My sincere thanks and appreciation go to all fellow lecturers and staff of the Electrical Engineering Study Program at Universitas Muhammadiyah Palembang for their support, collaboration, and the spirit of togetherness that have continuously strengthened me throughout the course of this doctoral journey. Their presence and attention have been an essential part of sustaining my motivation and commitment, enabling me to complete this dissertation successfully.

Special thanks to my husband Ir. Arvin., M.T for his love and for being my great supporting system and my root, and to my children Hafidz, Faiz and Fakhir for being always there, to my mother dr. A.M. Molly for your love and education and my sister Ar. Widya Fransiska Febriati Anwar, Ph.D for your support.

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Dissertation presented at Sriwijaya University for closed examination at the Faculty of Engineering, Sriwijaya University, on Tuesday, 10 June 2025 at 09:00 AM (WIB), for the degree of Doctor. Examination Committee : Ir. Irsyadi Yani, S.T., M.Eng.,Ph.D., IPM (Chairman), Prof. Ir. Zainuddin Nawawi, M.M., Ph.D, Dr.Ir. Bhakti Yudho Suprapto., S.T., M.T., IPM and Dr. Eng. Diah Permata, S.T.,M. T.

Wiwin Armoldo Oktaviani Anwar, supervised by Ir. Muh. Abu Bakar Sidik, S.T.,M. Eng.,Ph.D.,IPU., APEC Eng., Associate Prof. Dr.M. Ridhuan Ahmad and Ir. M. Irfan Jambak, S.T., M.Eng., Ph.D.

Abstract

Lightning remains a significant natural hazard, particularly in equatorial regions like Indonesia, where high flash densities pose risks to infrastructure and public safety. However, comprehensive local data on lightning characteristics—especially peak current and strike location—are still limited. This study addresses that gap by developing a lightning detection and observation system based on the interferometry method, using a parallel plate antenna, and applying it in Palembang, South Sumatra.

The system, installed at Sriwijaya University (Unsri Station), was designed to capture fast electric field variations induced by lightning discharges. It was validated through simulations and field measurements, confirming its responsiveness up to 1 MHz. Peak lightning currents were estimated indirectly using the Transmission Line Model (TLM), with velocity values adopted from previous literature. Results from February 2023 indicate that maritime lightning exhibited higher peak currents (up to 162 kA) compared to land-based lightning. The peak current data also followed a log-normal distribution, aligning with previous studies.

For lightning location, an interferometric method was implemented using phase differences from three VHF antennas. This enabled two-dimensional mapping of lightning strikes and the identification of initial discharge directions. The system also visualized the spatiotemporal development of lightning flashes on a microsecond scale.

The findings highlight the effectiveness of interferometry for lightning location, especially in single-station configurations. Compared to other techniques like MDF and ToA, interferometry offers simplicity, robustness, and fewer hardware requirements. This research provides the first implementation of such a system in Indonesia, contributing valuable insight into lightning behavior in the equatorial zone.

This work lays a foundation for further research in three-dimensional interferometry, calibrated current sensing, and advanced signal processing—offering practical applications for lightning protection, climate analysis, and public safety in lightning-prone regions.

Keywords : Lightning detection, Interferometry, Parallel plate antenna, Electromagnetic field, Peak current estimation, Lightning location system

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CHAPTER 1
INTRODUCTION

1.1 Research Background

Lightning is a natural phenomenon characterised by the rapid discharge of electrical energy, producing electromagnetic emissions that span a broad frequency range from very low frequency (VLF) to very high frequency (VHF) [1]. This phenomenon has been widely studied, with foundational research highlighting the significant role of charge movement and electromagnetic field generation in lightning dynamics [2]. This phenomenon involves the movement of charge, leading to the formation of electromagnetic fields. Lightning discharges occur in various forms, such as cloud-to-ground (CG), intracloud (IC), cloud-to-cloud (CC), and cloud-to-air (CA), with cloud to ground (CG) lightning being of particular interest due to its significant impact on ground-based systems and structures.

The initial stage of lightning formation begins with an avalanche of free electrons on a millimetre scale. This avalanche is triggered when the ambient electric field accelerates free electrons, causing them to collide with nearby gas molecules and release additional electrons. As a result, the number of electrons increases exponentially. This chain reaction continues and eventually generates a current of electrons moving in the opposite direction to the electric field's direction. When the electric field strength reaches approximately 3 MV/m, electrical breakdown occurs in the atmosphere [3], [4]. As the energy of the free electrons accumulates to about 108 - 109 eV, these electron avalanches evolve into streamers, which extend over centimetre-scale distances [4]. Repeated streamer formation and propagation can then lead to the development of a stepped leader. This leader may ultimately trigger a return stroke —one of several types of lightning discharges—as illustrated in Figure 1.1, depending on the conditions of the surrounding charge distribution.

