Lightning Warning System Based on Slow Field and Fast Transient Variations, Suitable for Oceanic Tropics

By

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Thesis submitted in partial fulfillment of the requirements of the degree of Master in Science of the University of Moratuwa

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DECLARATION

"I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university and to the best of my knowledge and belief it does not contain any material previously published or written or orally communicated by another person except where due reference is made in the text or in the figure captions or in the table captions".

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Signature of the candidate

To the best of our knowledge the above particulars are true and accurate.

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LIST OF ABBRIVIATIONS

Abbreviation	**Description**
ac	Alternating current
AM	Amplitude modulation
DSO	Digital storage oscilloscope
EM	Electromagnetic
GPS	Global positioning system
HF	High frequency
IMPATS	Improved accuracy using combined technology
LDS	Lightning detection systems
LED	Light emitting diode
LF	Low frequency
LPATS	Lightning position and tracking system
MDF	Method of direction finding
MF	Medium frequency
RMSE	Root mean square error
SAFIR	Systeme de surveillance et d'alerte foudre par interferometrie radioelectriqu
SSE	Sum of square error
TOA	Time of arrival
UHF	Ultra high frequency
ULF	Ultra low frequency
VHF	Very high frequency

ABSTRACT

Lightning causes a lot of property and human damage all over Sri Lanka. It has been a major requirement to develop a low cost lightning warning system.

The environmental vertical static electric field changes from 0.1 kVm^{-1} under fair weather conditions to extreme values like 10 kVm^{-1} under thunderstorm conditions. Also, lightning discharges generate electromagnetic radiation from ultra low frequency (ULF) through ultra high frequency (UHF) with peak energy emission at 10 kHz.

The work discussed in this thesis uses both the static field variation and the electromagnetic radiation emitted by lightning discharges to predict a thunderstorm. A portable transient detector using an envelope detector tuned to 1600 kHz is used to detect electromagnetic radiation emitted by lightning discharges. An operational amplifier circuit having a slow response with a horizontal plate antenna is used to detect the static field variation. Final decision is made by a third circuit and three levels of alarms are released accordingly.

Using the transient detector only, a warning can be released 25 minutes before the close by thunderstorm with 95% level of confidence. With the entire system, the confidence of the warning further increases.

The cost of the transient detector is about 2500 Sri Lankan rupees with a rechargeable battery bank. The entire system with a battery backup costs about 5000 Sri Lankan rupees.

According to the observations made by the transient detector the delay between cloud flashes and ground flashes shows a distribution of the form of a fractional function with a maximm at 27.52 minutes.

The newly designed lightning warning system shows an acceptable grade of performance with its low cost.

CHAPTER 1

INTRODUCTION

The lightning is one of the key natural disasters which causes a lot of damages including life losses and property such as computers, communication systems, power transmission and distribution systems, etc., worth of millions of rupees, every year [1]. Therefore it has been a major requirement to find a solution to prevent lightning hazards, or at least to detect or forecast lightning so that safety precautions can be taken in advance.

The lightning flash can reach an object mainly in three modes; *i.e.* as a direct strike, side-flash, or potential transfer [2]. Therefore precautions should be taken for protection from all of these. The most effective method for protection from direct lightning is installation of lightning arresters, which is costly even for a usual building. But majority of the Sri Lankans are not in a position to afford for lightning arresters.

A number of precautionary steps have been proposed for protection from lightning hazards in [2], [3]. Those ateps are as follows.

(i). Keep electrical instruments disconnected from the main power supply.

(ii). Television antennas should be disconnected from the television sets and the antenna socket should be placed close to the earth outside the house. Best precaution is to connect the antenna to an earthed conductor.

(iii). As far as possible, avoid handling or touching electrical instruments like refrigerator, electric iron, metal frame, TV, and radio.

(iv). Avoid touching or standing close to tall metal structures, wire fences and metal clothes lines.

(v). Limit the use of telephones when a thunderstorm is overhead. Best advice is not to touch the telephone in such instances.

(vi). Find shelter in a safe place to avoid exposing yourself to the open air. If the time interval between lightning flash and hearing thunder becomes less than 15 seconds, move quickly to a protected location, as there is immediate danger of a lightning strike nearby.

(vii). Try to avoid loitering in open areas like paddy fields, tea estates or play grounds. Specially avoid working in open air holding metal tools like mammoty, knife and iron rods. If this cannot be avoided, crouch down, singly, with feet together. Footwear or a layer of any non-absorbing material, such as plastic sheet, will offer some protection against ground currents.

(viii). Do not seek shelter under or near isolated tall trees and in high grounds. If the vicinity of a tree cannot be avoided, seek a position just beyond the spread of the foliage.

(ix). By sitting down or lying down, reduce the effective height of the body.

(x). If you are in an open boat, keep a low profile. Additional protection is gained by anchoring under relatively high objects such as jetties and bridges, provided that no direct contact is made with them.

(xi). Avoid riding horses or bicycles, or riding in any open vehicle such as a tractor.

(xii). Avoid swimming or wading.

Most of these precautionary steps can be implemented effectively if an early warning system is available at a reasonable cost. Therefore, it has been a long waiting requirement to develop a lightning detector, which meets the characteristics of lightning in Sri Lanka, at an affordable cost.

Observations show that ground flashes begin after some time from the begening of cloud flashes, in oceanic tropic countries like Sri Lanka. This characteristic can be used to predict a thunderstorm beforehand in Sri Lanka. Characteristics of lightning observed in Sri Lanka are discussed in detail in the background study.

CHAPTER 2

BACKGROUND STUDY

In designing a lightning warning system, the charge structure of the cloud, static and dynamic electric fields under fair weather conditions and thunderstorm situations should be able to identify as distinct entities by the resulting system. In addition, the electromagnetic radiation emitted by the lightning can be employed as a monitoring parameter. In this section those characteristics, which were identified in early studies of lightning, will be discussed.

2.1 Fair Weather Static Electric Field

The earth carries a net negative charge and due to positively charged ions present in the atmosphere, the atmosphere has a net positive charge [4]. Because of this situation, under normal conditions (with no charged up clouds), there is an electric field of magnitude ~0.13 kVm^{-1} directed towards the earth [4]. Conventionally in most of the literature the fair weather electric field is taken as positive [5] hence the same sign convention for electric fields is adopted in this thesis as well.

2.2 Charge Separation of a Thunder Cloud

Typically, the thunder cloud (Cumulonimbus) has a net positive charge in the upper part of the cloud and a net negative charge in the lower part of the cloud. In addition to these main charges, there may be a small pocket of positive charge at the base of the thunder cloud [5]. Figure 2.1 shows the charge separation of a typical South African thunder cloud with the altitude according to Malan (1952, 1963) [5]. The net charge in the upper part is about +40 Coulombs and that of the lower part is about -40 Coulombs while the charge of the small charge pocket is about +10 Coulombs.

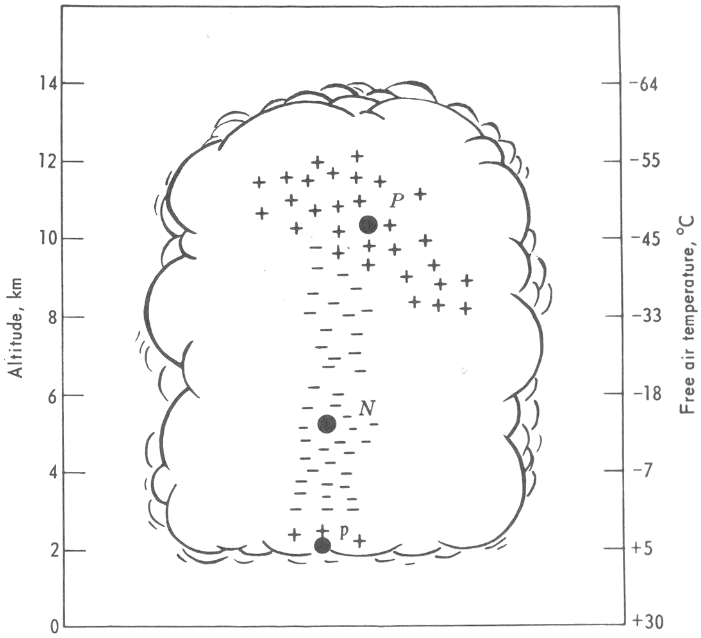


Figure 2.1 – Probable charge distribution of a thundercloud [5].

2.3 Electrostatic Field Under a Thunder Cloud

The electric field under a thunder cloud is a combinational effect of all three charge centers of the thunder cloud. The derivation of the effective electric field under a thunder cloud at ground level at a horizontal distance *D*, due to all three charge centers, is shown in Appendix I.

Figure 2.2 shows the variation of the electric field at the ground level as *D* varies. The same variation can be observed when an overhead thunder cloud is moving across the observation site.

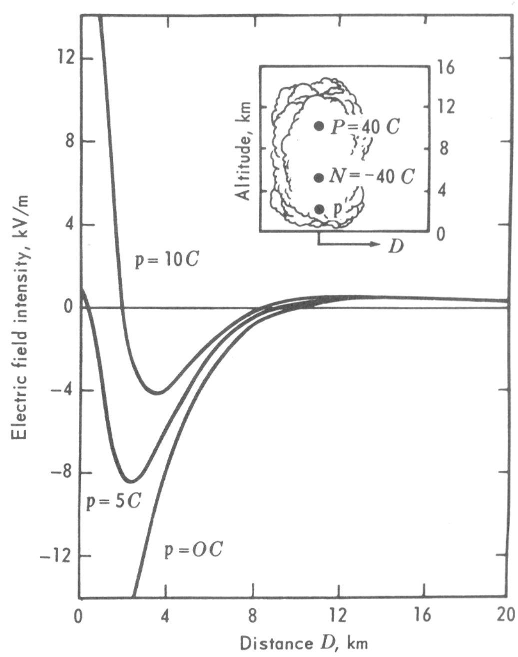


Figure 2.2 – Electric field intensity at the ground vs. distance [5].

2.4 Electric Field Conditions Under Thunderstorm

As discussed earlier, electric field in fair weather conditions is about 0.13 kVm^{-1} while the electric field under a thunder cloud can be as high as 10 kVm^{-1} and even higher than that [4]. There can be sudden changes in the measured electric field at the ground level under a thunderstorm due to electrical discharge of lightning. Figure 2.3 depicts the way in which the electrostatic field strength measured at the ground level changes with time in a thunderstorm.

