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***Abstract*— Two antennas - a slow-field antenna and a fast-field antenna - are constructed to measure the electric field generated by lightning. A 50-ohm RG-58 coaxial cable connects each antenna to a high-speed buffer circuit. The OPA633 is utilized in both buffer circuits, which have identical designs. The only difference between the two buffer circuits is the buffer capacitance value, which is 15 pF for the fast field and 10 nF for the slow field. The electric field measured by this circuit represents the electric field strength normal to the ground. Both buffer circuits function well up to frequencies of 100 kHz for the slow field and 1 MHz for the fast field, according to the test findings and circuit simulation with NI MULTISIM 13.0. This measuring equipment has successfully captured electromagnetic waves from lightning with noise levels as low as 180 mV.**

Keywords—slow field, fast field, buffer circuit, parallel plate antenna, lightning detection

I. Introduction

Lightning is a very complex discharge process that emits energy and electromagnetic radiation. Lightning occurs when two different regions of the atmosphere receive a charge large enough to produce an electric field. The increase in the electric field turns the air into a conductor. As a result, the lightning channel acts as an effective transmitting antenna for electromagnetic waves over a wide frequency range from ULF to VHF [1]. The lightning strike is an atmospheric discharge phenomenon regarded as one of the world's most severe natural disasters. This discharge can harm living beings or buildings directly or indirectly through induced currents that result in a rise in electric potential between one or more sites of contact. Forest fires, building damage, disruption to various electronic and telecommunications systems, damage to electrical power systems, and harm or death to humans and animals were examples of physical impairment [2]–[4]. This reason is the fundamental foundation of lightning protection.

Cloud-to-ground (CG) lightning is one of the four types of lightning that causes the most damage to people, facilities, structures, and equipment [5]. One of the most often used approaches for studying and characterizing the features of CG lightning flashes – such as current amplitude, current derivative, polarity, multiplicity, and total flash duration – was indirect lightning measurement. It utilized sensors and remote devices to capture the emitted electric fields formed during the discharge. These measurements led to the identification of several features of the CG flash that were important for formulating lightning protection standards and establishing a lightning warning network and localization system.

One feasible way for researchers to measure electric fields was to use two parallel plate antennas with identical characteristics [6]–[11] separated by a distance known as the baseline. Lightning electromagnetic radiations propagate vertically throughout all directions from the discharge channel, where they are recognized and recorded by the parallel plate antenna. Different field signatures are sensed by this antenna, which is linked to an electrical circuit through a coaxial cable. Lightning generates electric and magnetic field signatures recorded by the parallel plate antenna system. Detailed information about the parallel plate antenna system and calibration was found in [12]. This measuring system had some advantages, such as simplicity of implementation, low cost, and excellent capability to provide valuable information [5].

This paper presents the design of a parallel plate antenna and the electronic circuit, which was functioned to detect the intensity of the slow and fast electromagnetic fields generated by lightning discharges in the Southern Equator. The measuring system was installed on the roof of the PTBA Building at the Faculty of Engineering, Sriwijaya University Palembang Campus, South Sumatra. Preliminary findings are also presented in this paper.

II. Method

A. Electromagnetic Field Measurement System

The fast and slow electromagnetic fields are measured using two antennas separated by about 2 m. The physical dimensions and design of the antenna were based on research by Galvan and Fernando [12] that was later adjusted by other researchers [13]–[16]. Figures 1 and 2 show the physical features of the antennas used in this study and the configuration of the measuring equipment.

