Development of Lightning Detection for a Low-Cost System in Malacca

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.91100217

Received: 24 November 2025; Accepted: 30 November 2025; Published: 05 December 2025

ABSTRACT

This paper presents the development of a low-cost lightning detection system, addressing the limitation of existing systems that are typically expensive. The aim was to design a low-cost lightning detection system to accurately capture lightning flashes within the frequency range of 1Hz to 10MHz. The lightning detection system was fully assembled using a Fast Field buffer circuit integrated with a parallel-plate antenna to ensure accurate detection of lightning flashes. The system successfully detected a total of 60 negative cloud-to-ground (-CG) flashes and 51 intra-cloud (IC) flashes on 11 July 2023 between 01:32:00 and 08:3:00. Analysis of the –CG flashes indicates that the majority of 54 flashes consisted of single return strokes, while only 6 flashes exhibited subsequent return strokes which 4 flashes with two subsequent return strokes and 2 with three subsequent return strokes, respectively. The developed system achieved an 83% consistency in identifying lightning flashes when comparing with an existing lightning detection system, demonstrating its potential as a low-cost yet reliable alternative.

Keywords: Lightning Flashes, Fast Field, Electric field, return stroke

INTRODUCTION

Lightning is a phenomenon that produces extraordinary power (Mansoor et al., 2021). Lightning also has the potential to destroy and pose a major threat to public safety. With its ability to cause severe damage to electrical power devices (Kadir et al., 2023), injury to people (Christophides, 2017) and lead to casualties, and even destroy homes. Lightning can be defined as the occurrence of a high voltage between the Earth and the clouds, resulting in the acceleration of stray electrons in the air. These accelerated electrons acquire sufficient kinetic energy to dislodge electrons from atoms in the surrounding air, causing a transient and high-current electric discharge. The path length of lightning discharges is typically measured in kilometers. Another definition of lightning is an electrical discharge taking the form of a spark within a cloud that is charged (Kostinskiy et al., 2016). A typical lightning strike is composed of three to four strokes, although it can involve more. Each re-strike is separated by a relatively long-time interval, usually around 40 to 50 milliseconds (Rodriguez-Sanabria, 2005).

Lightning can be classified into various types which are cloud-to-cloud (CC), intra-cloud (IC), cloud-to-ground (CG). When focusing on the CG, further classification can be based on polarity, resulting in downward negative lightning, upward negative lightning, downward positive lightning, and upward positive lightning (Kalair, 2013; Shivalli, 2016). It can also be divided into positive (+CG) and negative (-CG) cloud-to-ground based on the polarity. Many studies have been conducted in various geographic regions found that around 10% of global CG

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XI November 2025

lightning is positive (Cooray et al., 1982; Rakov, 2003; Schumann and Saba, 2012; Uman, 2012; Romero et al., 2013; Mohammad et al., 2022; Herrera et al., 2018). The CC lightning refers to lightning discharges that occur between different clouds, where each cloud carries opposite charges without directly contacting the ground. IC lightning, on the other hand, takes place within the same cloud or inside the cloud and involves interactions between areas of opposite charge. The CG lightning involves a discharge between a cloud and the ground, where ions from the cloud are discharged and strike the ground. This type of lightning can involve a positive charge from the cloud hitting a negative charge on the ground.

The cost of existing lightning detection systems is quite expensive. The existing system uses high-cost components, and specialized sensors that can detect electromagnetic pulses associated with lightning (Adzhiev, 2013; Bitzer, 2015). Although these advanced systems provide accurate tracking and location capabilities, but the cost were still expensive. This creates a demand for the development of alternative solutions that offer comparable accuracy and reliability at a more affordable price point. By addressing cost issues and proposing low-cost lightning detection systems, lightning detection becomes more accessible to a wider variety of users and industries. Such a system would use cost-effective components and technology and ensure accurate lightning detection. To overcome the high cost of existing lightning detection systems and monitor lightning events, the development of low-cost alternatives may provide a solution.

This paper aims to design a low-cost lightning detection system by leveraging cost-effective components and technology without compromising accuracy and reliability. By utilizing affordable components such a system can detect and track lightning events effectively. For instance, instead of relying solely on specialized sensors, the system can make use of existing infrastructure, such as antenna to capture electromagnetic pulses associated with lightning. By addressing the cost barriers, a low-cost lightning detection system can make lightning monitoring more accessible to a broader range of industries, ensuring the safety and security of aviation, outdoor environments, and public welfare during thunderstorms.

