JASAE
Journal of Applied Science and Advanced Engineering
Vol. 2 No.1 (2024); p. 27-36

e-ISSN: XXX-XXX
https://jasae.org/

Explaining the Existence of Lightning: Literature Review and an Example of Calculating the Efficiency Value of a Detection System

Arief Goeritno[1]*, and Irham Muhammad Azama[2]
[1] Universitas Ibn Khaldun Bogor, Indonesia
[2] Universitas Muhammadiyah Purwokerto, Indonesia
*Email: arief.goeritno@uika-bogor.ac.id

ARTICLE HISTORY
Received: 26 February 2024
Revised: 17 March 2024
Accepted: 20 March 2024

KEYWORDS
Existence of lightning
Cumulonimbus cloud
Electromagnetic field measurement
Detection systems
Calculating of efficiency value

ABSTRACT–The existence of lightning as atmospheric electricity should be thoroughly reviewed concerning the process of going over a subject again in a study that can explain its existence. A review in the form of presenting the State-of-the-Art (SotA) of the existence of lightning with objectives is examined, which includes the description of (i) the forming Cumulonimbus (Cb) clouds and lightning generation; (ii) the principles of electromagnetic field measurement; and (iii) the lightning strike detection systems and an example of calculating the efficiency value. A researcher's algorithm for carrying out the study takes the shape of achievement and adherence to explain in the form of literature reviews. Therefore, a flowchart based on the form algorithm can be created. The results and discussion of three main things related to explaining the existence of lightning as atmospheric electricity include forming Cb cloud and lightning generation, electromagnetic field measurement principles, and lightning strike detection systems, which are equipped with an example of calculating the efficiency value. Based on the discussion of three main things, it can be concluded that explanations of many kinds of literature reviewed can elaborate an understanding of the existence of lightning.

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Introduction

To explain something [1-3], such as the existence of lightning as atmospheric electricity [4, 5], a literature review is the act of going over a subject again in the study [6]. The State-of-the-Art ('SotA'), sometimes referred to as cutting edge or leading edge, is a term that has been used since 1910 to define a set of critical goals as a robust effort to build knowledge about the research field under investigation, with several important pieces of literature having identified and critically evaluated the main issues at stake [7, 8]. The 'SotA,' on the other hand, is a sign of the development of original and cohesive viewpoints by combining and synthesizing the targeted research area's essential elements to put them in the context of the suggested new direction to be investigated [9]. The 'SotA' reviews aim to develop a three-part argument that addresses the subject's current location, historical development, and potential future directions. Generally, the 'SotA' evaluates our understanding of a particular phenomenon [8]. Lightning is a naturally occurring occurrence created or generated by electrostatic discharges in the Earth's atmosphere [4, 5]. The title of this review article is determined by referencing certain lines in the description.

Lightning is an event or phenomenon of the expansion or discharge of electrical charges on the Earth's atmosphere [10]. The process and mechanism of lightning are preceded by forming Cumulonimbus (abbreviated Cb) clouds. The main things that are the basis for the formation of Cb clouds [11] are (i) the heating of the land surface by sunlight, (ii) the presence of aerosol particles originating from sea salt particles and industrial pollutants that float in the air and are absorbent in water (hygroscopic), and (iii) the presence of moisture (sufficient water). The formation of Cb clouds also means they have a process of electrical charge separation [12]. Every lightning strike from the Earth sends a lightning current to the planet with an electric current value exceeding 200 kA [13], resulting in an electromagnetic field with a speed of approximately 300,000 km/hour that moves in all directions.

Efforts to measure the presence of lightning can be made by measuring the strength of the electric and magnetic fields associated with lightning. Electromagnetic waves emitted by the presence of a lightning strike can be used to determine the location of a measured lightning event from an observation station, with the principle that there are two ways to determine the location of a lightning strike, each based on [14]: (i) the intersection point of the two directions indicated by the two stations or more, and (ii) the intersection point of two circles with the radius of the distance from two or more stations based on the difference in wave arrival times at the stations concerned.

A lightning detector is a tool for locating thunderstorm-generated lightning [15, 16]. The three main categories of detectors are (i) round-based systems with many antennas, (ii) mobile systems with a direction and a sense antenna in the same spot (often on an aircraft), and (iii) space-based systems. The first such device was invented by Alexander Stepanovich Popov in 1894. It was also the first radio receiver in the world. In the past, Magnetic Direction Finding (MDF) was the most widely utilized method for detecting lightning[17]. The process was based on detecting lightning electromagnetic wave direction [18], and the Time of Arrival (TOA) technique was eventually created. The time interval between lightning and sensor-detected lightning is measured by the TOA method. The lightning's distance from the sensor is calculated based on that time. These days, modern sensors detect lightning using a combination of methods. The precise time and location of the lightning strike are ascertained using the combination technique [15, 16].A summary explaining the 'SotA' and critical recommendations about the occurrence of lightning has been provided, along with some explanations of the relevant papers [19, 20, 17]. The state of the art, also known as literature review and some also call novelty, of SotA describes a group of essential targets. First of all, it shows that you have built a strong knowledge of the field in which the research takes place, are familiar with the main issues at stake, and have identified and critically evaluated the key literature [21]. Many 'SotA' studies serve as a guide in this article.