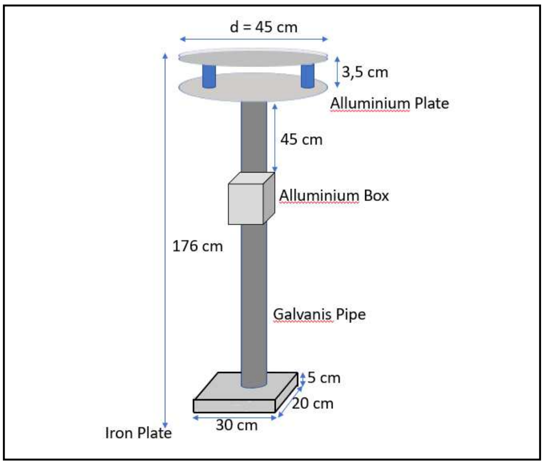


Fig 1. The physical dimensions and design of the antenna used in the study

In principle, any shape may be utilized for the antenna that measures the vertical electric field. The circular antenna is utilized in this study since a circle has no sharp edges like a rectangular shape at which corona may occur at the corner or tapered part, impacting the measurement. The air gap between plates, d, is set to 3.5 cm to keep the capacitance between parallel plates small, according to equation $C = (eA)/d$. The value of C will affect the value of the decay time constant τ_d.

As shown in Figure 2, measurement of changes in the intensity of electromagnetic fields generated during flash is carried out using broadband E-field parallel plate antenna connected to the:

1. Buffer circuit as a signal amplifier/buffer in the certain frequency range in the form of : (a) slow-field buffer that works at the frequency of 1Hz-100 kHz to record static components and induction changes in electromagnetic fields from lightning strikes that occur at a radius of less than 30 km from the observation station [17]; (b) fast-field buffers are used to record the activity of electromagnetic radiation fields with frequencies of 1 Hz – 3 MHz, indicating a series of processes from a series of CG-flashes pulses and also to observe amplitude and rise time values.
2. Picoscope 5000 series data acquisition device integrated into a PC.

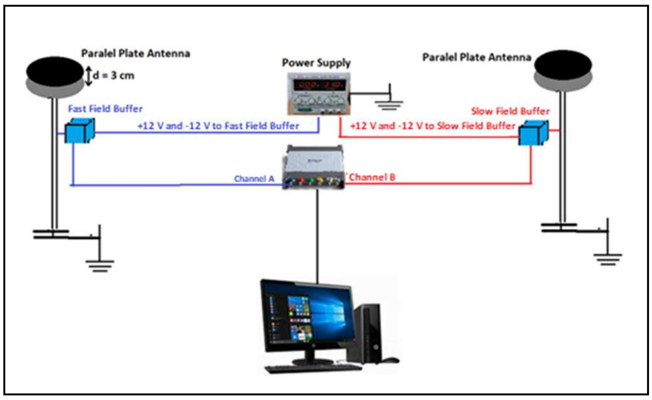


Fig 2. System measurement configuration

The 50-Ω coaxial cable (type RG-58) connects both antennas with a series of buffers. The cable length leading to the fast-field buffer input is 23 cm long, and the slow-field buffer input along 28 cm. Both buffer outputs are connected to a Picoscope 5000 series input using a 6 m long coaxial cable. The fast-field buffer circuit is connected to channel A (CH. A) on a Picoscope, while a slow-field buffer circuit is connected to channel B (CH. B). The equivalent circuit of the measurement system is shown in Fig 3.

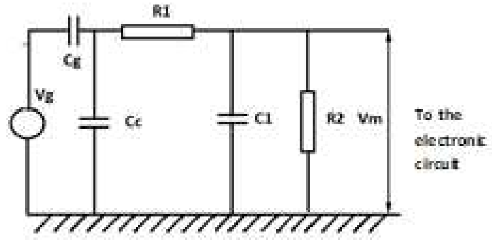


Fig 3. The equivalent circuit of measurement system [12],[18],[19].

The parallel plate antenna has a capacitance of 60.5 pF (Cg). It is connected to the electronic circuit through an RG58 coaxial cable with a capacitance value of 93.5085 pF/m (Cc). Capacitor C1 is an electrical element to measure the voltage change on the antenna plate (Vg). This voltage change is proportional to the electric field change produced by a lightning flash. For the fast field antenna, the value of C1 is 15 pF, while for the slow field is 10 nF. A 50-ohm resistor, R1, is placed at the entry of the electrical circuit to terminate the characteristic impedance of the coaxial cable, which connects the antenna and the electrical circuit. Since the input impedance of the buffer amplifier is very high, resistor R2 is shunted with C1 to extend the decay time constant, R2C1. The value of R2 is 100 MΩ.