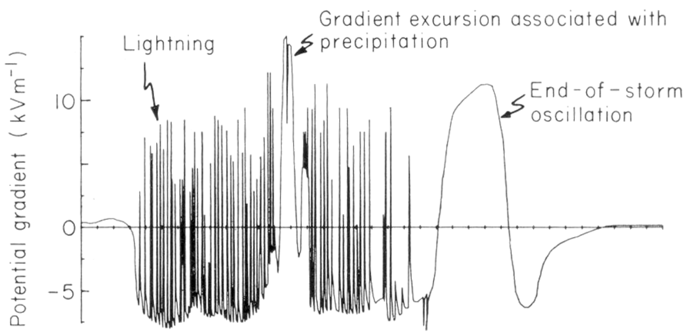


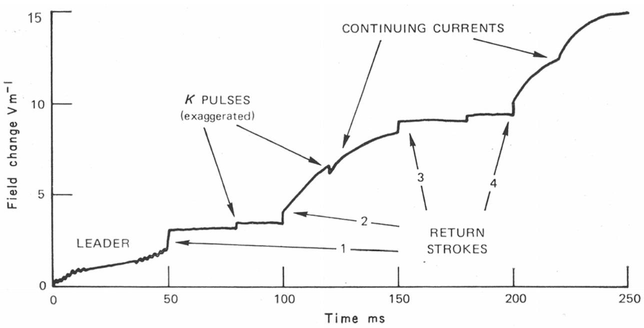
Figure 2.3 – Electric potential gradient beneath an isolated, horizontally stationary thundercloud [4].

2.5 Electromagnetic Fields Radiated by Lightning Discharges

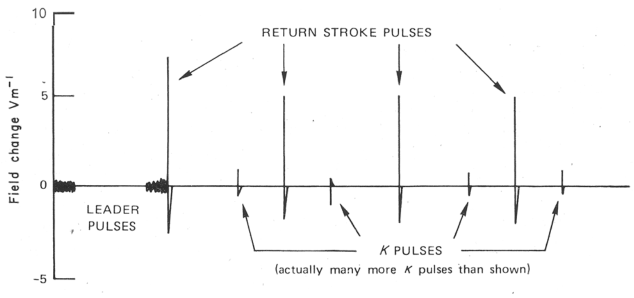
The transient electrical activity in thunderstorms generates electromagnetic radiation events known as atmospherics or spherics. The emitted radiation ranges from ultra low frequency (ULF) through ultra high frequency (UHF) [6]. A typical return stroke produces radiation with peak energy around 10 kHz [7], [8]. The number of separate impulses radiated per flash increases from lower frequencies to 30 MHz, which has the maximum number of impulses radiated per flash and there after the number decreases. Three frequency bands can be identified which has different number of impulses per flesh [4]. They are shown in Table 2.1.

Table 2.1 – Characteristics of spherics in three frequency ranges.

Frequency range	Source signals from flash
LF and below (<300 kHz)	A few isolated transients. Number increases with increasing frequency.
MF and HF (300 kHz to 30 MHz)	Very high number of impulses.
VHF and above (>30 MHz)	Impulses initially very high but becomes much less as frequency increases.



(a)



(b)

(c)

Figure 2.4 – Electric field changes due to a flash to ground 50km away [4].
(a) Frequency Band: 1 to 1000 Hz
(b) Frequency Band: 1 to 100 kHz
(c) Frequency Band: 1 to 100 MHz (Diagrammatic)

Changes in electric field at the earth's surface due to lightning in three different frequency ranges are shown in Figure 2.4. From 1 Hz to 1000 Hz the signal is dominated by the electrostatic near-field component.

In the frequency range 1 kHz to 100 kHz the electromagnetic far-field component dominates. Strong discrete pulses are generated by return strokes and isolated signals of small magnitude are generated from *K* processes.

At 1 MHz to 100 MHz range the characteristics are completely different. A series of pulses can be seen just before the return strokes and *K* process. The pulses quench highly after return strokes and lightly after *K* process.

As the frequency increases above 100 MHz, the number of radiated pulses decreases [4].

2.6 Rate of Occurrence of Lightning

An electrically active cell has a lifetime from about 30 minutes to an hour. During this period, the flashing rate varies from less than one per minute to a maximum of 10 to 20 flashes per minutes [4]. Extremely high rates of flashes of about 60 to 70 flashes per minute have been reported in some observations [4]. The maximum flashing rate is usually reached at about 10 to 20 minutes after the first flash [4]. The average rate of flashes for a thunderstorm is around 3 to 4 flashes per minute [4].

2.7 Measuring Techniques

There are several methods of detecting and warning lightning conditions. They are namely [4],

1. using weather radars
2. by detecting shperics
3. by measuring electric field changes
4. by measuring static electric field
5. using a combination of the above.

To detect static electric field and field changes, electric field measurements are used while detection of shperics is done by electromagnetic detection. Methods of electric field measurements and electromagnetic detection are discussed in the following sections.

2.7.1 Electric Field Measurements

The principle behind electric field measurements is to measure the potential at a given height with respect to the earth using an antenna [4]. Several antenna types that can be used to measure electric field are shown in Figure 2.5 [9].

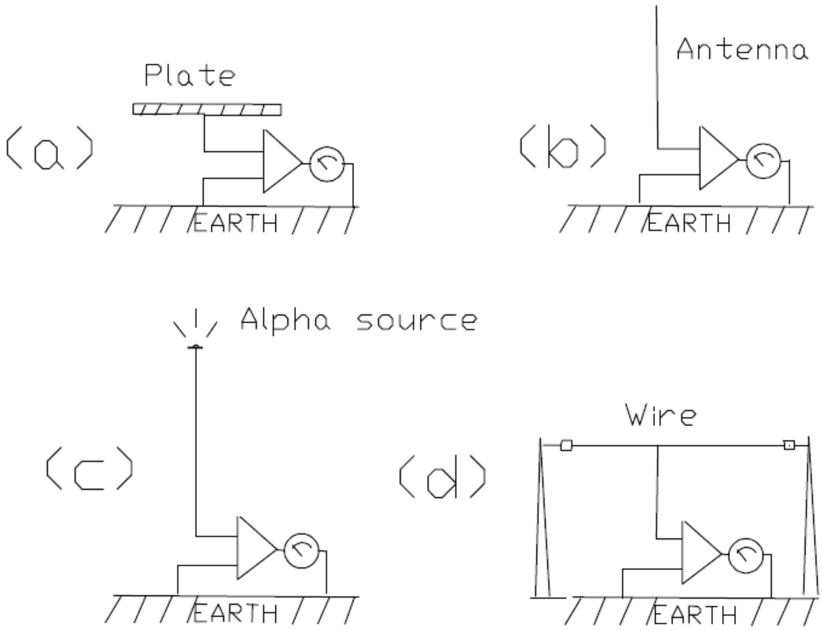
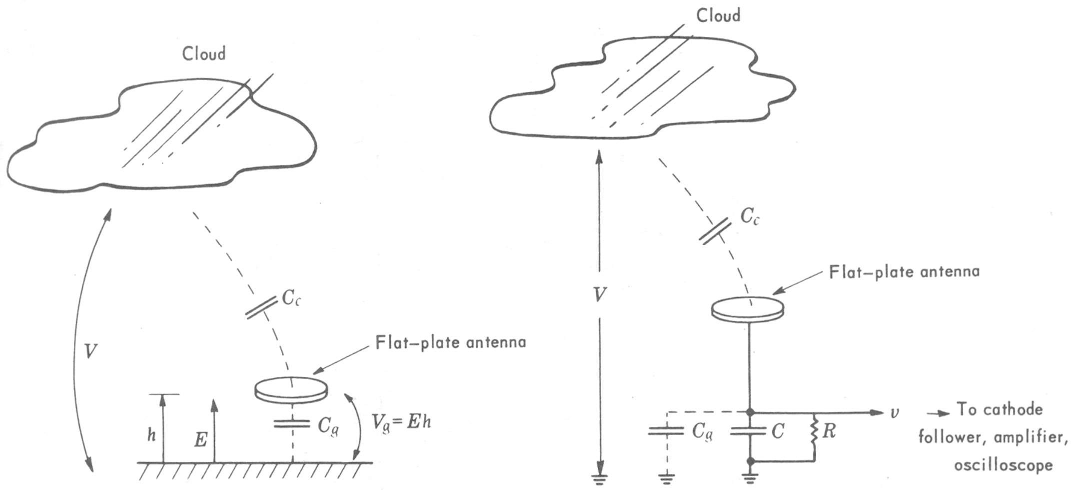


Figure 2.5 – Different antenna configurations for electric field measurements in the atmosphere [9]
(a) Disc antenna (b) Whip antenna (c) Whip antenna with radioactive probe (d) Long wire antenna.

The antenna can be a conducting disc placed at a predetermined height above ground (Figure 2.5 a). The disc will charge and reach a potential which is equal to or very near the potential of the atmosphere at that height. The diagram in Figure 2.5 b shows an electrometer connected to a short whip antenna which gives voltage readings that are difficult to calibrate since the antenna whip will protrude through many levels of electric potentials. An ion-producing radioactive alpha source at the tip of the whip antenna (Figure 2.5 c) will increase the electric conductivity in the air near the tip and ensure a better accuracy of potential measurement as a function of height. A long wire, suspended above ground at predetermined levels, will give accurate readings of atmospheric potentials as a function of height (Figure 2.5 d).

Out of these, the most common is the plate antenna in which the relationship of the measured voltage to the potential at the cloud is shown in equation 2.1 [5]. The derivation of this relationship is shown in Appendix II. Figure 2.6 depicts a schematic of a plate antenna without the circuit (a) and with the circuit (b).



(a) (b)

Figure 2.6 – (a) Flat-plate antenna not attached to electronics
(b) Flat-plate antenna with associated electronics [5].

$$v \approx Eh \frac{C_g}{C_g + C} \qquad \textbf{(2.1)}$$

where,

v – Voltage measured at the output of the plate antenna circuit

E – Vertical electric field near the antenna

h – Height to the antenna from ground

C – Capacitance of the antenna circuit

C_g – Capacitance between the antenna and the ground

The electric field mill, a device based on electrostatic induction, is another method that can be used to measure electric field [4], [9]. It consists of one or two electrodes which either rotate in an electrostatic field or become periodically exposed to a field by rotating vanes. Figure 2.7 illustrates a cylindrical field mill which consists of two cylinder halves that are electrically insulated from each other. An electric motor rotates the two halves in the electric field to be measured so that they become alternately exposed to both the positive and negative direction of the field. The result is that an alternating (ac) signal is generated across the two halves which can be easily amplified.

The rotating shutter field mill, on the other hand, comprises a stationary electrode, which becomes periodically exposed to the external electric field through a rotating grounded disc (Figure 2.8). A variation on this type of field mill is a stationary grounded cover plate with a rotating disc electrode.

Although not commonly used, the cylindrical field mill has the advantage that when mounted in a fixed position it can also indicate the direction of the field. This is accomplished by measuring the phase shift of the ac signal relative to the orientation of electric fields needs to be measured. The rotating shutter type field mill has to be pointed towards the source of the field in order to obtain a maximum reading. The rotating shutter field mill is commercially available in several countries.