METHODOLOGY

Lightning Measurement Setup

The process of designing the lightning detection system involved assembling several components such as antenna, coaxial cable, Fast Field buffer circuit, Pico Scope, and laptop as shown in Figure 1. A parallel plate antenna constructed using metallic material have been used for lightning detection. The antenna used in this design had a capacitance of 59pF. The designed antenna was linked to the buffer circuit through a short 60cm coaxial cable with a 50Ω impedance to establish the connectivity. The capacitance of the coaxial cable is 60pF. Subsequently, the buffer circuit was connected to the Pico Scope via a longer coaxial cable, and the Pico Scope was interfaced with the laptop. Upon triggering by lightning flashes, the system collected and stored all the data within the Pico Scope software for further analysis and evaluation. The result analysis obtain from the new system will be label as FF2. Then, the result will be compare with the existing system will label as FF1. Figure 2 displays an example signal of –CG flashes captured by FF1 and FF2 system. The Pico Scope allows both channels to be displayed at the same time with channel A producing the blue signal and channel B producing the red signal.

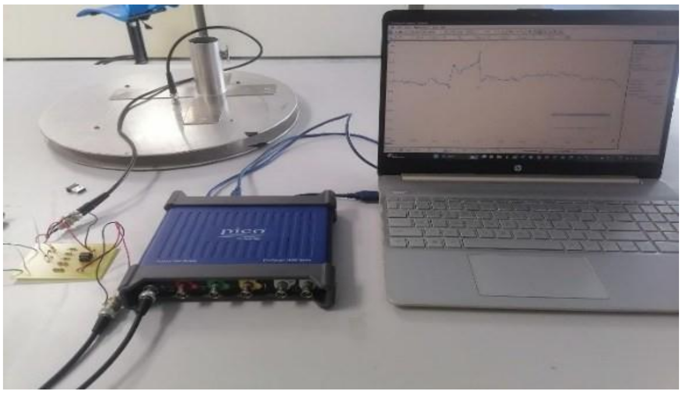


Figure 1. The configuration of the lightning detection system

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XI November 2025

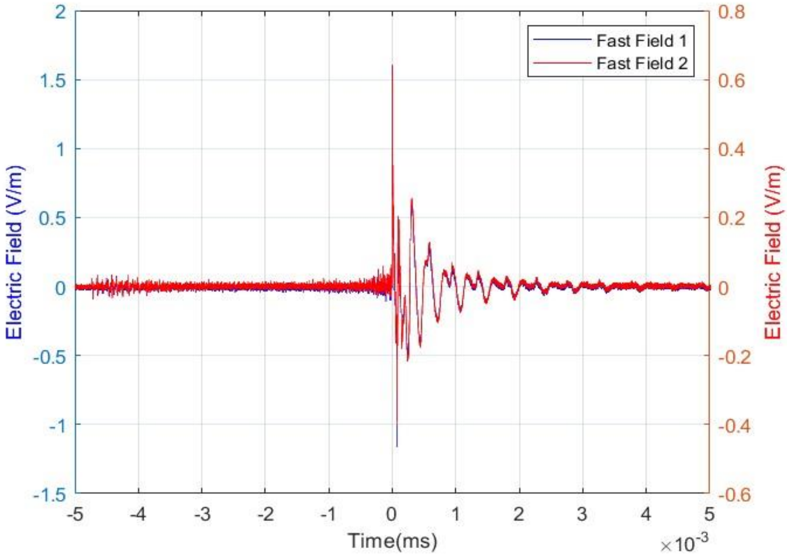


Figure 2. Example signal of –CG flashes captured by FF1 and FF2 system

The installation setup of a comprehensive lightning detection system was done in real time measurement at the rooftop UTeM building. This emphasizing key considerations such as accessibility, unobstructed exposure to the open sky and the absence of significant barriers that might impede detection accuracy. The setup entails the meticulous installation of a lightning detection system comprising a parallel plate antenna, a fast field buffer circuit, and a coaxial cable. Each component was methodically positioned and configured to ensure optimal functionality and accurate lightning detection. Strategic placement of lightning detection system across the rooftop was executed to maximize coverage area. Many factors such as the field of view, elevation angles, and line of sight were carefully evaluated to enhance the system's detection capabilities. This placement aimed to optimize the system's ability to capture lightning signals effectively. Figure 3 shows the installation setup for the lightning system in real time measurement at the rooftop. This setup was designed with thorough consideration of various environmental and technical factors to enable precise and comprehensive lightning detection.