A high-speed buffer circuit is required to obtain accurate lightning E-field measurement results. IC OPA 633 KP from Burr Brown was utilized as a high-speed buffer. The IC OPA 633 KP is a high-speed buffer amplifier with monolithic gain with a bandwidth of 260 MHz and a high slew rate (2500 V/µs) [20]. Another advantage of this IC is that its high output current capability allows the OPA633 to drive the 50 Ω cable used in our measurement system

B. Calculation of Capacitance Values and Buffer Circuit Initiation Frequency

The first step was calculating the capacitance values of the fast-field buffer circuit and slow field (*Cb*), the connecting coaxial cable from the antenna to each input buffer circuit buffer (*Cc*-in), and the connecting coaxial cable from the buffer circuit output buffer to the Picoscope input (*Cc*-out). The capacitance value of this coaxial cable was determined by its length multiplied by its specific capacitance value. The circuit capacitance value is listed in Table 1.

TABLE I. THE CAPACITANCE VALUE OF THE ELECTROMAGNETIC FIELD MEASUREMENT SYSTEM

No	Component	Capacitance
1	Parallel plate antenna, C_a	60,5 pF
2	Buffer fast field, C_{ff}	15 pF
3	Buffer slow field, C_{sf}	10 nF
4	Coaxial cable – input buffer fast field, $C_{c\text{-in-ff}}$	21,507 pF
5	Coaxial cable – input buffer slow field, $C_{c\text{-in-sf}}$	26,182 pF
6	Coaxial cable buffer fast field – input Picoscope	1533.539 pF
7	Coaxial cable buffer slow field – input Picoscope	1366.159 pF

The next step determined each buffer circuit's decay time and the initial frequency response. By using the capacitance values listed in Table 1, it is obtained:
The decay time constant (τ) for fast-field buffer antenna is calculated using Eq. 1.

$$\tau = R.C_T = R.\left(C_a + C_{c-in-ff} + C_{ff}\right) \quad (1)$$

τ = (100MΩ) (60.5 pF+21,507 pF+15pF)
= 9,7007ms

And the decay time constant (τ) antenna for the slow-field buffer is obtained using Eq. 2.

$$\tau = R.C_T = R.\left(C_a + C_{c-in-sf} + C_{sf}\right) \quad (2)$$

τ = (100MΩ)(60.6 pF+26,182 pF+10 nF
= 1008,2007ms

Those decay time constants are large enough to record lightning-generated electric field signals accurately with reasonable accuracy.

From the value of τ, the initial frequency response (f_o) in the fast-field buffer amplifier circuit is calculated using Eq. 3.

$$f_o = \frac{1}{2\pi\tau} = \frac{1}{2\ .\ 3{,}14\ .(0{,}0097s)} = 16.4Hz \quad (3)$$

And for slow-field buffer amplifier circuit is obtained using Eq. 4.

$$f_o = \frac{1}{2\pi\tau} = \frac{1}{2\ .\ 3{,}14\ .(1{,}0082s)} = 0{,}16\ Hz \quad (4)$$

C. Testing of Buffer Circuit

Before being used for actual measurement, the slow and fast field buffer circuits needed to be tested. The arrangement of the measurement circuit is shown in Figure 4. Direct measurements on the buffer circuit were performed by connecting the buffer output to the Chanel A of the Picoscope. And the buffer input was connected to the generator function in the Picoscope device. Two 9 V batteries were used to power the buffer circuit. Then, the circuit was injected with various values of the sine wave frequency. The frequency was set in Picoscope application software on the PC. The frequency response waveform of the buffer circuit will appear on the PC screen.

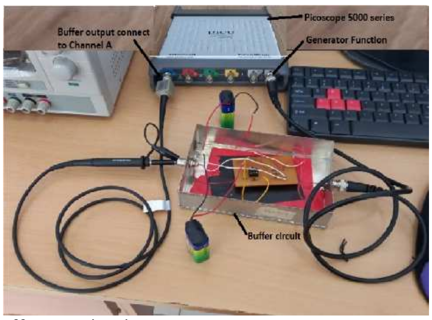
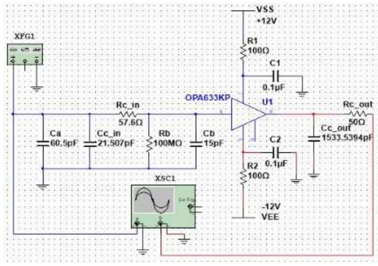