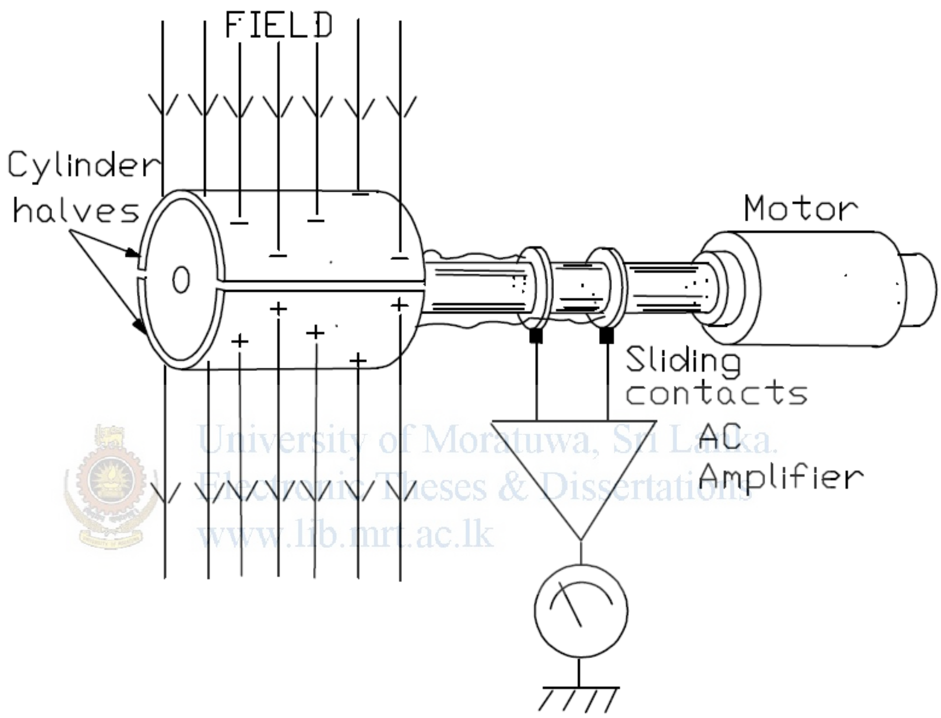


Figure 2.7 – Cylindrical electric field mill [9].

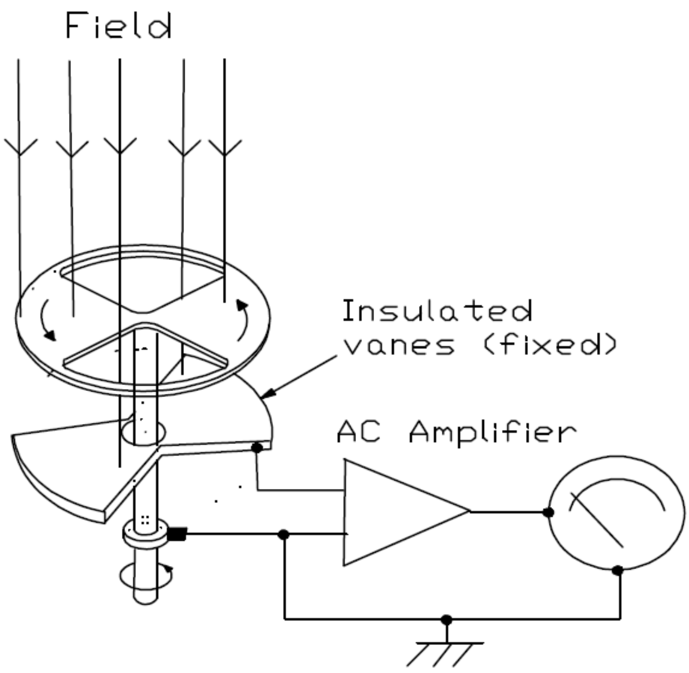


Figure 2.8 – Rotating shutter electric field mill [9].

2.7.2 Electromagnetic Detection

The crackling sound of atmospherics generated by lightning is familiar to everyone who listens to radio. "Spherics" interference is usually stronger in the low frequency band (10 - 500 kHz) were the electromagnetic energy spectrum of lightning is most powerful [9]. There is also an interest in the higher frequency bands of lightning radiation, around 10 - 30 MHz, relating to corona discharges and fast field changes [9]. An attractive feature of atmospherics is that it enables long distance detection of lightning storms [9].

Radio receivers with directional antennae are used to determine the position and movement of thunderstorms [9]. Several stations can accurately locate storms by triangulation. Loop or frame antennas, such as seen on ships, are used and a typical electric block diagram is shown in Figure 2.9.

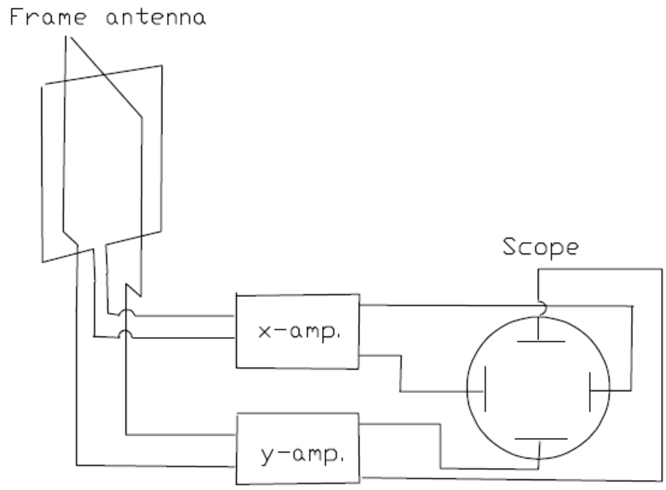


Figure 2.9 – Loop or frame antenna for lightning detection [9].

Experience has shown that the shape of electromagnetic pulses received from lightning changes with distance, which makes it possible to estimate the distance from the antenna to the discharge [9]. Some aircraft are fitted with "storm scopes" utilizing the above principles to determine the direction and distance of nearby intra-cloud discharges in order to avoid dangerous confrontation with lightning [9].

2.8 Existing Lightning Warning Systems

In this section, some of the existing lightning warning systems and the methods used to detect lightning are discussed. There are currently several lightning detection systems (LDS) in operation around the world. The main technologies in use, operating in LF, VLF and VHF, are [10]:

1. Methods of direction finding (MDF), using VLF and LF, determines the stroke position by means of triangulation using at least two sensors, and the peak current can be estimated from the measurement of peak field. Though the methods can have a good estimate of the cloud-ground lightning, there are certain conditions where the geometrical relationship between the sensors and the discharges produce poor results.

2. Time of arrival (TOA), using VLF is based on the measurements of the time-of-arrival of a radio pulse at several stations that are precisely synchronized. This technique may fail in detecting the correct position of the stroke source if less than

four sensors are used. However, if the antennas are properly sited, it can provide accurate locations at long ranges and the systematic errors are minimal.

3. Lightning position and tracking system (LPATS), which is a wideband TOA receiver that is suitable for locating lightning sources at medium and long ranges, through a hyperbolic method.

4. Improved accuracy using combined technology (IMPACT), which can take information from combination of MDF, TOA and LPATS. The methodology can provide information about both intra-cloud and cloud-ground discharges, using the same instrumentation and with reliable propagation through mountainous terrains.

5. Systeme de surveillance et d'alerte foudre par interferometrie radioelectrique (SAFIR), which consists of a network of detection stations combining a VHF interferometric array and a LF sensor for the localization and characterization of total lightning activity. The SAFIR interferometric array uses differential phase measurement on electromagnetic lightning waves for long-range direction finding of lightning activity. The SAFIR LF discrimination sensor is a wide-band electric antenna capable of identifying cloud-ground lightning characteristic. The data is all GPS synchronized and reported to a central station, which computes the location by the triangulation technique.

Impart of these major systems, there are a lot more manufacturers who produce lightning detection and warning systems. Most of these systems detect the electromagnetic radiation emitted by cloud flashes and cloud to ground flashes [11], [12], [13], [14].

Some researchers have developed lightning warning systems using combinations of electrostatic field and electromagnetic radiation. John Chubb and John Harbour [15] have developed an advanced lightning warning system using static electric field, dynamic electric field and electromagnetic radiation as measures to predict lightning. Fedosseeve Serghei and Fedosseeve Serghei [16] have developed a lightning detection system using electromagnetic radiation to detect lightning and photonics to locate the lightning stroke.

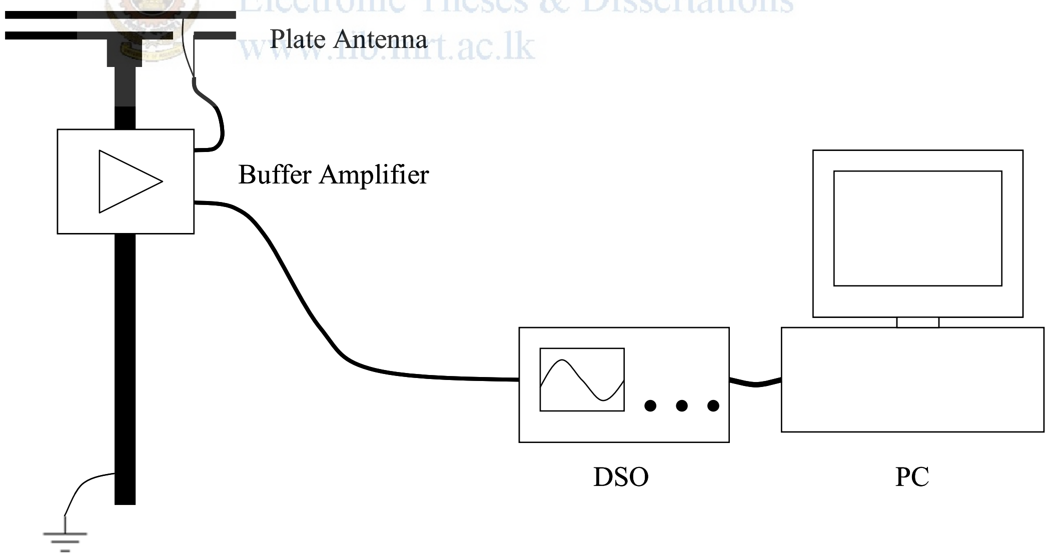
CHAPTER 3

FIELD MEASUREMENTS

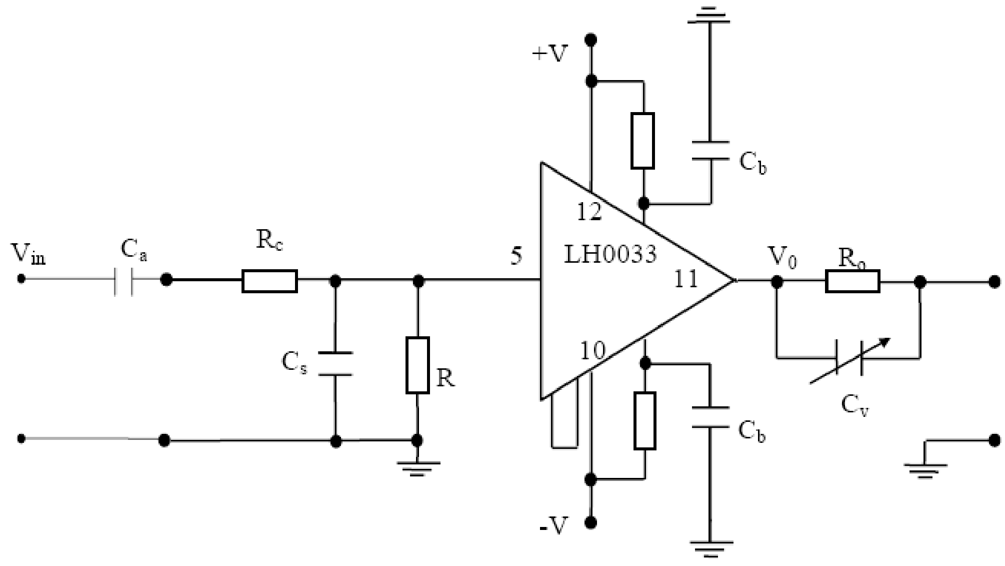
In order to verify the characteristics of static and dynamic environmental electric field variations during thunderstorms that were described in Chapter 2, some field measurements were taken. The apparatus used to observe electric field variation and the observations made will be discussed in this chapter.