In connection with this physical development of lightning, each type of discharge exhibits distinct electromagnetic emission characteristics at specific frequency ranges.

For instance, cloud-to-ground (CG) lightning typically produces strong emissions near the ground in the low-frequency (LF) radio band, as reported by [5] and [6]. In contrast, intra-cloud (IC) lightning emits Very High Frequency (VHF) radio signals originating from within the cloud. In addition to LF and VHF signals, theoretical and observational studies have indicated that electron avalanches and subsequent lightning processes can also radiate in the microwave spectrum. Theoretical analysis suggests that electron avalanches emit significant radiation in the microwave band around 1.0 GHz [7]. Furthermore, Petersen and Beasley [8] reported that microwave radiation from lightning discharges can occur at frequencies as high as 1.63 GHz. Further supporting the presence of microwave radiation in lightning events, several studies have found that microwave emissions are present in nearly all phases of lightning activity [8]-[9].

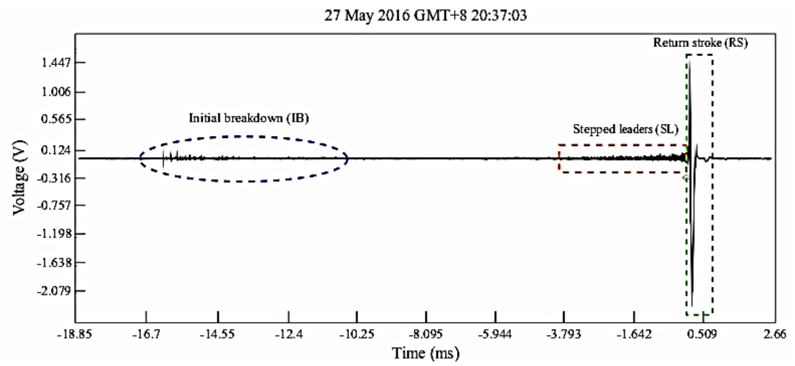

Figure 1. 1. Examples of electric field waves (E-fields) generated by CG flash that begin with IB (circle of blue dots), followed by SL (red dots) and RS (green dots) [10].

Observations of lightning characteristics conducted in Padang, West Sumatra, in 2013 revealed that the electric field changes associated with the first negative return stroke, following the preliminary breakdown process, exhibited statistical similarities to those observed in Johor, Malaysia. [11]. The Arithmetic Mean value and Geometric Mean for the pre-returns stroke of 57 ms and 32 ms, respectively. While the characteristics for 0%–100% and 10%–90% rise time of positive cloud to ground flash lightning have Arithmetic Mean (AM) and Geometric Mean (GM) values of 12.7 s, 11.9 s, 6.1 s, and 5.8 s, respectively. This study also revealed that the percentages of single, double, and triple strikes of lightning flashes in Padang were 83%, 16%, and 1%, respectively [12]. Both electric field measurement systems utilised a parallel plate antenna and an electric field mill. The statistical study provides information about how many multiple ground terminations occurred from a stroke.

Lightning strikes cause direct damage to the object being struck and other objects that experience electromagnetic wave induction due to the extensive amount of electromagnetic radiation produced by lightning. In some countries, lightning is even the cause of death. Lightning strikes murder about 2,000 Indians each year [13], while in Malawi, there were 84 deaths per million per annum from lightning strikes [14]. Florida recorded more than 2,000 injuries from lightning strikes over the past 50 years [15]. Therefore, investigating lightning characteristics, including the peak current, and detecting lightning location are essential for understanding its physical processes and mitigating adverse effects. The lightning location and lightning peak current are critical parameters influencing the design of lightning protection systems and evaluating the risks associated with lightning strikes. Accurate determination of lightning location and its peak current contribute to better protection schemes for infrastructure and helps to predict and minimize damage caused by lightning. In other words, to prevent or reduce the impact of damage due to lightning strikes, a method is needed to detect the lightning location and from which direction the potential for lightning will strike, as well as to determine the lightning peak current.