Figure 3. Installation setup for the lightning system in real time measurement

RESULTS AND DISCUSSION

This section will present the results and discussion obtained from the development of lightning detection system. The signal received will be process and analyse throughout the observation. Then, the results will be compared with the other existing lightning system available in UTeM.

The type of lightning flashes

The results obtained shows a total of 111 lightning flashes were detected using the low-cost lightning detection system. These lightning flashes were detected within a small radius of topical thunderstorms in Malacca, Malaysia (UTeM). The entire dataset has been analysed and categorized into several types of lightning such as -CG and IC flashes. The identification of the flash type was based on the recorded fast electric field change. The recorded data includes 60 -CG and 51 IC lightning flashes as shown in Figure 4. The separated data comprises the selected data with a strong flash signal. Majority of the -CG flashes were found to have a single strokes and others consisted of two or more return strokes. In detail, out of the 60 recorded –CG flashes, 54 were single return strokes, 4 consisted of two subsequent return strokes, and 2 had three subsequent return strokes. Figure 5 illustrates the number of strokes for -CG flashes.

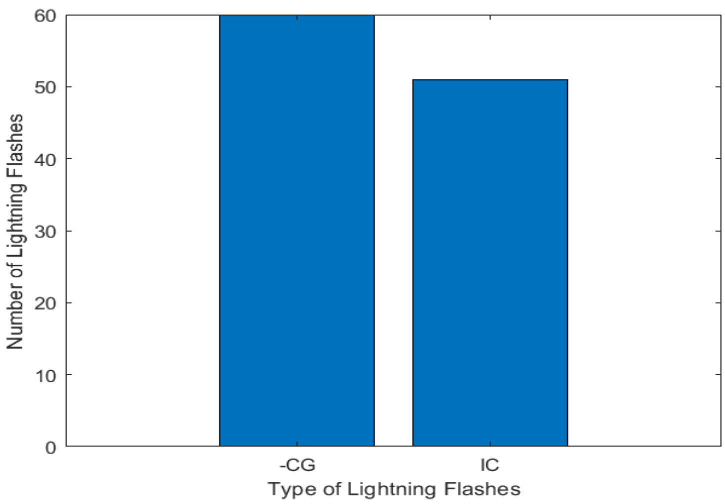


Figure 4. The types of lightning flashes captured by the lightning system

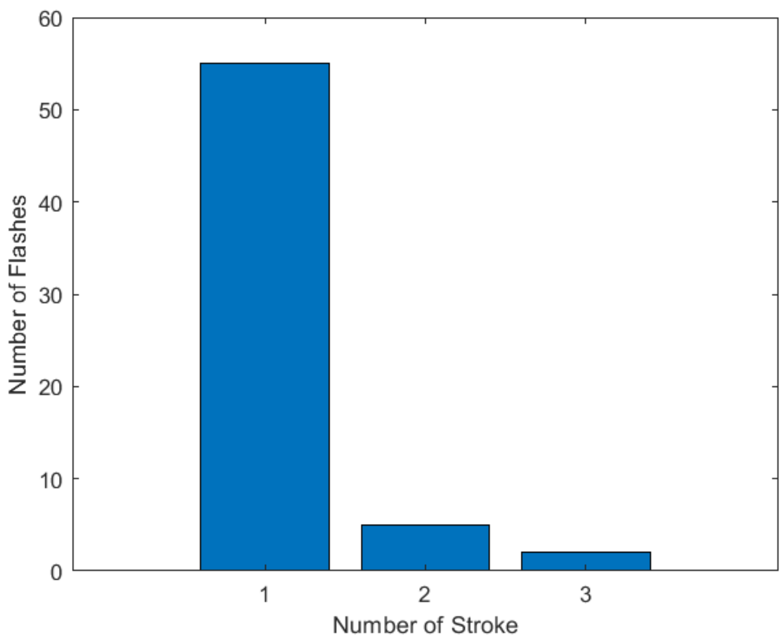


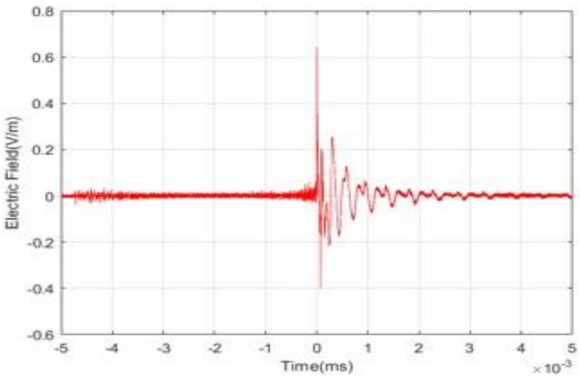
Figure 5. Distribution of the number of strokes per flash for -CG flashes