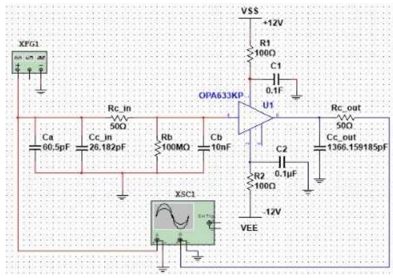
Fig 4. Buffer test circuit

D. Simulating the system using MULTISIM

The circuit was then simulated using NI MULTISIM 13.0 software to determine the frequency response of the measurement system. Figure 5 depicts the simulation equivalent circuit of a fast-field buffer and a slow-field buffer.



(a)



(b)

Fig 5. The simulation test circuit of (a) fast filed antenna and (b) slow field antenna

The electronic components used in this study refer to the previous research[12], [13]. Two high-frequency ceramic capacitors of 0.1 µF (C1 & C2) were used in both buffer circuits to bypass the power supply connection. They are placed as close as possible to the power supply pins of the buffer for high-frequency decoupling. The 100-ohm resistors R1 & R2 were connected in series with the power supply pins to protect the circuit against damage caused by high currents. The 50-ohm resistor, Rc-out, was placed in series at the output buffer to match the impedance of the circuit to the line's characteristic impedance.

The parameter used to assess circuit performance was the ratio between the input voltage of the buffer circuit (Vm) and the voltage change on the antenna plate (Vg). A buffer circuit filters the frequency spectrum of the lightning flash signal [21] without amplifying it [17]; thus, a suitable buffer circuit has a ratio value close to 1. For simulation, the frequency values tested on both circuits were 1 Hz, 10 Hz, 100 Hz, 1 kHz, 10 kHz, 100 kHz, and 1 MHz, and specifically for fast-field buffer circuits, one test frequency value of 10 MHz was added.

E. Himawari-8 Satellite Cloud Type Imaging

The Himawari-8 geostationary satellites operated by the Japan Meteorological Agency (JMA) support weather forecasting, tropical cyclone tracking, and meteorology research. Most meteorological agencies in East Asia, Southeast Asia, Australia, and New Zealand utilize satellites for their weather monitoring and forecasting operations. One Japanese institution that operates the Himawari-8 data archiving and redistribution service is JAXA (Japan Aerospace Exploration Agency) Himawari Monitor which provides Himawari-8 download system services and data processing (http://www.eorc.jaxa.jp/ptree/index.html).

On the Jaxa Himawari Monitor website, there is a cloud-type option that lists the cloud top pressure and optical thickness measurements made for each cloudy pixel throughout the day. As demonstrated in the figure's color caption section, this information may be used to categorize various types of clouds. The names of the cloud categories used here merely approximate the climatological link between the satellite-measured optical characteristics and the traditional morphological cloud types. Cloud types are indicated by color coding at the bottom of the satellite image, where cumulus clouds are shown in pink.

Additionally, a cloud thickness menu that shows the optical thickness parameter of the cloud at visible wavelengths is available on this page (approximately 0.6 microns). If the cloud equally covers the pixels, the cloud thickness determines the amount of apparent solar reflectivity recorded by the satellite from the cloudy scene. Figure 6 illustrates the association between cloud type and cloud thickness.

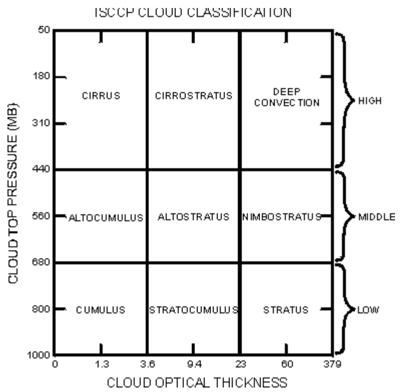


Fig 6. ISCCP Cloud Clasification [21]

III. Result And Discussion

A. Buffer Circuit Performance

The buffer circuit was simulated with NI MULTISIM 13.0 software. The simulation results of the fast-field buffer and slow-field buffer circuits are shown in Figure 7. The result indicates that both buffer circuits have a good response and perform well up to 1 MHz for the fast field and 100 kHz for the slow field. The proposed buffer circuit may therefore be used to measure the E-field produced by lightning.