There are three types of techniques commonly used in lightning location systems (LLS), namely Magnetic Direction Finder (MDF), Time of Arrival (ToA), and Interferometry. These techniques differ in the sensor frequency range, the number of antennas, and the type of baselines used [16],[17]. The number and configuration of antennas are selected to minimise errors in identifying strike points [16] and influence whether the resulting strike mapping is in two or three dimensions [17].

In addition to the techniques mentioned above, lightning location systems also rely on measurements of the vertical component of the electric field, typically obtained using sensors such as parallel plate antennas. These electromagnetic sensors facilitate the investigation of lightning characteristics and their relationship to the location of occurrence. Yoshida et al [18] introduced a lightning detection system called BOLT, which uses low-frequency (LF) sensors to observe electrical activity such as preliminary breakdown, negative leaders, and return strokes. Through these observations, BOLT was able to determine the locations of both intra-cloud (IC) and cloud-to-ground (CG) discharges. However, according to Sonnadara et al [19], such systems may sometimes misinterpret subsequent strokes as first strokes, leading to erroneous classification of lightning events. To address this limitation, and to provide a more comprehensive analysis, especially for single-station detection systems, mathematical approaches and geometric formulations can also be utilised to enhance strike location determination [20].

Most lightning detection systems operate using a single broadband frequency; however, using dual-frequency systems remains a viable possibility. Liu et al [21] implemented a system that simultaneously utilised both Very High Frequency (VHF) and Very Low/Low Frequency (VLF/LF) sensors, known as the Dual-band Lightning Location System (DULLS). Their findings indicated that VHF sensors were more effective in detecting intra-cloud discharges, while VLF/LF sensors were more responsive to return strokes [21].

At certain limits, a single station can better describe slow magnetic field changes and preliminary breakdown pulse (PBP) than multi-station [16], allowing for better observation in distinguishing various flashing activities in the Intra Cloud and on the ground.

Mulyadi and Hazmi [22] use a Magnetic Direction Finder (MDF) by applying two orthogonal magnetic loop antennas as electromagnetic sensor devices. These antennas are placed on three stations to obtain triangulation of lightning locations. The triangulation is then optimised to produce lightning location points. In Japan, Wu et al [23] used an antenna with a constant decay time of 200 microseconds, operating in a frequency range of 500 Hz to 500 kHz, which was deployed at nine locations to observe lightning strikes during the winter. A distinctive characteristic of this lightning is that bipolar events only appear on land, although most lightning occurs in the ocean region during the winter season.

Sonnadara used a flat plate antenna with a capacitance value to the ground of 58 pF and an effective height of 1.88 m to determine the parameters of the negative strike of the cloud to the ground through measurement of the vertical magnetic field [19]. These parameters were then compared to the parameters obtained from direct measurements. The comparison results show that the lightning location system achieves a high percentage accuracy rate of 93% in detecting the first stroke of negative cloud-to-ground lightning discharges. However, its accuracy decreases to 77% when detecting all strokes, including both the initial and subsequent strokes within a single lightning event.

In estimating the location of lightning strikes, errors are caused by several things, including the difference in arrival time from two signals from several sensors. The error could be overcome by incorporating each sensor's difference in azimuth and altitude into the calculation [23] and assimilation between various lightning-related data. The data assimilation technique provides better accuracy in predicting lightning location [24].

The interferometry technique is believed to be the most promising method of determining the location of the strike because this technique does not require many antennas and sensors and is not sensitive to the noise that usually arises along with the signal to be recorded [17]. The basic concept is to calculate the difference in phase from the emission of electromagnetic waves captured by a pair of antennas to obtain the azimuth and elevation angle from the electromagnetic source. Antenna configuration in Interferometry techniques requires a baseline formed by two antennas separated by a distance (d). The baseline magnitude will determine the accuracy in determining the location of the strike. Some of the baseline sizes used in previous studies were 5.0 m [21],[25], 6.0 m [26], 9.0 m [27], and above 10.0 m [28] - [29].

The main advantage of Interferometry is its ability to scan for more lightning events than other methods of determining the strike's location, such as Magnetic Direction Finder (MDF) and Time of Arrival (ToA). In addition, the recording of strike event data can be conducted continuously so that the quality of visualisation of strike mapping in two dimensions becomes better [30]. Interferometry does not require many antennas to improve its accuracy, unlike ToA, which requires many sensors/antennas to get accurate results. Therefore, Interferometry has become a promising method of determining lightning location [17].