3.1 Apparatus Used

A flat plate antenna of which the capacitance to ground 58 pF and the physical height 1.88 m was used to sense the vertical electric field. The antenna was fed to a Digital Storage Oscilloscope (DSO) through a buffer amplifier (an operational amplifier and RC circuit which acts as an active integrator). Then the DSO was connected to a personal computer to upload the data. Diagram of the apparatus and the schematic of the buffer amplifier are shown in Figure 3.1.



(a)



(b)

Figure 3.1 – (a) Diagram of the apparatus (b) Schematic of the buffer amplifier [17].

The decay time constant of the antenna system is determined by the product *R(Ca+Cs)*. The expression for the output voltage is given by equation 3.1 [17] as,

$$V_{in}(s) = V_o(s)\frac{C_s}{C_s + C_a}\frac{s}{s + \frac{1}{R(C_a + C_s)}} \tag{3.1}$$

where $V_{in}(s) = E(s)\, h_{eff}$

$s = j\omega$

$V_{in}(s)$: The induced voltage in the flat plate antenna (in Laplace domain)

$E(s)$: Electric field in the absence of the antenna (in Laplace domain)

h_{eff} : Effective height of the antenna

$V_o(s)$: The output voltage of the amplifier (in Laplace domain)

C_a : Antenna capacitance

C_s : Parallel capacitance connected to the amplifier

R : Parallel resistance connected to the amplifier

In order to measure the electric field without distortion, $1/R(C_s+C_a) << |s|$ or in other words, the decay time constant of the system, $R(C_s+C_a) >> \tau$, where τ is the slowest time component of the signal to be measured.

Two time constant values were used to measure dynamic field variation and static field variation. Time constant was set to 20ms for measuring dynamic field variations and it was set to 1min to measure static field variations.

The apparatus was placed within the premises of the University of Moratuwa, close to the Department of Electronic & Telecommunication Engineering. Some observations made will be discussed in the next section.

3.2 Observations of the Field Measurements

In the section some of the observations made in the field study will be discussed.

3.2.1 Static Electric Field Variation

Environmental static electric field showed almost no change and had a low value under fair weather conditions. An observation made on static electric field is shown in Figure 3.2.

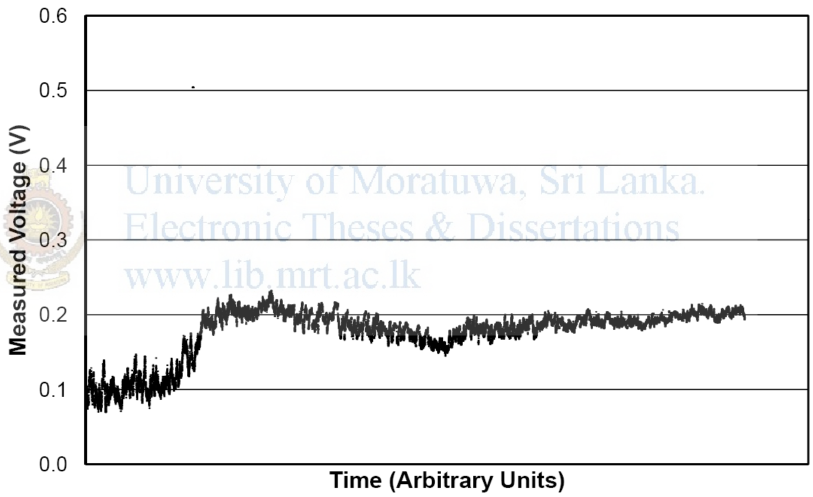


Figure 3.2 – Static field variation observed on 10th August 2004.

Environmental static electric field showed extremely high values before thunderstorms and during thunderstorms. A typical observation is shown in Figure 3.3 with the starting time of lightning (by visual observation).

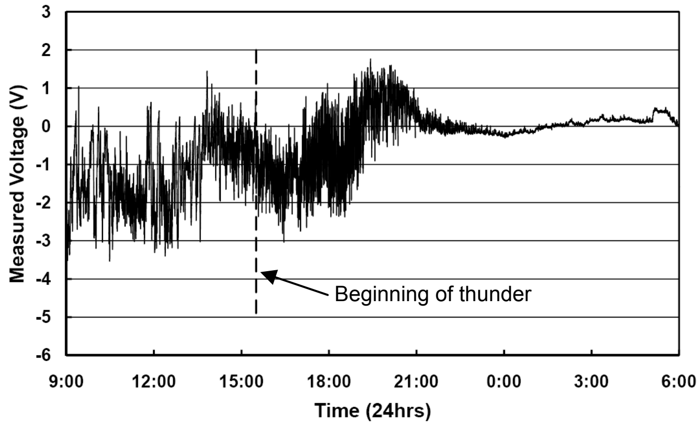


Figure 3.3 – Static field variation observed on 22nd October 2004.

3.2.2 Dynamic Electric Field Variation

Some of the transient voltages observed during a thunderstorm are shown in Figure 3.4.

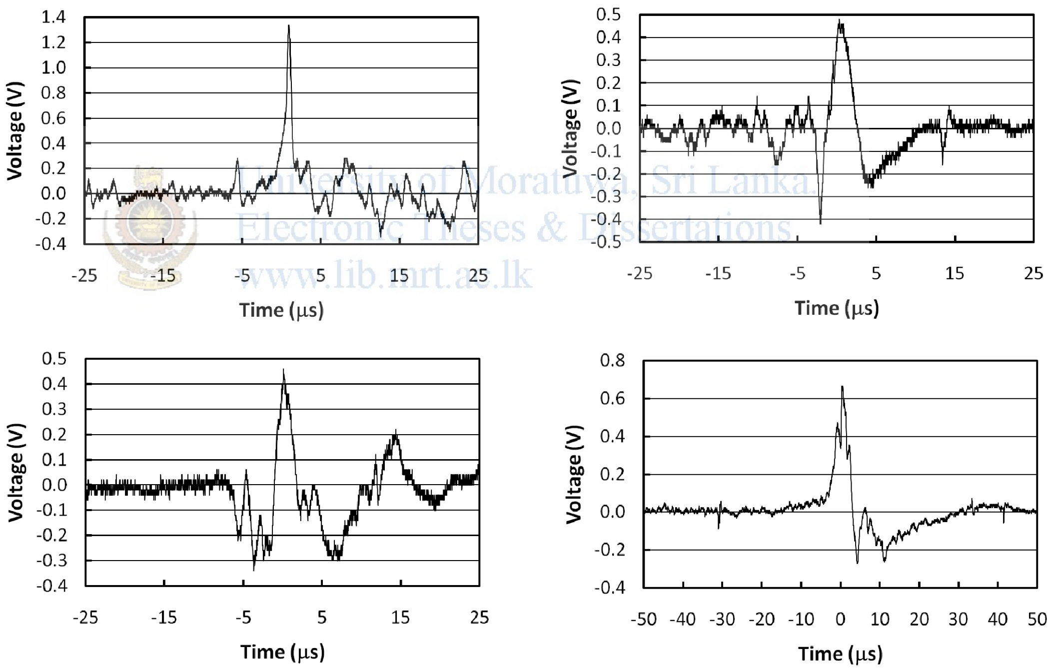
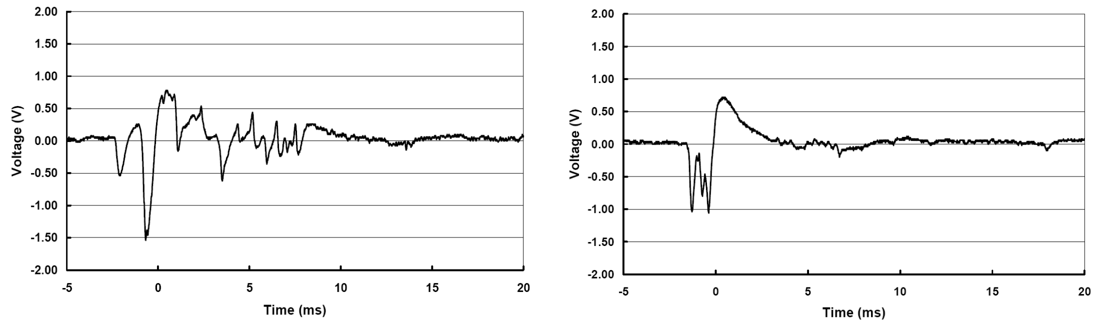


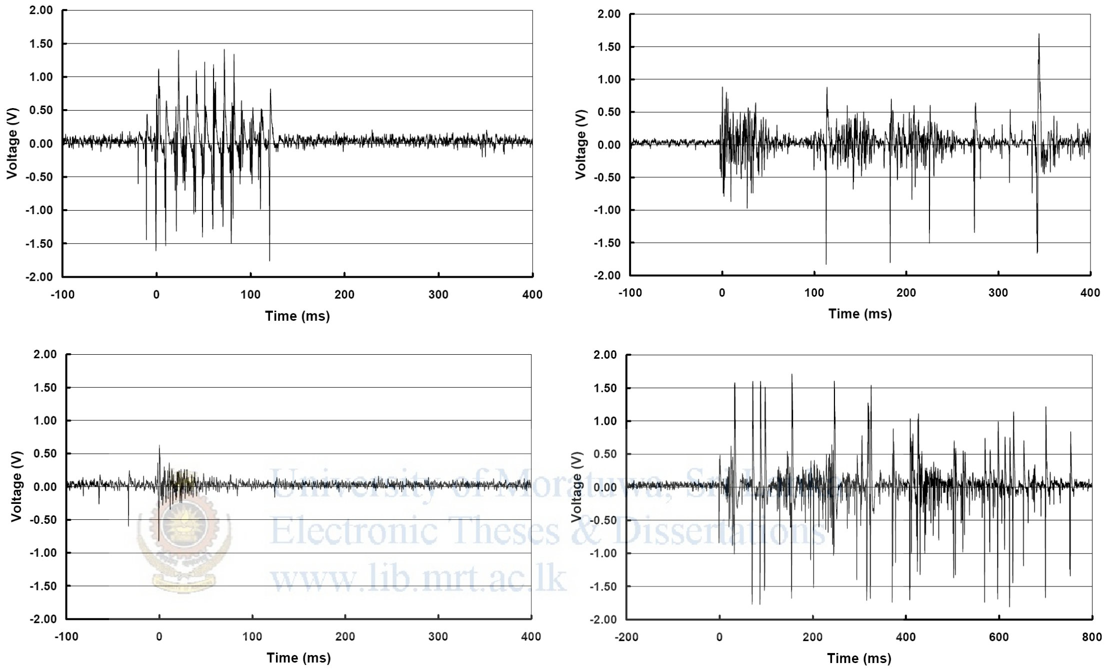
Figure 3.4 – Transient voltages observed during four different lightning strokes.