As previously stated, the buffer circuit is initially evaluated using a generator function to determine how the buffer circuit responds to frequency. Figure 8 demonstrates that both buffer circuits have a good frequency response, shown by frequency response waveforms that are almost pure sinusoidal. The waveform has a little ripple, especially at low frequencies (1 Hz to 100 Hz), although the ripple lessens as the frequency increases. This result demonstrates that the buffer circuit still generates tolerable noise.

This test also measured the voltage, as shown in Table 2. These results indicate that the buffer circuit is functioning well, as indicated by the value of the measuring voltage Vm which is close to the voltage value on the antenna, Vg.

Table II. Buffer Voltage Measurement

Buffer Circuit	Frekuensi (Hz)	Vg (V)	Vm(V)
Slow-field	1	2,091	2
	10	4,041	4
	100	4,106	4
	1000	4,041	4
	10000	4,041	4
	100000	3,341	4
	1000000	0,6241	4
Fast-field	1	2,091	2
	10	4,041	4
	100	4,041	4
	1000	4,041	4
	10000	4,041	4
	100000	4,041	4
	1000000	4,041	4

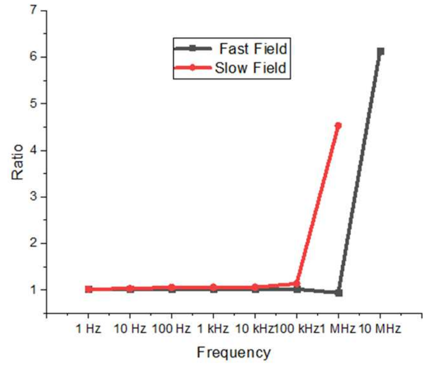


Fig 7. The comparison ratio (Vm/Vg) between slow and fast field buffers

B. Result of Measurement System Field Test

Field tests are the next step to see if the measuring system—the antenna and a buffer circuit—delivers accurate E-field measuring. The measuring system is located on top of the PTBA Building (-3° 22' 13.87",103° 42' 37.14"), Faculty of Engineering Sriwijaya University, Palembang Campus, which has a height of 9.17 m from ground level.

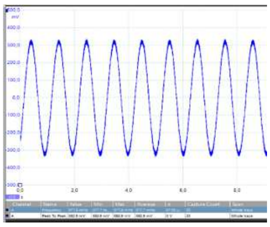
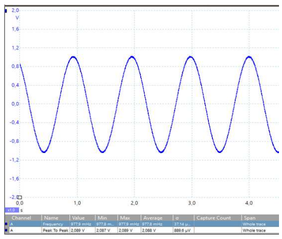
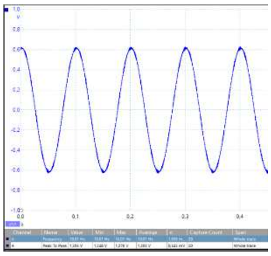
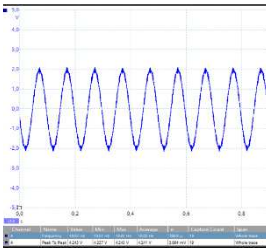
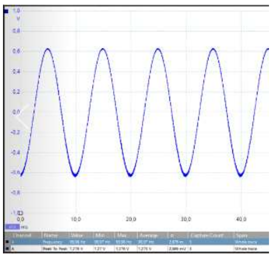
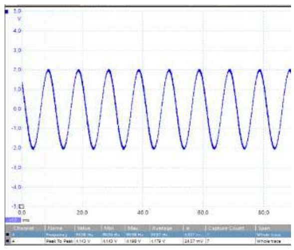
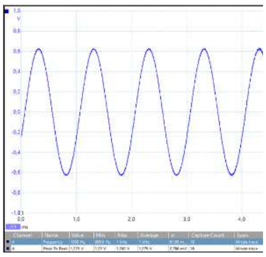
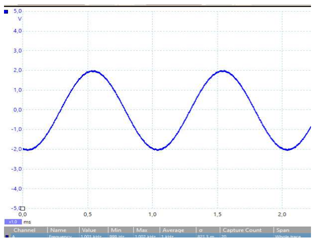
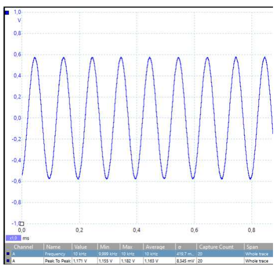
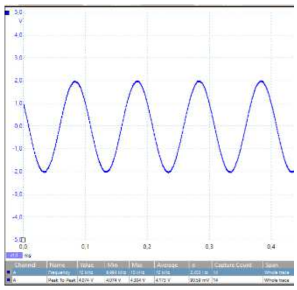
The Picoscope display was configured as follows to obtain the measurement of E-field emission, particularly the return stroke wave :