Based on the descriptions for a review in the form of explaining the 'SotA,' the literature review objectives included: i) describing the process of forming Cb cloud and lightning generation [22], ii) describing the principles of electromagnetic field measurement, and iii) describing the lightning strike detection systems and an example of calculating the efficiency value. Explanation and description are done by explaining the definition, function, and types. After achieving the research objectives, the research benefits include several previous studies [1], which are related to (a) the explanation of the problem of separating electric charges in clouds, (b) the principle of measuring the electric field strength at a point above the Earth's surface and (c) The lightning detection system has detection capabilities up to several hundred kilometers. This review article is fully adopted from the previous articles, and the delivery order for each section [23-25]. The rest of this article is organized as follows: section 2 presents our proposed materials and methods of the studies; Section 3 presents the results and discussion; and Section 4 presents the conclusion.

Material and Methods

A. Materials for Studies

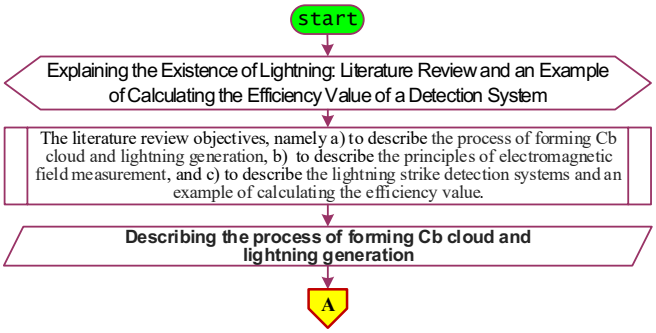
This sub-section relates to the paper's title, emphasizing how different scientific disciplines are interrelated. The following readings are among the most significant and foundations: (i) processing for the formation of Cb clouds and lightning generation [22], (ii) electromagnetic field measurement principles, and (iii) systems for detecting. The elaboration of the three most significant foundations is described in the next paragraph, related to the definition, knowledge base, terminology, structure, methodology, and epistemology.

A definition conveys the significance, features, or essential attributes of individuals, objects, actions, or procedures. Accordingly, a definition is a set of terms intended to clarify the meaning of an object [26]. Knowledge is the state or fact of having familiarity with something acquired by association or experience [27]. On the other hand, a knowledge base is observed when an individual applies mental recognition to objects or events that they have never seen or experienced before [28]. The technical or specialized terms used in business, art, science, or other subjects are terminology. One of the most utilized categories in science and technology is "structure," which is something of a complex entity made up of many components or can be understood as the arrangement of the parts of a system, item, event, or place [29]. A methodology can be defined as a specific technique or series of procedures or a body of principles, postulates, or methodologies used by disciplines [29]. The study or theory of knowledge's foundations and nature, particularly its boundaries and validity, is known as epistemology [26, 29].

The process of Cb cloud formation goes through three conditions, i.e., processes of merging clouds, mature state, and dissipating state [30]. An electric field is produced when charges that originate in the clouds induce charges to form on the Earth's surface. This process is known as lightning generation [30]. The electromagnetic field measurement principles are based on two fundamental laws, i.e., Faraday's principle of electromagnetic induction and the realistic idea that electric currents generate magnetic fields, expressed in Ampere's circuital law. Lightning detection systems are used (i) for alerting of nearby thunderstorms and also can detect high electric-field conditions that precede the first lightning strike for planning and (ii) to track and display lightning storms in real-time on a personal computer (PC) or laptop.

B. Methods for Reviewing through the Explaining

According to several published articles, a researcher's algorithm for carrying out the study takes the shape of achievement and adherence to the objectives of the literature review. A flowchart can be created based on the form algorithm [31, 32, 6]. The layout of the flowchart that outlines the steps of the literature review methodology is shown in Figure 1.