The return stroke of the (-CG) lightning flashes

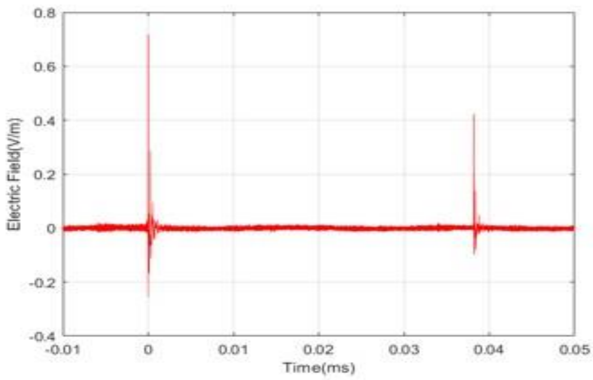
Figure 6 shows the characteristics of a return stroke captured on July 11, 2023, from 01:32:00 to 08:30:00. The results indicate three characteristics of –CG flashes were recorded a single return stroke, two return strokes, and

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XI November 2025

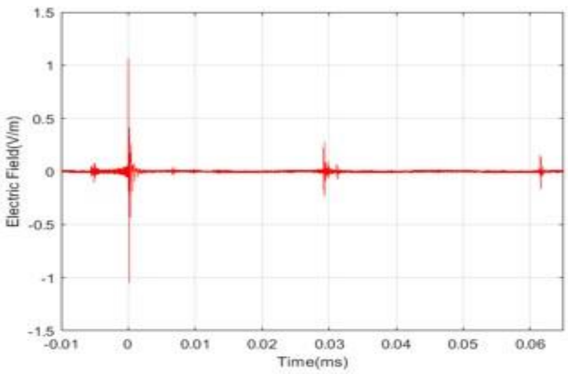
three return strokes. Each flash exhibits its own signal pattern. As shown in Figure 6(a), the process begins with an initial breakdown pulse (or preliminary breakdown pulse), followed by a stepped leader and a return stroke. In Figure 6(b), the same process occurs, but the signal contains two repeated return strokes, classified as a –CG flash with two subsequent return strokes. Figure 6(c) shows a signal with three repeated return strokes, classified as a –CG flash with three subsequent return strokes.



(a)



(b)



(c)

Figure 6. The return stroke captured by the lightning system (a) -CG flashes (b) -CG flashes with two return strokes and (c) -CG with three return strokes.

The comparison of return stroke captured by the lightning systems FF1 and FF2

Figure 7-9 illustrates the comparison of return strokes captured by the lightning system FF1 and FF2 for –CG flashes with a single return stroke, two and three return strokes. Analysis of the –CG flashes indicates that the majority of 54 flashes consisted of single return strokes, while only 6 flashes exhibited subsequent return strokes which 4 flashes with two subsequent return strokes and 2 with three subsequent return strokes, respectively. The similarity of lightning flashes between two lightning systems FF1 and FF2 as shown in Figure 9. Both of the systems have their own performance because both use different type of ICs. The FF1 system using OPA633 which is a high-speed, current-feedback op-amp that's often used in applications requiring wide bandwidth and high slew rates, while the FF2 system using BUF634 is a high-current buffer amplifier designed to provide high output current with low distortion. Due to that, the similarity in terms of performance may have quite a difference. Similar measurement applies to both systems to quantify how related or close data samples are to each other. The similarity measure is usually expressed as a numerical value, typically between 0 and 1, where 0 represents low similarity (dissimilar data objects) and 1 represents high similarity (very similar data objects). The analysis of 60 flashes results in a mean similarity value of 0.8266. This indicates similarity performance achieved in the 60 flashes was around 83%. Through the analysis obtained, 0.9936 maximum similarity was achieved while minimum similarity is 0.7149. The parameter of similarity between system FF1 and FF2 as shown in Table 1.