- Recording time : 500 ms
- Number of samples : 10 MS.
- Hardware resolution : 12 bit
- Trigger Mode : single
- Coupling mode : AC.
- Voltage range channel A : $\pm$ 5V (fast field)
- Voltage range channel B : $\pm$ 2V (slow field)
- Pre-trigger time : 20%
- Trigger level : 2V for channel A (fast field)

The recording time, the number of samples, hardware resolution, and pre-trigger time are based on prior studies [22]–[24]. The system managed to capture a return stroke of lightning E-field waves on 8 June 2022, as shown in Figure 9. The 180 mV range of noise is still present in the collected waves for both antennas, but it is tolerable.

The return stroke wave taken by the fast field antenna is shown in Figure 9 as a blue line, while the return stroke wave captured by the slow field antenna is shown as a red line. The waveform changes of both antennas co-occurred, indicating that the RS wave captured by the measurement system was within a radius of 30 km from the station.

Buffer Circuit Testing Result

Frequency	Slow Filed Buffer	Fast Field Buffer
1 Hz		
10 Hz		
100 Hz		
1 kHz		
10 kHz		

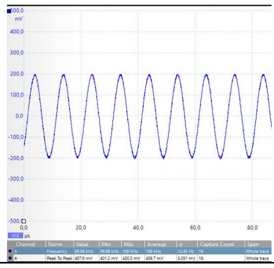
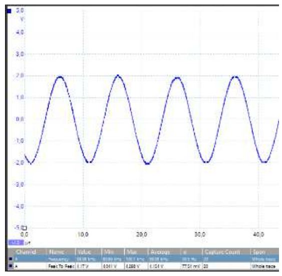
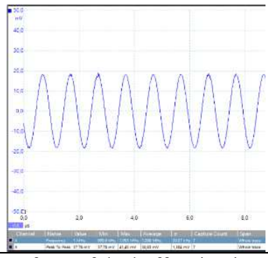
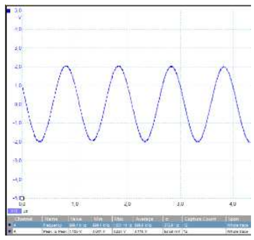
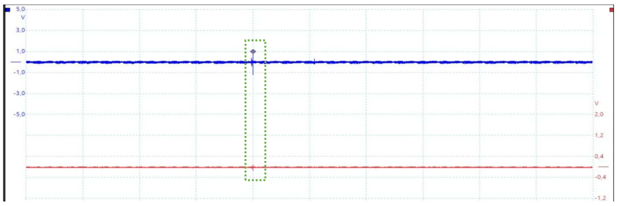
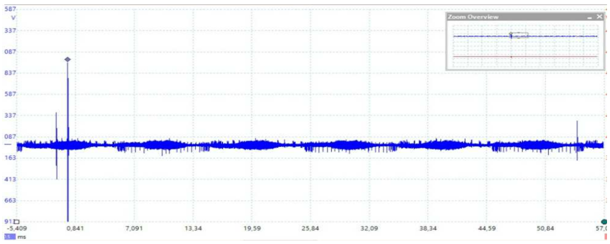
100 kHz		
1 MHz		