Based on the frequency used, the Interferometry method is divided into Narrowband Interferometry and Broadband Interferometry. Narrowband Interferometry has good sensitivity in operating frequency conditions with few distortions (quiet band operation), but easily interferes with the surrounding broadband frequency [31]. The second type of Interferometry has a higher resolution for recording electromagnetic data emission from lightning. Researchers more widely use broadband Interferometry to observe behaviour and determine the location of lightning strikes. Determining strike locations with Broadband Interferometry is classified based on the preprocessing signal in three categories: Linear Fit Method, Wavelet Transform Method, and Cross-correlation Method [17].

The primary techniques for measuring lightning current can be categorised into direct and indirect measurements. The fundamental differences between those measurement methods lie in their approach to capturing lightning current data. Direct measurement involves capturing the actual lightning current as it flows through a conductor or grounded object. It requires a physical connection to the lightning strike point. Previous studies about lightning currents in Indonesia used indirect methods, and most of the research was done on Java Island, especially West Java [32], [33], [34], [35]. At the same time, the indirect method estimates lightning current by analysing the electromagnetic fields generated by the lightning discharge. This method does not require physical contact with the lightning channel [32], [36], [37].

As stated previously, electromagnetic emission is one parameter used to determine the lightning location and the lightning peak current in the indirect method. The vertical components of the electric field are measured using **parallel plate antennas**. These electromagnetic sensors can help detect lightning location and calculate the lightning peak current. In addition to applying electromagnetic sensors, mathematical approaches, and geometric formulations can also be used to detect the strike's location, especially in providing a thorough overview of the detection system at single detection stations [20].

The measurement of lightning current plays a crucial role in lightning research, infrastructure protection, and safety planning. Using indirect electromagnetic methods, such as antennas and detection networks, allows for safer and broader monitoring of lightning activities. It is also more practical than direct measurement for widespread monitoring and real-time analysis of lightning activity. In summary, indirect measurement methods for lightning current provide significant advantages regarding safety, coverage, versatility, sensitivity, and cost-effectiveness, making them essential tools in lightning research and management.

Parallel plate antennas have been widely used to capture the electromagnetic fields generated by lightning discharges. By analysing the electric field waveforms received by these antennas, various lightning parameters [38], [39]. Previous studies have focused extensively on lightning location and electromagnetic field characteristics [18], [19], [22], [23]; however, there is a growing need to shift the focus toward understanding the peak current, which is vital for improving safety standards and infrastructure resilience in lightning-prone regions [33], [40], [41], [42].

1.2 Problem Statement

Accurate detection of lightning strike locations and peak current, particularly for cloud-to-ground (CG) lightning, requires a comprehensive understanding of a country's lightning characteristics, as inferred from the electromagnetic fields they produce.

Knowledge of the lightning characteristics in an area and the detection of the strike location become useful in determining the specifications of appropriate lightning protection equipment for better planning of lightning protection systems. The proper lightning equipment can minimise the impact of the damage [43]. In designing lightning protection schemes, Rakov suggested considering moderately severe strikes with a significant probability of occurrence as the representative worst-case scenario, thereby ensuring that the object is protected from the vast majority of lightning strikes. In his calculations, Rakov considered lightning strikes with peak currents of up to 60 kA, accounting for approximately 85% of the lightning strike population as observed in measurements [44]. In technical calculations, lightning parameters are needed to design a good lightning protection system. They are also crucial for detailed investigations of incidents involving human casualties, such as those reported in oil palm plantations in Lukut, Negeri Sembilan, Malaysia [45].

In support of such analyses, researchers have conducted numerous studies to measure lightning parameters using specialised sensing methods. For instance, research by [46] demonstrated that a parallel-plate antenna could effectively capture the vertical component of the electric field, which was essential for lightning location and peak current estimation [47], [48]. Various studies have employed interferometry techniques based on parallel- or flat-plate antennas to investigate lightning characteristics. However, most of these investigations were conducted in regions located north of the Equator, such as in Sweden [19], Japan [23], [49], and China [24], [21]. Comparative studies have also been carried out between northern regions, for example, between Sri Lanka and Sweden [50] and Johor, Malaysia, with Florida in America [51]. In contrast, research on lightning characteristics in the Southern Equatorial region has been conducted in Australia using the Lightning Detection Network (LINET), which is based on the time-of-arrival method [52], [53]. Collectively, these studies highlight that lightning characteristics, including peak current, can vary significantly across different geographical regions.