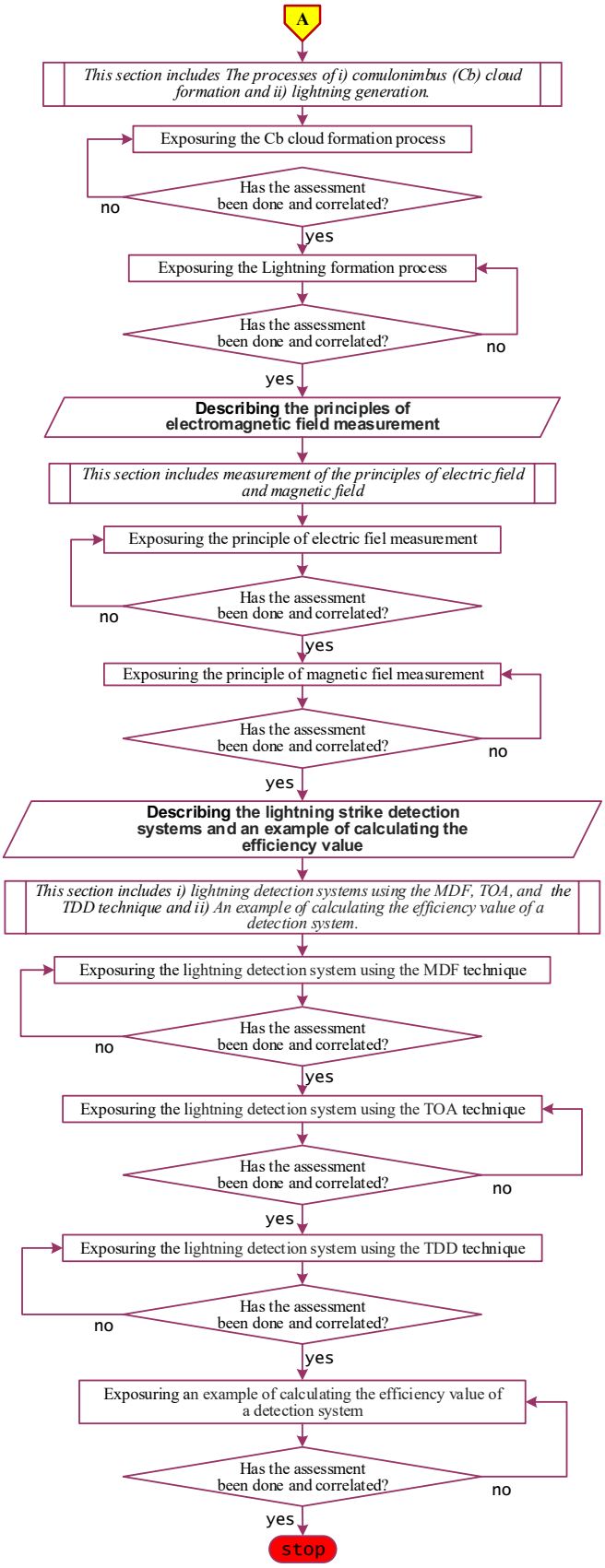


Figure 1. The layout of the flowchart that outlines the steps of the literature review methodology

Based on Figure 1, it is shown. There are three review research objectives, i.e., to describe the processes of forming Cb clouds and lightning generation, the principle of electromagnetic field measurement, and the detection of systems equipped with an example of calculating the efficiency value.

Results and Discussion

This section discusses three sub-sections related to explaining the existence of lightning as atmospheric electricity. These three things include describing the process of forming Cb clouds and lightning generation, the principles of electromagnetic field measurement, (iii) lightning strike detection systems, and an example of calculating the efficiency value.

A. Process of Forming Cb Cloud and Lightning Generation

This sub-section consists of two crucial sub-sections related to the process of forming Cb clouds and lightning generation. The basic theorem specifically for explaining the problem of separating electric charges in clouds [33, 34] includes three things: the thermoelectric theorem [35, 36], polarization [37, 38], and Pöhringer induction [39].

#i) Thermoelectric theory [35, 36]. This theory explains how strong electrification first appears in clouds that are also experiencing heavy rain and hail. The thermoelectric effect, comparable to an ice rod heated at one end but cold at the other, explains how charge grows in Cb clouds. The heated end was negatively charged, and the cold end was positively charged. This theory is applied to Cb clouds containing hailstones that fall when they pass through supercool droplets.

#ii) Polarization theory [37, 38]. This theory explains the process of charge formation in Cb clouds. With a clear weather electric field in a downward direction, cloud and precipitation particles (ice crystals and rain drops) are polarised so that the lower surface is positively charged and the upper surface is negatively charged. When cloud particles collide with precipitation particles moving downward, the negative charge is transferred to the precipitation particles. The gravitational downward movement of negatively charged precipitation particles and the upward movement of positively charged cloud particles are the causes of the growth of two main charge centers in Cb clouds.

#iii) Pöhringer's Induction theorem [39, 40]. This theory explains the influence of the Earth's magnetic field on particles moving in the air due to the wind. In conditions where clouds move in the air so that the Earth's magnetic field lines are cut, the particles in the cloud are induced by a strong electric field. Between these particles, the process of separating new charges continues as a result of electromagnetic induction so that the charge in the cloud continues to increase.

Based on the three theories in question, charge separation in the Cb cloud is the cause of the charge distribution within it. Based on the research results, the charge distribution in the Cb cloud was obtained. A schematic diagram of charge distribution in a Cb cloud [33, 34] is shown in Figure 2.