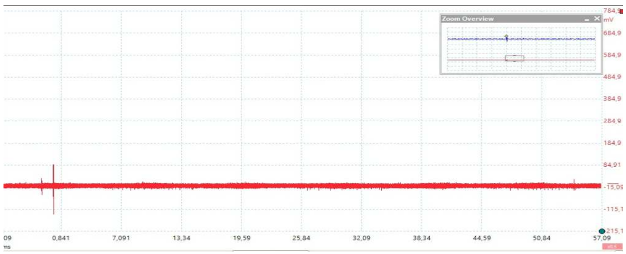
Fig 8. The frequency response waveform of the buffer circuit



(a) Lightning E-field in slow and fast field buffer on June 8th, 2022



(b) Enlarged image of fast field wave on June 8th, 2022

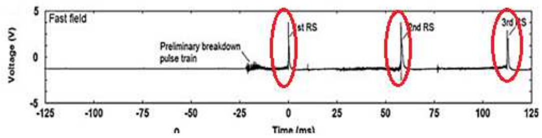


(c) Enlarged image of slow field wave on June 8th, 2022

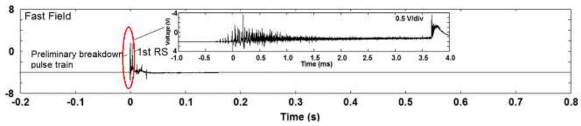
Fig 9. Lighting E-field recorded by the proposed measurement system

The captured waveform resembles the return stroke (RS) wave observed in several other areas, such as Malaysia and Sweden [25] and Padang, West Sumatra [24], as shown in Figure 10. RS waves are characterized by sudden high spikes on the microsecond and sub-microsecond timescales [26].

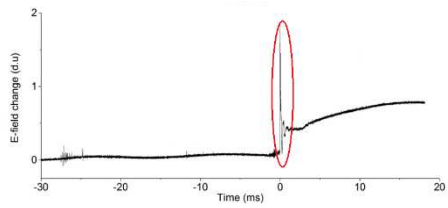
The data from sensors were also confirmed by comparing the changes in the electric field recorded by the measurement system with the Himawari-8 IR-enhanced satellite imaging results. The image showed lightning flash occurrences accompanied by lightning cloud activity (cumulonimbus) in the Palembang region, as shown in Figure 11. The cumulus cloud activity in the Palembang region appeared on June 8th, 2022 at 01.00 UTC (08.00 WIB), as shown in the Himawari satellite image. This image indicated that lightning activity occurred simultaneously with the detected waves.



(a)



(b)



(c)

Fig 10. Examples of return stroke waveforms taken during a thunderstorm in (a) Malaysia, (b) Sweden, and (c) Padang,West Sumatera [24], [25].

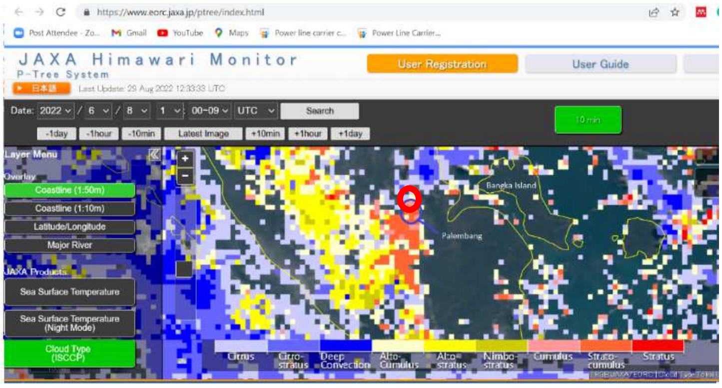


Fig 11. JAXA Himawari Monitor's cloud-type for the Palembang area at 01.00 UTC on June 8th, 2022

IV. Conclusion

The developed system has proven capable of receiving and recording the lightning-generated electric fields on June 2022 in Palembang, South Sumatra. Since this system is also meant to be a lightning locating system in South Sumatra, the study described in this paper still needs development and improvement. Further works will involve creating a VHF antenna to complement the current system and formulating a mathematical model for signal pre-processing based on the South Sumatra lightning emission signal characteristics to improve lightning strike location detection.

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