1.3 State of the Art / Original Contribution

Previous studies in regions like Sweden, Japan, and China have provided valuable insights into lightning characteristics. Still, their findings may not directly apply to equatorial regions due to differences in lightning behaviour. Equatorial regions experience higher lightning flash densities and more frequent negative cloud-to-ground strikes than temperate zones [54]. Based on the literature study, Interferometry offers distinct advantages over other Lightning Location Systems (LLS), but **there is a notable gap in research using Interferometry in Indonesia.** Furthermore, **studies regarding lightning peak current in Indonesia, which is in the Equator region (0^0 - 10^0 N or 0^0 - 10^0 S), based on electric field measurement remain limited.** Therefore, this research aims to fill those gaps by investigating the peak current characteristics and the location of lightning in Palembang, which is geographically located at $2^0$52'-$3^0$5' South Latitude, as depicted in Figure 1.2.

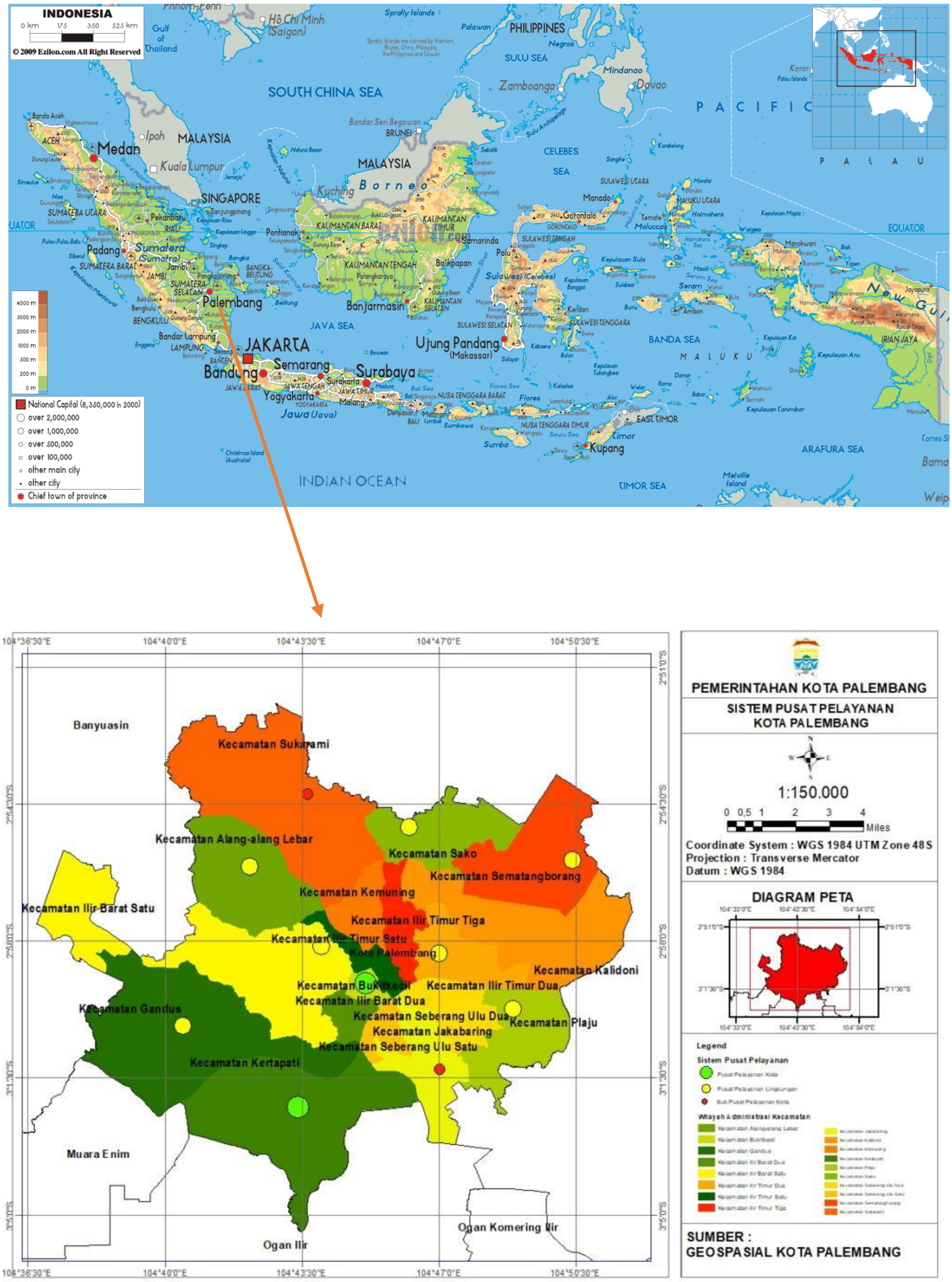

Figure 1. 2. The Indonesian Map and Geographical Map of Palembang City [55]

1.4 Research Objective

From the formulation of the problems that have been described before, the objective of this research are:

1. To design and develop a lightning location system based on Interferometry method using a parallel plate antenna to capture electric fields and collect lightning characteristic data in Palembang.
2. To determine the lightning peak current and location in Palembang based on the electric field captured.
3. To analyse the characteristics of lightning peak current in Palembang and compare it to a previous study in the same area.
4. To determine lightning location and observe the temporal structure of lightning discharges and their propagation on a microsecond scale.