3.2.3 Radio Frequency Noise

A crackle can be heard on an AM receiver with each and every lightning stroke. Switching transients are also observed as crackles but in a shorter period of time with respect to the time period of a crackle due to lightning strokes. Figure 3.5 shows waveform of crackle received due to a lightning stroke and waveform of crackle received due to a switching transient.



(a)



(b)

Figure 3.5 – (a) Some waveforms of crackle due to switching transient

(b) Some waveforms of crackle due to lightning.

CHAPTER 4

DESIGN OF THE NEW LIGHTNING WARNING SYSTEM

In designing the lightning warning system, some observations and information from literature study were taken in to consideration. They are namely:

1. Crackle detected on an AM receiver
2. Rate of lightning strokes has a minimum of about one stroke per minute
3. Static electric field varies from about $100Vm^{-1}$ during fair weather conditions to about $10kVm^{-1}$ during a thunderstorm

Key aim of the design is to minimize the cost of the warning system as far as possible while keeping the level of protection up to the standard. A brief block diagram of the warning system is shown in Figure 4.1, which will be discussed in detail later in this chapter.

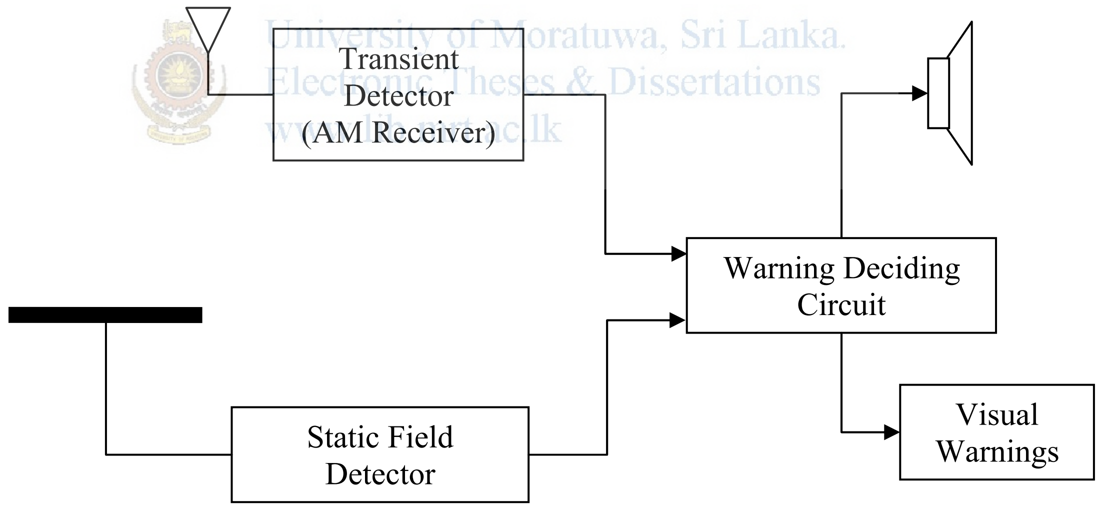


Figure 4.1 – Block diagram of the lightning warning system.

4.1 Transient Detector

An AM receiver is used to detect the transients due to lightning as it should not be exposed to direct lightning hence the risk is a minimum. A proper high amplitude noise (crackle) can be detected at the output of the AM receiver. The frequency of reception was selected to be close to 1600 kHz as the average noise around 1600 kHz was found to be less compared to other ranges according to observations made in the present study. Also the amount of radio noise emitted is higher in the range 300 kHz to 30 MHz according to literature.

One drawback of using an AM receiver to detect lightning transients is that it also detects switching transients. To eliminate detecting switching transients to a great extend, two methods were employed. They are:

1. Using a slower response so that switching transients that has a shorter period compared to transients due to lightning can be eliminated
2. Output of the transient detector is triggered only if at least two transients are detected in two minutes period (effectively at least one stroke per minute)

Block diagram of the transient detector is shown in Figure 4.2.

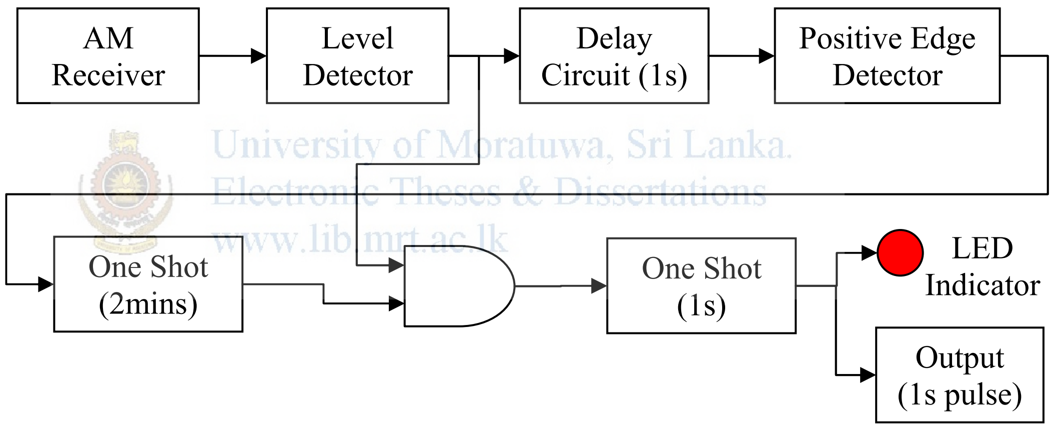


Figure 4.2 – Block diagram of the transient detector.

An advantage of the transient detector developed in the present work is that it, itself, can be used as a stand alone lightning warning device. It is designed to operate using four AA sized rechargeable batteries so that it can also be used as a hand held device. Once the batteries are fully charged, the device can be used for about two days. The device is functional even while charging batteries. When the transient detector is connected with the other units, it does not need batteries and it can be powered from the main supply. An explanation on the operation of the transient detector is given in the following sections. A photograph of the transient detector is shown in Figure 4.3.

Figure 4.3 – Transient detector.

4.1.1 AM Receiver

This is an ordinary AM receiver which is an envelope detector tuned to a frequency around 1600 kHz. Response time of the output circuitry of the receiver has increased by putting a high value capacitor to its output to eliminate responding to switching transients.

4.1.2 Level Detector

Level detector is used for noise cancellation. It triggers the rest of the circuit if the output of the AM receiver increases beyond the set value. Reducing the set value will increase the false alarm probability while increasing it, will reduce the detectability of transients.

4.1.3 Warning Indicator Circuit

The rest of the circuit is designed in such a way that when more than two transients are detected within two minutes (effectively more than one lightning stroke per minute), 1s pulse is released at the output. LED also goes “ON” during that period. Output will not trigger if the number of lightning strokes per minute is less than one because of the 1s delay circuit and 2min one-shot. Also, it will not trigger for a single stroke because of the 1s delay circuit.

4.2 Static Electric Field Detector

The static field detector consists of a charge sense antenna, a 60 Hz notch filter, a self-zeroing integrator, a signal limiter and a zero adjustment.

The charge-sense antenna is a large plate antenna. The charge induced on the plate antenna is then sent to the self-zeroing integrator through a 60Hz notch filter which filters off any noise induced on the plate from ac main supply. The circuit works with a 12V single supply. The front end of the circuit, the notch filter, is biased at 6V instead of 0V so that the output, when no high charge is present, will be close to 6V. The integrator has a very slow response time and hence it does not response to fast change of charges. The zero adjustment can be used to adjust the output back to 6V if there are any changes due to leakage. Sensitivity of the device can be increased by increasing the size of the charge-sense antenna.

The static field detector should be kept in a place which is not directly exposed to lightning to reduce the risk of getting struck by lightning. At the same time, it should not be kept in a well shielded place so that the change of static field will not be detected. A large opening, like a large window, a balcony or an open veranda would be an ideal place to keep the unit. It should be mentioned that the charge-sense antenna should not be touching anything. Also it should not be wet; otherwise, the charge induced on the antenna would be discharged to earth.

A picture of the static field detector is shown in Figure 4.4. Some readings taken using the static field detector are discussed in the following section.

(a) (b)

Figure 4.4 – (a) Static electric field detector (b) A proper placement of the static field detector.

4.3 Warning Deciding Circuit

Warning deciding circuit is the rear end of the warning system. This circuit derives the final warnings. The warning is released in three levels.

- If and only if the output of the static field detector goes away from its normal value, *i.e.* 6V, more than a certain amount, then the Green LED goes ON for 30 seconds. This alarm informs people that there is a possibility of a thunderstorm in few hours time.
- If the output of the static field detector goes away from its normal value, *i.e.* 6V, more than a certain amount, and the transient detector detects EM bursts at a rate greater that 2 bursts per minute then the Yellow LED goes ON with an audible alarm at the same time for 30 seconds. This alarm informs people that there is a possibility of a thunderstorm in about 20 minutes time.
- If the output of the static field detector goes away from its normal value, *i.e.* 6V, more than a certain amount, and the transient detector detects EM bursts at a rate greater that 5 bursts per minute then the Red LED goes ON with an audible alarm at the same time for 30 seconds. This alarm informs people that the thunderstorm is active and they should take precautionary action immediately.

The block diagram of the decision making circuit is shown in Figure 4.5.

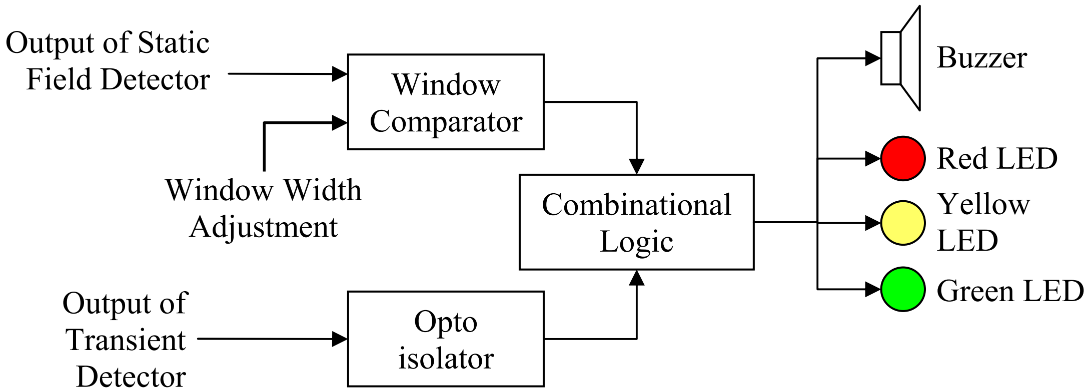


Figure 4.5 – Block diagram of the warning deciding circuit.

By the "Window Width Adjustment", an upper voltage and a lower voltage can be set such that when the output voltage of the static field detector goes beyond the upper voltage or when it goes below the lower voltage, the output of the widow comparator will be high. This adjustment helps to tune the system to suit the place in which it is located. The warning deciding circuit and the main power supply are implanted in the same unit and a photograph of it is shown in Figure 4.6.