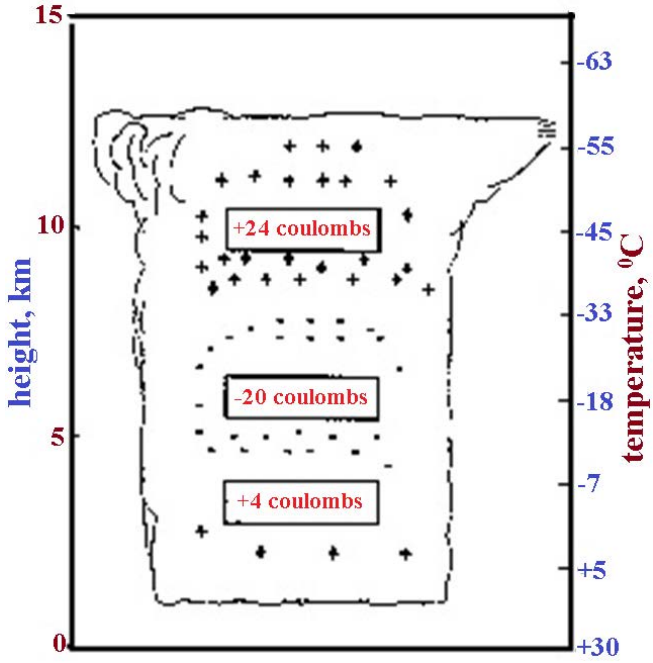


Figure 2. A schematic diagram of charge distribution in a Cb cloud

A.1. Cumulonimbus (Cb) cloud formation process

In certain circumstances, heating the parcel (layer) of moist surface air surrounding the Earth causes the humid air to move upward due to thermal buoyancy, and small cumulus clouds are formed. As long as the air column in the cloud is hotter than the surrounding air temperature, the cloud continues to grow and rise upwards until the temperature inside the cloud is the same as the temperature of the surrounding air, as formulated by equations. (1) and (2) [33].

$$\theta_e = \theta \cdot \exp.^{\left(\frac{2675 \cdot W}{T_c}\right)} \quad (1)$$

$$\theta = T \cdot \left(\frac{1.000 \cdot hP_a}{P}\right)^x \quad (2)$$

where:

θ_e = equivalent potential temperature, [in degrees of Kelvin, K];

W = mixing ratio;

T_c = isentropic condensation temperature, [in degrees of Kelvin, K];

θ = potential temperature, [in degrees of Kelvin, K];

T = air temperature, [in degrees of Kelvin, K];

hP_a = hecto-Pascal

P = air pressure, [Pascal];

x = constant = $\frac{C_p - C_v}{C_p} \approx 0.286$;

C_p = specific heat at constant pressure, [1005 J.kg^{-1}.K^{-1} = 0,240 kalori.g^{-1}.K^{-1}];

C_v = specific heat at constant volume, [718 J.kg^{-1}.K^{-1}].

Due to the upward movement of the wind (updraft), with the participation of moist air, the humid air condenses into water droplets, forming more giant clouds [33]. Movement with the involvement of moist air becomes higher and higher from the Earth's surface, resulting in lower pressure and temperature. With the help of strong winds blowing upwards at a speed of 30,000 feet per hour (10 km per hour) to 40,000 feet per hour (13 km per hour), the clouds are carried to higher ground to a height of around 5,000 (five thousand) meters, so that the clouds At this height, it freezes into ice crystals, then falls back to the Earth's surface because of the Earth's gravity. The existence of water droplets that experience horizontal and vertical friction causes electrical charge separation. Water droplets are positively charged at the top, while the bottom is negatively charged [33]. Simson and Screse's explanation [12, 13] is that the source of clouds with the potential to generate lightning is a charge separation event in cumulonimbus (Cb) clouds, so Cb clouds are known as thunderclouds.

A.2. Lightning generation process

The presence of charges that form in the clouds creates induced charges on the Earth's surface, resulting in an electric field. The Earth's dimensions are assumed to be flat against the clouds so that the clouds and the Earth are considered as two capacitor plates, and there is an accumulation of charge in the cloud with a different polarity from the charge on the Earth's surface [41]. The distance between one charge center and another charge center is on the order of kilometers. With the increase in charge, the potential difference between the cloud and the Earth increases so that the voltage gradient (ΔV) in the atmosphere also increases, while the distribution of ΔV in the two places in question is uneven, usually more robust at the charge center in the cloud. For conditions where ΔV has excess dielectric resistance between the charged cloud and the Earth, a breakdown voltage occurs, which causes the initial leader to go toward the Earth. The ΔV value for the initiation of pioneer formation is approximately 5 to 10 kilovolts per cm (kV/cm), and lightning strikes occur if the potential difference between the cloud and the Earth is in the range of 5 to 10 megavolts (MV) [42]. In conditions of unstable polarity, the separation of cloud charges in the atmosphere may not occur between positive charges at the top and negative charges at the bottom. However, the vertical separation occurs in the opposite direction, namely between positive charges at the bottom and negative charges at the top. This is the cause of the lightning discharge from the Earth to the clouds [43].

Horizontal charge separation can also occur, and a discharge between two clouds, called cloud-to-cloud lightning, is also known as a cloud thunderstorm [44]. Each lightning strike, caused by the downward movement of a charged cloud and the movement of an initial precursor followed by jumps of points of light, is called a lightning bolt [45]. The direction of each step of the lightning tongue changes so that it is not straight and is broken overall. This lightning tongue consists of two parts. The corona, a negative charge surrounding the second part, encircles the first component's thin, highly conductive core. The stress gradient in the corona envelope has characteristics of a corona discharge, low temperature, and being penetrated by many

grooves. Explaining the process of forming lightning tongues is continuous and moving forward [45, 46]. For conditions where the charge center in the cloud can still be charged on the lightning tongue until the value ΔV is greater than the dielectric resistance of the air, then the electrostatic field that arises when the lightning tongue approaches the Earth increases, and ΔV on the Earth's surface becomes very large, then arises a forerunner that rises from the world to the charged clouds [47]. In conditions where this channel meets the lightning tongue, a backlash occurs at a speed of approximately 30 meters per microsecond (m/ms) at the point of impact. The charge from the Earth is neutralized by the charge in the clouds through a high current flow from the reverse stroke, namely the flow of charge from the world to a charge center in the clouds [48].