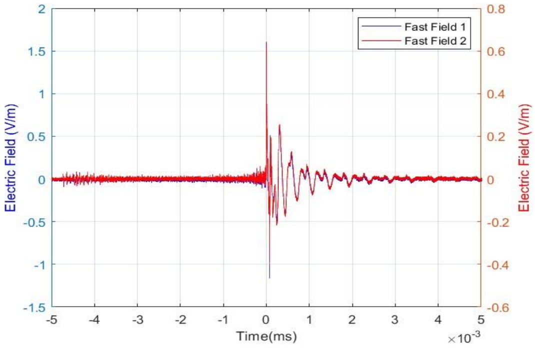


Figure 7. Negative cloud-to-ground flashes with a single return stroke

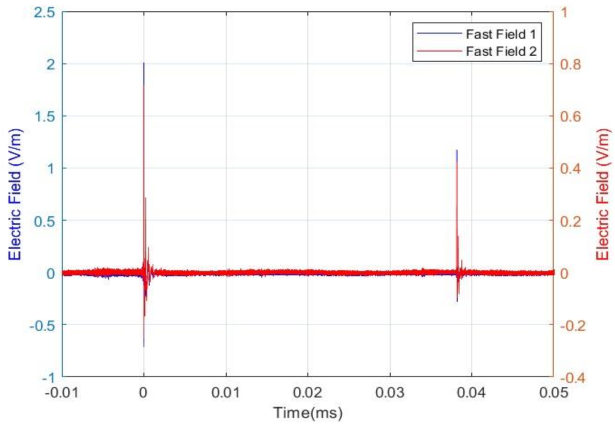


Figure 8. Negative cloud-to-ground flashes with two return strokes

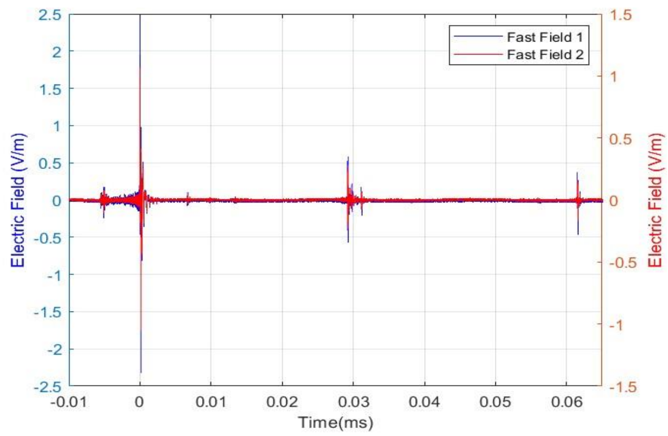


Figure 9. Negative cloud-to-ground flashes with three return strokes

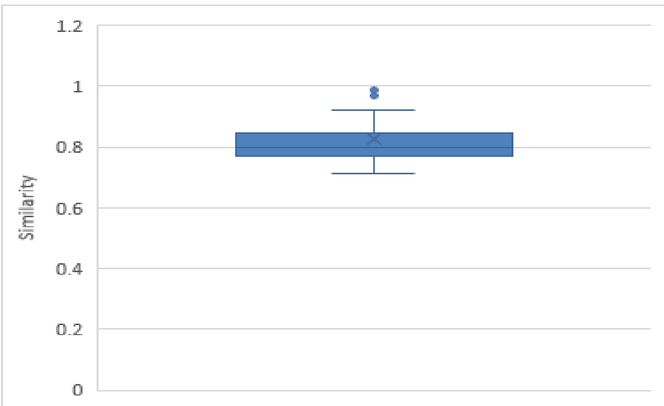


Figure 9: The similarity of lightning flashes between FF1 and FF2

Table 1: Parameter of similarity between FF1 and FF2

	Minimum	Maximum	Mean	Median	First Quartile	Third Quartile
Similarity	0.7149	0.9936	0.8266	0.7971	0.7692	0.8461

CONCLUSION

As conclusion, the project has been achieved and fully met where the lightning detection system has been designed and tested functionally to detect the lightning flashes on 11 July 2023. The lightning system capable to detected 60 -CG and 51 IC lightning flashes between 1:32:00 and 8:30:00. Three different characteristics of –CG flashes were recorded consists of 54 flashes a single return strokes, 4 with two subsequent return strokes and 2 with three subsequent return strokes, respectively. According to the analysis, the comparative analysis between the new and existing lightning detection systems revealed an 83% similarity in lightning flash detection capability. Despite these variations, the new development system proves capable of detecting similar types of lightning flashes -CG and IC, showcasing potential cost-effectiveness without compromising crucial detection capabilities.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support provided by Faculty of Electronics and Computer Technology and Engineering (FTKEK), Universiti Teknikal Malaysia Melaka (UTeM) for the opportunity, support and resources. This project also is part of the output UTeM Short Term Grant PJP/2020/FKEKK/PP/S01761.

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