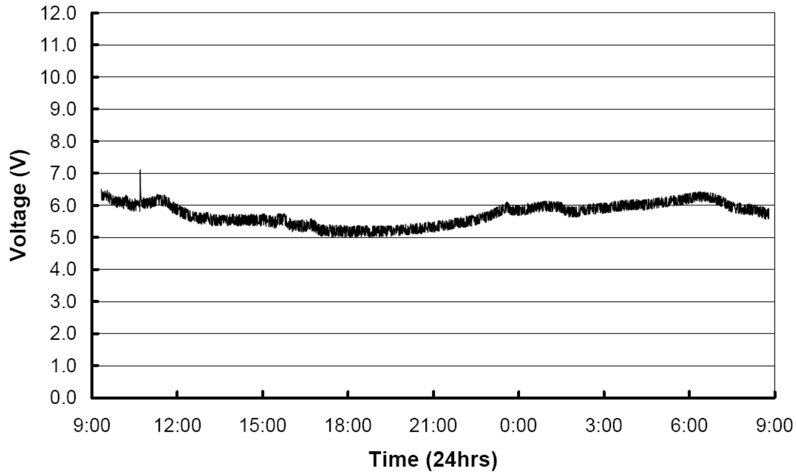
Figure 4.6 – Unit containing warning deciding circuit and main power supply.

CHAPTER 5

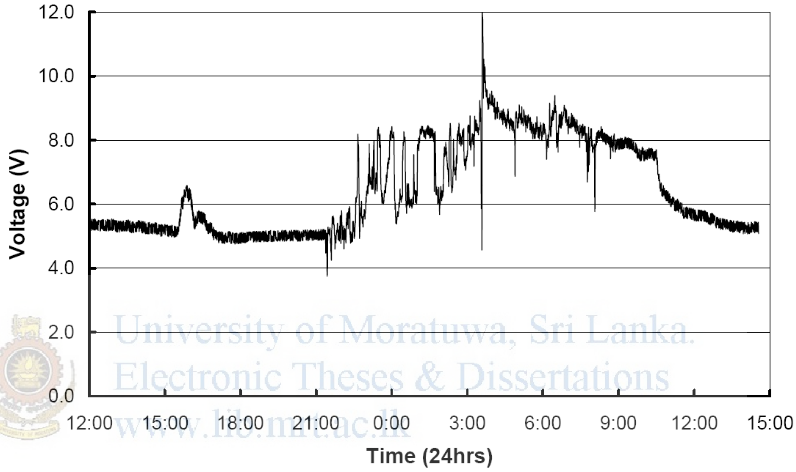
RESULTS

5.1 Observations Made with Static Field Detector

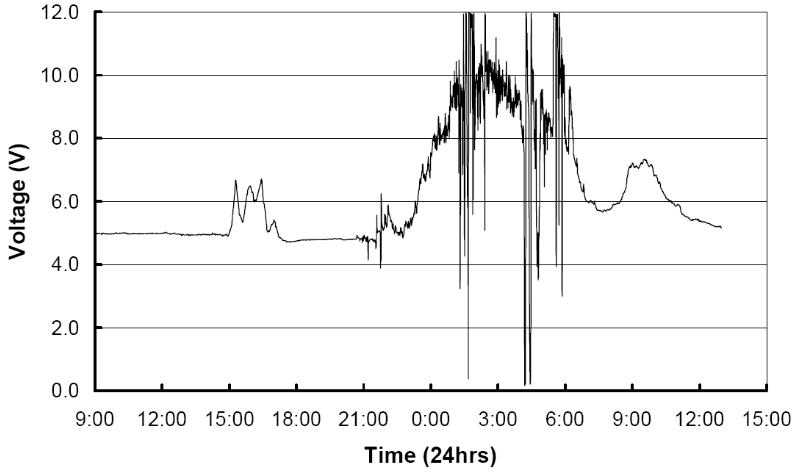
Some observations made with the static field detector with different conditions are shown in the following figures. Figure 5.1 shows the variation of the output of the device under fair weather conditions, when there is a close by thunderstorm and when there is an overhead thunderstorm.



(a)



(b)



(c)

Figure 5.1 – Observed output variation of the static field detector under different weather conditions.

(a) Under fair weather conditions (26th September 2006)

(b) When there is a close by thunderstorm (1st October 2006)

(c) When there is an overhead thunderstorm (10th October 2006)

5.2 Observations Made with the Transient Detector

In this sub section, observations made during the period of 190 days from November 8, 2006 to May 16, 2007 in three sites, Colombo, Madapatha (12/4/2007 to 16/05/2007) and Kandy (12/4/2007 to 16/05/2007) using the transient detector are discussed. Table 5.1 shows a brief of the data collection.

Table 5.1 – Observation brief made with the transient detector

Description	Number of Days
Total period	190
Total thunder days reported in all sites	65

Figure 5.2 shows the distribution of the time between the time at which the alarm was released for the first time, *i.e.* detectable cloud flashes, and beginning of the close by thunderstorm, *i.e.* ground flashes during the entire period.

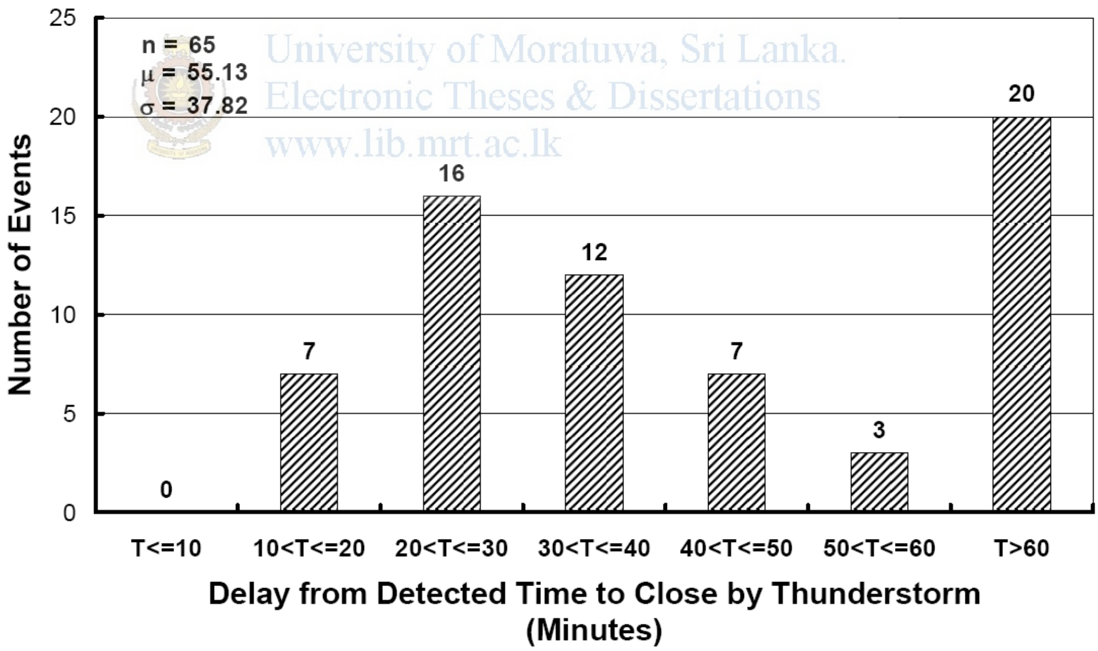


Figure 5.2 – Distribution of the time between the time at which the alarm was released for the first time and beginning of the close by thunderstorm (entire period).

Figure 5.3 shows the distribution of the same excluding the extreme delay readings observed during a low pressure system.

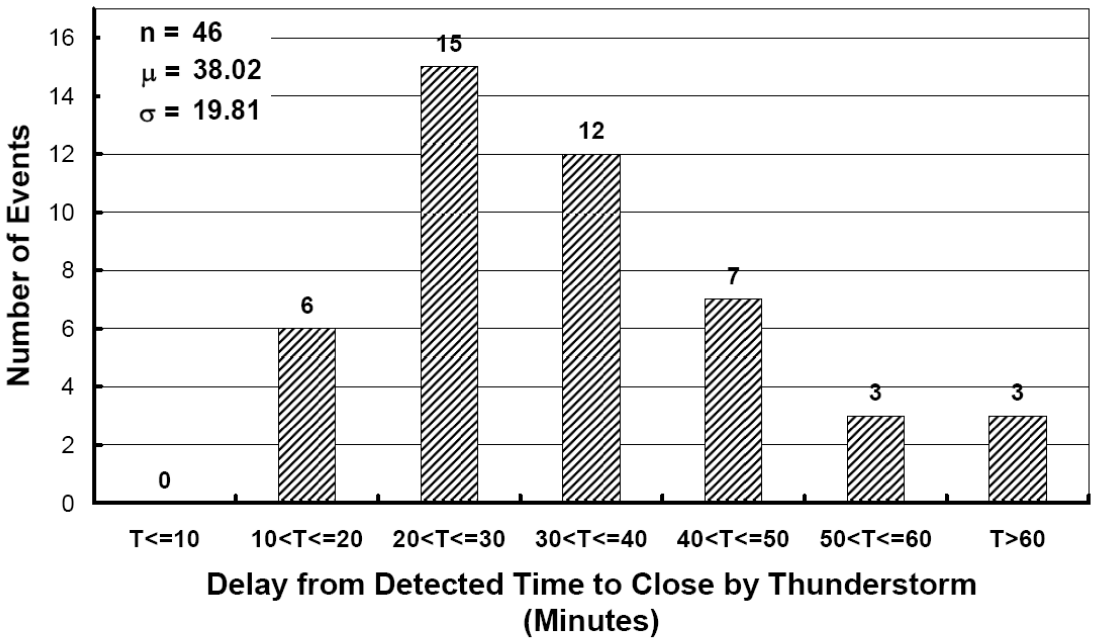


Figure 5.3 – Distribution of the time between the time at which the alarm was released for the first time and beginning of the close by thunderstorm (excluding extreme delay readings).

Figure 5.4 shows the distribution fitted to a Gaussian curve with the normal error values and goodness of the fit (a) and 95% confidence bounds for the function (b). Figure 5.5 shows the distribution fitted to a rational curve with quadratic numerator and a cubic denominator with the normal error values and goodness of the fit (a) and 95% confidence bounds for the function (b).