When the electrical gradient in the cloud is more significant than the permeability value of ionized air, an initial pioneer occurs, as explained by Sirait, as determining the direction of charge propagation from the cloud to air with low ionization and is followed by the presence of a point of light. Hidayat's explanation [13] is that more than half of all lightning events occur in clouds. However, cloud-to-earth lightning is more widely studied due to practical considerations and because it causes danger to humans, disrupts electrical and telecommunication systems, and causes fires. Uman's explanation [46] is that the phenomenon of lightning from the cloud to the Earth is more widely studied because it is easier to observe.

Berger's explanation [45] states that lightning from the cloud to the Earth is grouped into four groups based on the type of charge moving and the start of its movement. Henceforth, lightning within or between clouds is called cloud lightning, while lightning from clouds to the Earth is called earth lightning [41]. Typically, a pioneer moves from the clouds to the Earth, then a return stroke from the Earth to the clouds, neutralizing the charge by tens of Coulombs. The entire charge-discharge event is called lightning, which can last in the range of $5x10^5$ microseconds. One flash consists of several discharge components, with 3 or 4 high-current pulses called a lightning strike [45, 46]. Each strike lasts less than one millisecond (ms), while the time between two consecutive strikes lasts 40 to 80 milliseconds. After several times, the negative charge overflows into the Earth, and the positive charge remains at the top of the lightning. A moment later, the positive charge overflowed to the planet with a greater current intensity. Generally, positive lightning occurs less frequently than negative lightning [41].

B. Principle of Electromagnetic Fields Measurement

. This sub-section consists of two critical sections related to electric and magnetic field measurement principles.

B.1. Principle of electric field measurement

The principle of measuring the electric field strength at a point above the Earth's surface can be applied by measuring the voltage value between the antenna and the Earth. This can be explained with the analogy of a capacitive plate antenna. A schematic diagram of a capacitive plate antenna is shown in Figure 3.[41].

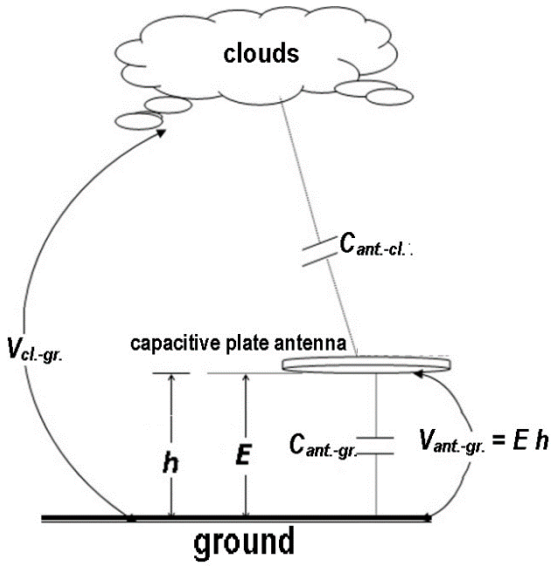


Figure 3. A schematic diagram of a capacitive plate antenna

Figure 3 shows and explains that a dish-shaped antenna is placed high above the Earth's surface. The plate antenna plane is chosen horizontally and directed perpendicular to the measured electric field vector.

The assumption is that the antenna's presence does not impact the electric field's uniformity [49]. Capacitance values are formed: (i) between the antenna and the cloud and (ii) between the antenna and the Earth: $C_{ant.-gr.}$, with $C_{ant.-gr.}$"$C_{ant.-cl.}$. Equation (3) shows the electric field between the antenna and the Earth and the potential difference between them in kV/m.

$$V_{ant.-gr.} = E \cdot h \tag{3}$$

Equation (4) shows the input voltage of the measuring instrument ($V_{in\ (instr.)}$) for conditions where the antenna is connected to the measuring instrument via a coaxial cable with impedance, $Z_{coax.}$.

$$V_{in\ (instr.)} = V_{ant.-gr.} \cdot \frac{Z_{coax.}}{j\omega C_{ant.-gr.}, +2Z_{coax.}} \tag{4}$$

The circuit is formed with a time constant of $\tau = C_{ant.-gr.} \cdot Z_{coax.}$.

For conditions where an antenna with a capacitance value of 25 pF is connected to a coaxial cable with an impedance of 75 Ω (ohm), the circuit time constant is 1.875 nanoseconds; and for conditions where the observed signal time is much greater than 1.875 nanoseconds, the cable output signal can be approximated by equation (5) [41, 49]. Equation (5) is based on equation (4), which was simplified.

$$V_{in\ (instr.)} = V_{ant.-gr.} \cdot \frac{Z_{coax.}}{j\omega C_{ant.-gr.}}$$

$$V_{in\ (instr.)} = \frac{Z_{coax.}}{C_{ant.-gr.}} \cdot \frac{d}{dt} V_{ant.-gr.}$$

$$V_{in\ (instr.)} = \frac{Z_{coax.}}{C_{ant.-gr.}} \cdot h \cdot \frac{d}{dt} E$$

$$V_{in\ (instr.)} = Z_{coax.} \cdot \varepsilon_0 \cdot A \cdot \frac{d}{dt} E \quad (5)$$

where:

A = dish antenna surface area;

W = vacuum permittivity.