1.5 Scope of Work

This research focuses on the development and application of a lightning location system using the interferometry method, as well as the estimation of lightning peak current based on measured electric field data. The main tasks carried out in this study include:

1. Developing Lightning Location System (LLS) based on the Interferometry Method in Sriwijaya University, Palembang.

2. Applying a parallel plate antenna as a sensor to determine the lightning peak current in Palembang

3. Simulating a MATLAB program using data collected by Sriwijaya University's LLS to determine location and peak current

4. The lightning current is calculated using the lightning velocity obtained from a study conducted by Willet et al. (1.2×10^8 to 1.9×10^8 m/s).
5. The obtained data from the fast field antenna will be calibrated in future work due to the shortage of environmental circumstances. The calibration works require

enough open area and close lightning events to the installed antenna.

1.6 Research Benefit

The outcomes of this research are expected to:

1. Provide a deeper understanding of lightning peak current characteristics in equatorial regions, especially in Palembang area, addressing a significant gap in the literature.
2. Contribute to developing more effective lightning protection systems by offering better accuracy of peak current data and lightning location.
3. Support safety and infrastructure resilience efforts in regions prone to frequent and intense lightning activity.
4. Advance the scientific knowledge of lightning phenomena, particularly concerning electromagnetic field emissions and their relationship with peak current and lightning location.

By focusing on the accurate measurement and analysis of lightning behaviour (peak currents, location and development), this research will provide valuable insights and practical solutions for managing lightning risks in equatorial regions, particularly by improving the accuracy of protection system designs and advancing the understanding of lightning dynamics.

1.7 Hypothesis

It is presumed in this study that the measurements of peak current obtained with a parallel plate antenna in Palembang will be considerably different from those for other equatorial areas, with indications of local weather and geographical differences. Further, it is assumed that there must be a good agreement between the vertical electric field strength measured by the parallel plate antenna and the corresponding lightning peak current. Furthermore, applying the parallel plate antenna with an interferometric technique will likely increase the precision of lightning location determination and peak current estimation. Together, these suggestions are designed to give complete knowledge about lightning parameters in Palembang, while simultaneously elevating the reliability and accuracy of lightning detection techniques.

1.8 Dissertation Structure

The structure of this dissertation is as follows:

Chapter I. Introduction

This chapter discusses the research background, problem statement, objectives, scope of work, and research hypothesis.

Chapter II. General Research Frameworks

This chapter explains the processes and stages of this dissertation research, which is detailed in this section, including the research framework, research dataset, and development of antenna and electromagnetic field sensors. The preliminary results of the system proposed are presented in this chapter.

Chapter III. Lightning Peak Current Measurement

This chapter comprehensively details the methodologies, instrumentation, and analysis techniques for measuring and estimating lightning peak currents. It begins by outlining direct and indirect lightning current measurement methods. Each method's advantages and limitations are discussed, providing insight into their applications in both urban and natural environments. The chapter also introduces a specially designed measurement system employing fast and slow-field E-field antennas integrated with buffer circuits and a digital oscilloscope. Subsequently, a procedure for estimating lightning peak current using the transmission line model was established, relying on waveform data, antenna calibration, and the spatial distance between the lightning event and the observation station.

Chapter IV. Lightning Peak Current Measurement

This chapter comprehensively explains the methodology and instruments used to determine the location of lightning strikes. It begins by outlining the lightning location determination methods, particularly emphasising the Interferometry Method. Signal denoising techniques are also presented in this chapter. The configuration of the equipment used and the data processing techniques implemented in MATLAB are illustrated in the form of flowcharts. The discussion and conclusions drawn from the results are presented in the last section of this chapter.

Chapter V. Conclusion and Future Work

This chapter concludes with the research results presented in CHAPTER II, CHAPTER III, and CHAPTER IV and suggestions related to FUTURE WORK.

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