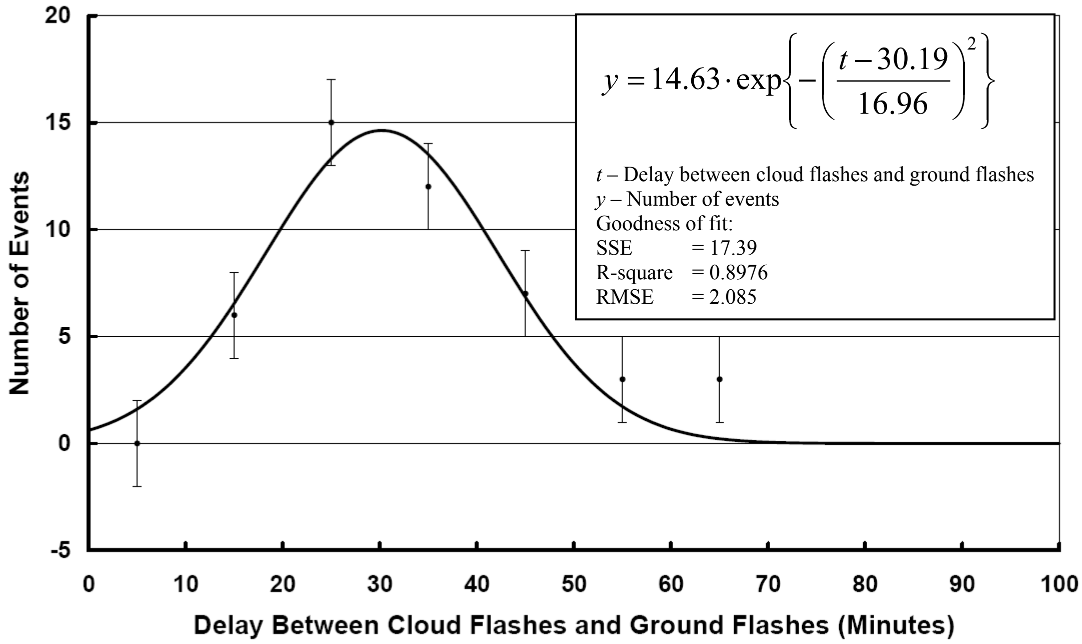
Although the 95% confidence bounds are wider for the rational fit, the parameters that give the goodness of fit, *i.e.* sum of square error (SSE), r-square value and the root mean square error (RMSE) shows that the rational fit is better than the Gaussian fit. Therefore it can be seen that the time between cloud flashes and ground flashes in Sri Lanka shows a distribution given by Equation 5.1 with a maximum at 27.52 minutes.

$$y = \frac{16.57t^2 + 4511t - 2.301\times 10^4}{t^3 - 37.4t^2 + 134.2t + 1.108\times 10^4} \qquad \textbf{(5.1)}$$

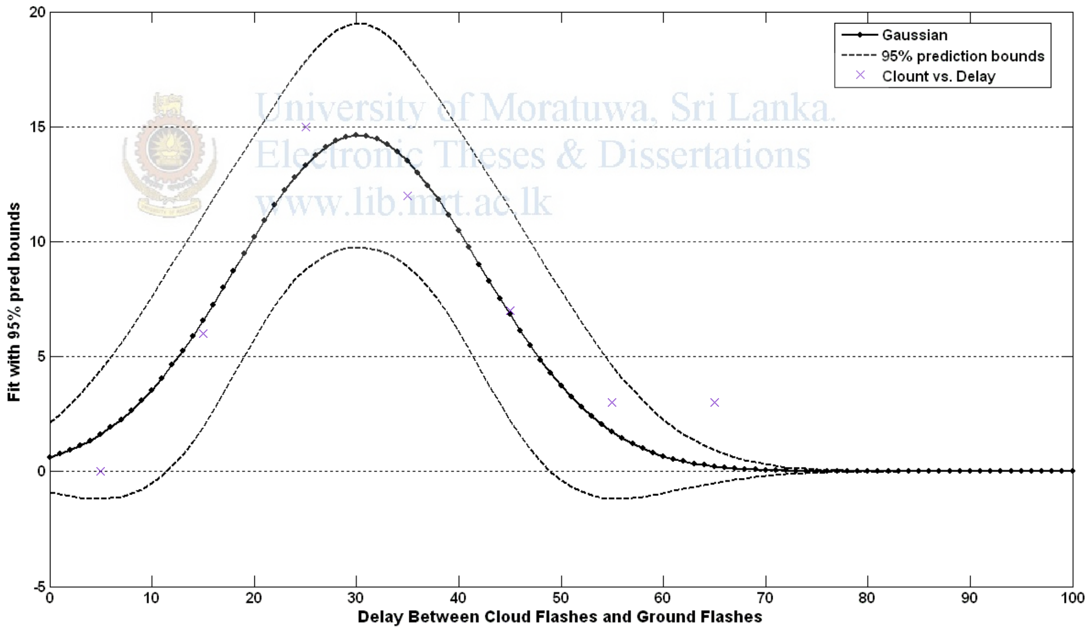
where, t – time between cloud flashes and ground flashes

y – number of events

If normal distribution is assumed, 0.95 cumulative probability occurs at 25.31 minutes. Therefore the transient detector can release a warning 25.31 minutes before the close by thunderstorm with 95% level of confidence.



(a)

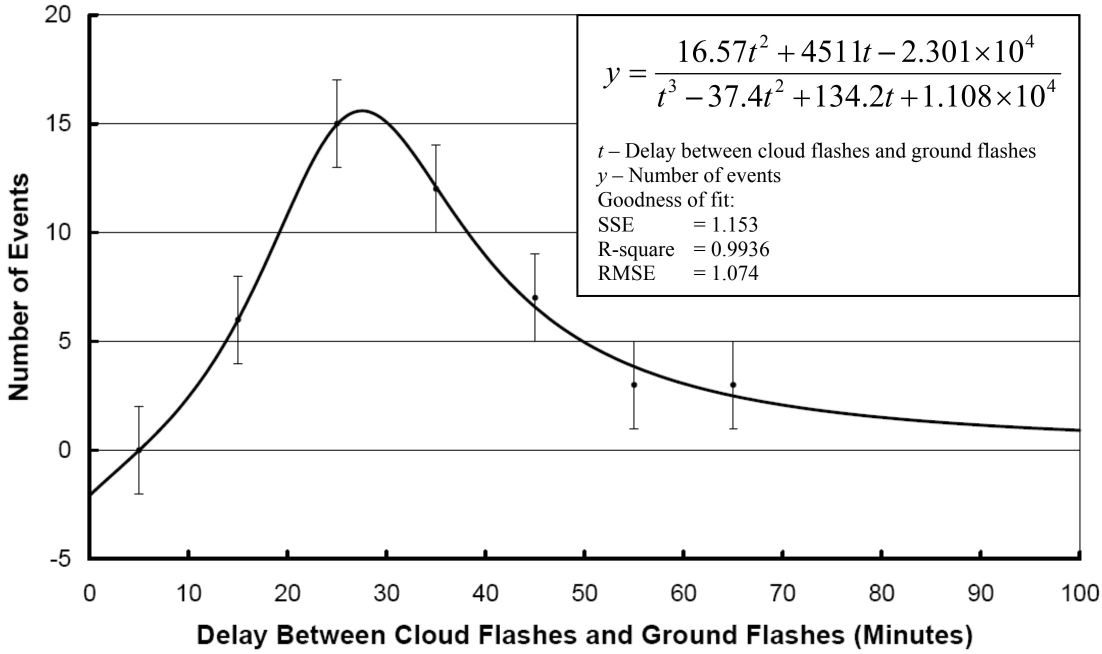


(b)

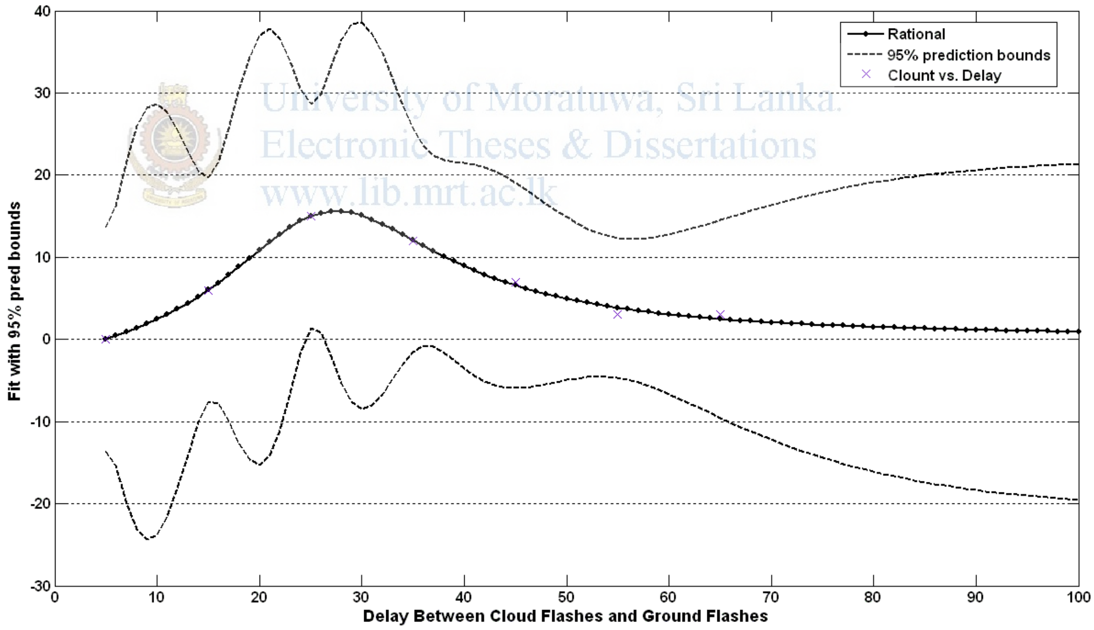
Figure 5.4 – Gaussian fit for the distribution of time between cloud flashes and ground flashes.

(a) Gaussian fit with error bars and goodness of fit

(b) Gaussian fit with 95% confidence bounds



(a)



(b)

Figure 5.5 – Rational fit for the distribution of time between cloud flashes and ground flashes.

(a) Rational fit with error bars and goodness of fit

(b) Rational fit with 95% confidence bounds

5.3 Comparison with Available Systems

The simplest lightning warning system available in the market, which can detect lightning at a distance of about 90 km away, costs about US$55 without tax, where as a hand held unit, which can detect lightning at a distance of about 60 km away, would cost about US$90 and that value is the manufacturer's price [11], [14]. Manufacture's prices for those two units in Sri Lankan Rupees are approximately Rs. 6000 and Rs. 10000 respectively. With taxes, the price would increase further. Both these units use electromagnetic radiation emitted by lightning strokes.

Similar unit costs about 15000 Sri Lankan rupees in the local market [18] and only a limited number of different products are available in Sri Lanka.

The static electric field detectors available in the market, field mills, cost about US$ 1800, *i.e.* about 200,000 Sri Lankan rupees.

The newly developed transient detector, which can predict a thunderstorm 25 minutes before the close by thunderstorm, costs about 1500 Sri Lankan rupees without rechargeable batteries and about 2500 Sri Lankan rupees with rechargeable batteries. That unit can be used as a hand held unit. The sensitivity of the transient detector can be further increased with an expense of increased false alarm probability. The entire warning system including the transient detector, static field detector, alarm unit and a battery backup, which has a further improved accuracy, costs about 5000 Sri Lankan rupees.

John Chubb and John Harbour [15] have improved the accuracy of their lightning warning system by using static electric field variation, dynamic electric field and electromagnetic noise in combination. However, as they are using a field mill to measure static electric field and a personal computer for alarm generation, the risk of direct lightning strike to the system and the cost are high.

The system designed by Fedosseeve Serghei and Samruay Sangkasaad [16] uses a computer algorithm to resolve the input signals and therefore a personal computer is incorporated. Therefore the cost of the system is very high.

CHAPTER 6

CONCLUSIONS AND FURTHER IMPROVEMENTS

The expectation of this project is to have a low cost lightning warning system to reduce the amount of human deaths and other property damages. In the same time, the system should be reliable.