To recover a voltage value proportional to changes in field strength, an integrator circuit is installed at the output of the coaxial cable. An antenna circuit with an integrator is shown in Figure 4.

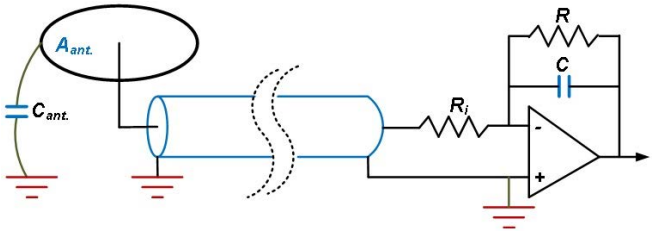


Figure 4. An antenna circuit with an integrator

Figure 4 shows and explains that the output voltage from the integrator can be written as equation (6).

$$V_{out\ (instr.)} = \frac{Z_{coax.}}{R_i \cdot C_{ant.-gr.}} \cdot \varepsilon_0 \cdot A \cdot \Delta E \quad (6)$$

B.2. Principle of magnetic field measurement

The detection tool is two crossed magnetic antennas. The schematic diagram of a magnetic loop antenna [41, 49] is shown in Figure 5.

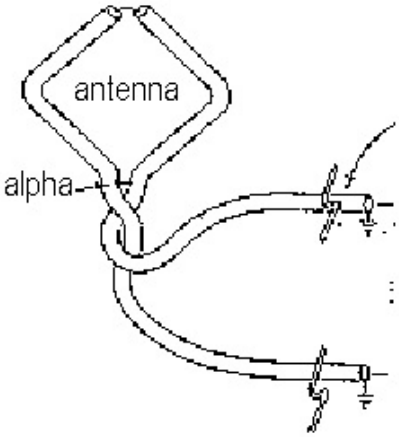


Figure 5. The schematic diagram of a magnetic loop antenna

Based on Figure 5, it is shown and can be explained that the magnetic field of B striking an antenna in an area produces a voltage at the tip of the antenna, as shown in equation (7).

$$V_{out\ (ant.)} = A \cdot \frac{d}{dt} \cdot \cos \alpha \quad (7)$$

where:

α = angle of the incident field with respect to the normal plane of the loop.

An integrator is installed at the end of the loop, as in the electric field measurement, to obtain an output voltage proportional to the magnetic field strength. Therefore, equation (8) is obtained.

$$V_{out\ (ant.)} = \frac{A}{RC} \cdot B \cdot \cos \alpha \quad (8)$$

where:

R = resistance of the integrator,

C = capacitance of the integrator..

For conditions where two loops are installed perpendicular to each other, the same magnetic field produces a voltage in each loop, as shown in equations (9) and (10).

$$V_{out\ (ant.);-1} = A \cdot \frac{d}{dt} \cdot B \cdot \cos \alpha \quad (9)$$

$$V_{out\ (ant.);-2} = A \cdot \frac{d}{dt} \cdot B \cdot \sin \alpha \quad (10)$$

C. Lightning Strike Location Detection System and an Example of Calculating the Efficiency Value

Lightning detection systems with detection capabilities up to several hundred kilometers have been in operation. Three basic principles for determining the location of a lightning strike, namely (i) Magnetic Direction Finding (MDF) Technique, (ii) Time of Arrival (TOA) technique, and (iii) Time Difference and Direction (TDD) technique.

C.1. Lightning detection system using the MDF technique

Lightning detection systems using the MDF technique have been in operation worldwide since the 1970s. This technique determines the location of a lightning strike by forming a triangular shape using the angle and distance received by two sensors [48, 50]. The principle of determining the lightning location using the MDF technique is shown in Figure 6.

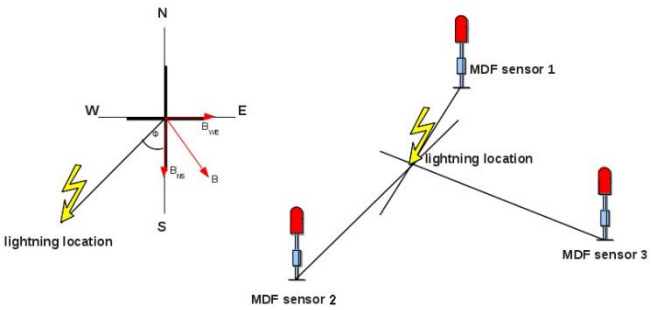


Figure 6. The principle of determining the lightning location using the MDF technique

Figure 6 shows and explains that the main sensor is a crossed magnetic loop antenna consisting of two antennas perpendicular to each other in the North-South (NS) and East-West (EW) directions.

Determining the direction of the strike from the observation station can be done by comparing the amplitude of the two magnetic field components induced perpendicular to each other in the EW loop and the NS loop, which is

proportional to the direction of the lightning arrival. The electric field antenna, as a complement to MDF, functions to eliminate another 180° angle.

C.2. Lightning detection system using the TOA technique

Lightning tracking systems using the TOA technique began to be developed and used worldwide in the 1980s. This system needs at least three or four sensors (receivers, #R#). The principle of determining the lightning location using the TOA technique [48, 50] is shown in Figure 7.

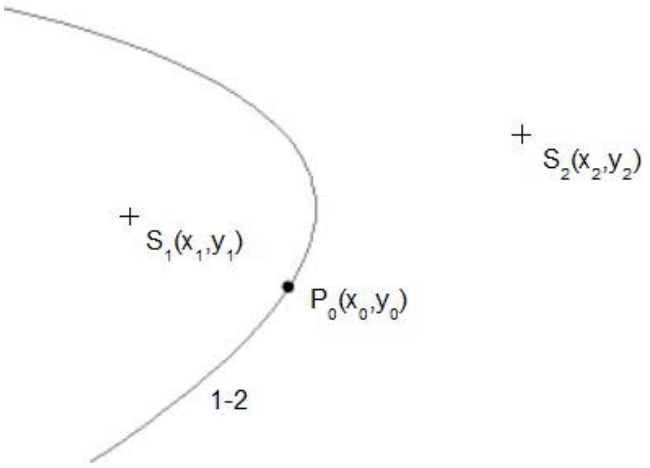


Figure 7. The principle of determining the lightning location using the TOA technique

Figure 7 shows and explains that the TOA system uses information on the arrival time of electromagnetic signals at each sensor. The difference in signal arrival time at each #R# sensor provides a different distance.

For conditions where a lightning strike occurs, the electromagnetic pulse is detected by each #R#, and the detection time is recorded by each #R# using an internal timekeeper synchronized with the time signal from the Global Positioning Satellite (GPS). The locus of the time difference is in the form of a hyperbola. The hyperbola lines from the three sensors intersect at one point so that the lightning strike point can be determined [48, 50]. The meeting of three hyperbolic curved lines is shown in Figure 8.

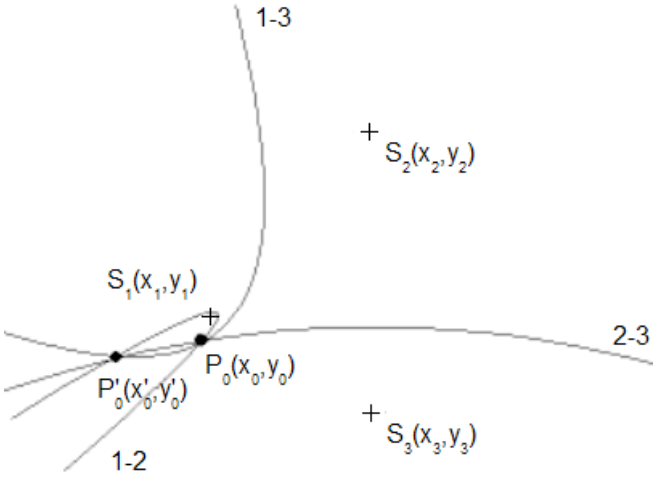


Figure 8. The meeting of three hyperbolic curved lines

C.3. Lightning detection system using the TDD technique

There are two types of TDD techniques related to the use of sensors [48, 50], namely (i) the use of 2 sensors and (ii) the use of 3 sensors. A schematic diagram of the principle for lightning location determination using the TDD technique is shown in Figure 9.

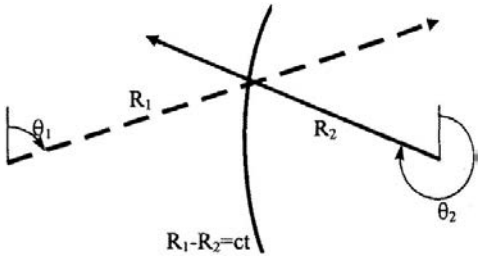


Figure 9. A schematic diagram of the principle for lightning location determination using the TDD technique

Based on Figure 9, it is shown and can be explained that the receiver stations are precisely time-synchronized, and the differences in the signal arrival time between the stations are measured. When a third station is added by utilizing arrival time data from three stations, one may obtain a second hyperbola in addition to the previous one. Combining these modes in a 3-station detection system, called the TDD3, can improve location accuracy and detection efficiency. The schematic diagram of the TDD technique using three stations is shown in Figure 10.

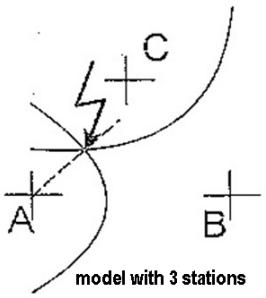


Figure 10. The schematic diagram of the TDD technique uses three stations

The lightning detection system using TDD techniques has been built on the island of Java (is called Java Lightning Location Network, JLLN) since February 1994 [48, 50]. The TDD technique uses pairs of sensors at the same time and accurately on a crossed-loop antenna so that the difference in signal arrival time at the two sensors can be measured along with the angle of arrival. Based on this, the location of the lightning strike can be determined from the intersection of the hyperbolic line and the straight line from a sensor with the angle of incidence of the electromagnetic wave that has been measured. The main equipment for the lightning detection system in each set of sensors is a Direction Finder type DF 80-02 made by LLP Inc., equipped with GPS, which has an accuracy of approximately 0.2 microseconds [48, 50]. A block diagram of a set of detection system sensors using the TDD technique is shown in Figure 11.

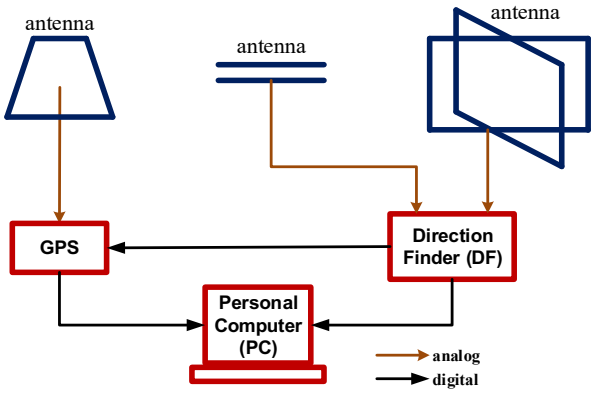


Figure 11. A block diagram of a set of detection system sensors using the TDD technique

C.4. An example of calculating the efficiency value of a detection system

The discussion of lightning detection systems has previously been explained, and detection system equipment using the Lightning Location and Protection - Direction Finder (LLP-DF) System is a direction finder or DF. Based on this, the detection efficiency described in this section is the detection efficiency of an LLP-DF detection system that is needed to determine the number of cloud-to-earth lightning strike densities in a particular area. The system of LLP-DF detection efficiency is defined as the probability of detecting a lightning return stroke related to the signal's amplitude. It depends on the distance of the lightning strike, so the detection efficiency is based on the distance. Hidayat's explanation [48, 50] is that detection efficiency is related to the detection efficiency of the Java Lightning Location Network, as shown by equation (11).

$$P_i = E_i = \frac{N_i}{N_t} \tag{11}$$

where:

E_i = i-th LLP-DF detection efficiency,

N_i = the number of return strokes detected by each DF.

N_t = the total number of actual strokes contained in the area under discussion.

For example, a pair of LLP-DF in a lightning location network has a detection efficiency of E_1 and E_2. The probability of LLP-DF to detect a return stroke is independent of one another; by ignoring various lightning signals with unnecessary waveforms, the detection efficiency of a network consisting of two observation locations, namely locations 1 and 2, can be estimated using equation (12).

$$E_{(m,n)} = E_m \cdot E_n \tag{12}$$

In this case, $E_{(m,n)}$, the network detection efficiency is the minimum number of m stations that detect strikes among a number of n stations in the network.

An explanation of the previous LLP-DF detection efficiency can be analyzed if the number of strikes detected by LLP-DF-1 (N_1), the number of strikes detected by LLP-DF-2 (N_2), and the combined number of strikes detected by LLP-DF-1 and LLP -DF-2 ($N_{1,2}$) is known, then the detection efficiency of LLP-DF-1 is calculated by equation (13).

$$E_1 = \frac{E_{(2,2)}}{E_2} = \frac{N_{(1,2)}}{N_2} \tag{13}$$

In this case, LLP-DF-2 is said to be the reference. For conditions where the thundercloud area is limited, there is no error in determining the location of the lightning strike.

To determine the location of a lightning strike using the MDF or TDD-3 technique (a combination of the TDD-2 technique and the TOA technique), a minimum of two observation locations are required for duplicate lightning strike detection. Based on this, the efficiency of a lightning location network consisting of 3 observation locations can be calculated [48, 50] with equations (14) and (15).

$$\begin{aligned} E_{TDD-3} = E_{MDF} &= E_{(2,3)} \\ &= (E_1 \cdot E_2 + E_1 \cdot E_3 + E_2 \cdot E_3) \\ &\quad - 2(E_1 \cdot E_2 \cdot E_3) \end{aligned} \tag{14}$$

$$E_{TOA} = E_{(3,3)} = E_1 \cdot E_2 \cdot E_3 \tag{15}$$

It can also be calculated [10] with equations (16) and (17) for four observation locations.

$$\begin{aligned} E_{TDD-3} = E_{MDF} = E_{(2,4)} &= \sum_{i=1;j=i+1}^{3,4} E_i \cdot E_j \\ &\quad - 2 \sum_{i=1;j=i+1;k=j+1}^{2,3,4} E_i \cdot E_j \cdot E_k \\ &\quad - 3(E_1 \cdot E_2 \cdot E_3 \cdot E_4) \end{aligned} \tag{16}$$

$$\begin{aligned} E_{TOA} = E_{(3,4)} &= \sum_{i=1;j=i+1;k=j+1}^{2,3,4} E_i \cdot E_j \cdot E_k \\ &\quad - 3(E_1 \cdot E_2 \cdot E_3 \cdot E_4) \end{aligned} \tag{17}$$

Conclusion

Based on the results and discussion, there are three main things related to explaining the existence of lightning as atmospheric electricity, including forming Cb clouds and lightning generation, electromagnetic field measurement principles, and lightning strike detection systems, which are equipped with an example of calculating the efficiency value of a detection system. According to the discussion of those three main things, an explanation of the kinds of literature reviews can elaborate an understanding of the existence of lightning.

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