After taking several field measurements, the aim was to develop a warning system using both environmental static electric field variation and radio frequency emissions due to lightning strokes.

The transient detector, which detects radio frequency emissions, costs about 2500 Sri Lankan rupees and with that unit only, a warning can be released 25 minutes before a close by thunderstorm with 95% level of confidence.

The static field detector measures the environmental vertical static electric field. Output of the static field detector deviates from the rest value by large values when a close by thunderstorm is there. The third unit, which derives the final warnings, detects whether the static field goes to extremes and/or whether transients are detected and releases the warnings accordingly. The static field detection further increases accuracy and reliability of the warning system.

The entire warning system has met with the requirements and aims of the project as the cost is only about 5000 Sri Lankan rupees and in the same time it can release a more reliable warning.

The time between the detectable cloud flashes and ground flashes obeys a distribution given by:

$$y = \frac{16.57t^2 + 4511t - 2.301\times 10^4}{t^3 - 37.4t^2 + 134.2t + 1.108\times 10^4}$$

where, t – time between cloud flashes and ground flashes

y – number of events, with the maximum at 27.52 minutes.

The distribution of the time between cloud flashes and ground flashes is shown in

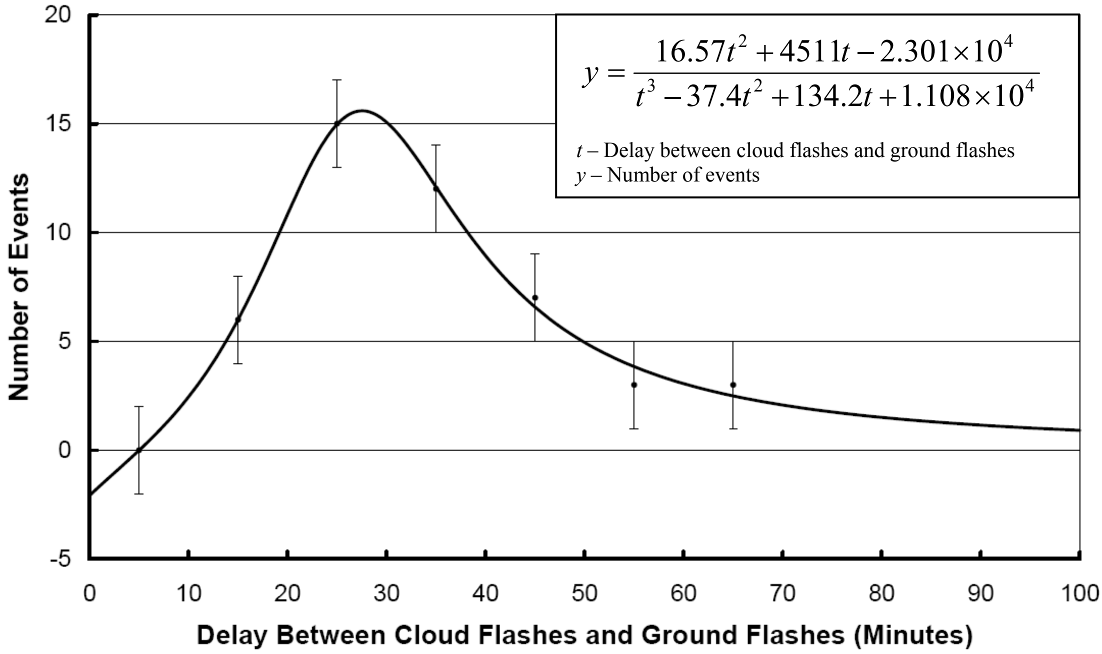


Figure 6.1 – Distribution of time between cloud flashes and ground flashes

As the aim of the project was to develop a low cost lightning warning system, the design was restricted to a simple circuitry. To improve the reliability of the system further, a microcontroller or a microprocessor based system can be designed. That is one of the future improvements that can be introduced to the system.

Another development which can be made to the system is to develop a USB based system which can be integrated with a personal computer or a laptop with software to determine warnings and log the data so that it can be used for research purposes as well. A system like that can be extended to an internet based lightning warning system.

There can be a lot more alternatives to a lightning warning system, but those will deviate from the scope of having a low cost product as a result. The alternative discussed above will be higher in cost when compared to the result of the project discussed in this thesis, but will definitely increase the level of accuracy and reliability. Keeping the cost of the final product as less as possible should be the key aim of such project.

The immediate next extension of this work is to develop a low cost, microcontroller based hand held lightning warning system.

CHAPTER 7

LIST OF PUBLICATIONS

1. K.N. Abhayasinghe and D.A.I. Munindradasa, "Low Cost Lightning Warning System", IX SIPDA (International Symposium on Lightning Protection), to be held from 26th – 30th November 2007 in Brazil.

   Status: Abstract accepted, full paper under review.

2. K.N. Abhayasinghe and G.A.C. Gomes, "On the Correlation Between Cloud Flashes and Ground Flashes of a Thundercloud System in Colombo", To be submitted to the 3rd Environmental Physics Conference, to be held from 19th – 23th Feb. 2008, Aswan, Egypt.

   Status: In preperation

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   Status: In preperation

APPENDIX I

The electric field strength E at a distance r from a positive point charge in air or vacuum is

$$E = \frac{Q}{4\pi\varepsilon_0 r^2} \quad Vm^{-1} \tag{A.1}$$

where,

Q – Point charge

ε_0 – dielectric constant of air

outwards from the charge. The direction of the electric field strength is in the opposite direction, i.e. into the charge, if the point charge is negative.

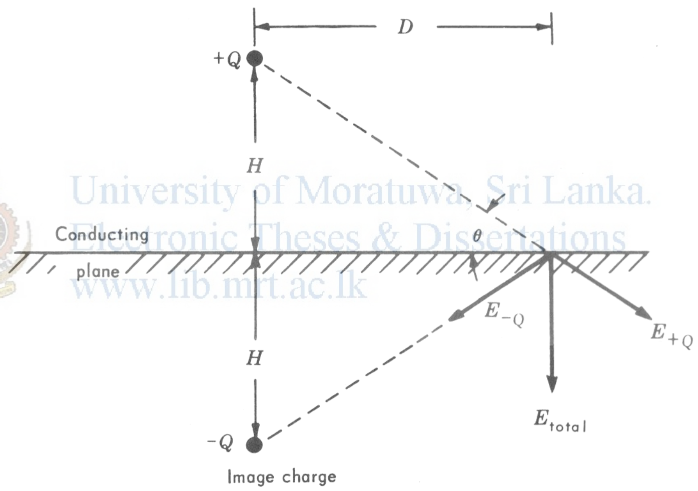

Figure A.1 – The electric field intensity calculation [5].

The earth can be considered as a flat conductive plane and the thunderstorm charge centers as point charges or as spherically distributed charge distributions [5]. Figure A.1 shows the charge configuration which can be used to calculate the electric field strength due to a positive point charge $+Q$ located at a distance H above a conductive surface. By the method of electrical images, the effect of charges induced on the conductive surface can be replaced by eliminating the surface and replacing it with a negative point charge $-Q$ located at a distance H below the surface. The magnitude of the electric field intensity at the surface at a distance of D down the surface due to each charge is given by

$$E = \frac{Q}{4\pi\varepsilon_0\left(H^2 + D^2\right)} \qquad \textbf{(A.2)}$$

Using the vector addition and that $\sin\theta = H/(H^2 + D^2)^{1/2}$, the total electric field can be found as

$$E_{total} = \frac{2QH}{4\pi\varepsilon_0\left(H^2 + D^2\right)^{3/2}} \qquad \textbf{(A.3)}$$

Using equation (2.3) the electric field strength at the ground level due to three regions of charge, *P*, *N*, and *p*, within a model thunder cloud can be calculated. By taking the values *P=40C* at 10km height, *N=-40C* at 5km height and *p* at a height 2km, the total electric field is given by,

$$E = 1.8\times10^{10}\left[\frac{2\times10^3 p}{\left(4\times10^6 + D^2\right)^{3/2}} - \frac{2\times10^5}{\left(2.5\times10^7 + D^2\right)^{3/2}} + \frac{4\times10^5}{\left(10^8 + D^2\right)^{3/2}}\right] \; Vm^{-1}. \qquad \textbf{(A.4)}$$

Figure A.2 shows the variation of the electric field at the ground level as *D* varies.

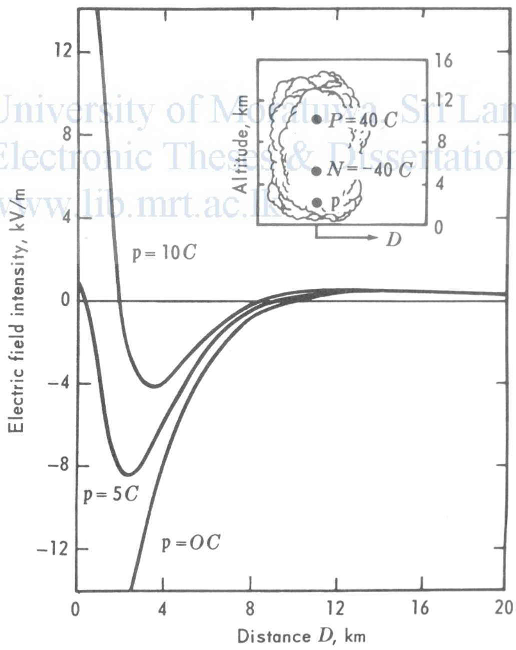

Figure A.2 – Electric field intensity at the ground vs. distance [5].

APPENDIX II

The relationship of the voltage measured from a plate antenna to the potential at the cloud can be calculated as follows [5]. In the absence of any loading of the antenna (Figure B.1 a) the electric field near the antenna is equal to the electric field without the antenna, E, and the potential difference between the ground and antenna is $V_g=Eh$ where h is the antenna height. The stray capacitance between antenna and cloud is C_c and between antenna and ground is C_g, where $C_g>>C_c$. If the potential difference between the cloud and the ground is V then,

$$V_g = V\frac{C_c}{C_c + C_g} \tag{B.1}$$

and since $V_g=Eh$, V can be obtained by

$$V = Eh\frac{C_c + C_g}{C_c} \tag{B.2}$$

When a measuring circuit is attached to the antenna as shown in Figure B.1 b, a potential v is measured which is less than V_g because of the loading to the antenna by the circuit (RC). If we assume that R is very large impedance compared to C, then the effect of R can be neglected and only the effect of C should be taken into account when calculating v. Then v can be calculated as follows.

$$v = V\frac{C_c}{C_c + C_g + C} \tag{B.3}$$

By substituting the value for V from equation (B.2)

$$v = Eh\frac{C_c + C_g}{C_c + C_g + C} \tag{B.4}$$

Since $C_g>>C_c$, equation (B.4) can be approximated as

$$v \approx Eh\frac{C_g}{C_g + C} \tag{B.5}$$

The measured voltage is proportional to the electric field E. The proportionality constant can either be measured or calculated. The effect of R allows v to decay with a time constant approximately RC and by adjusting the value of R, the response rate can also be adjusted.

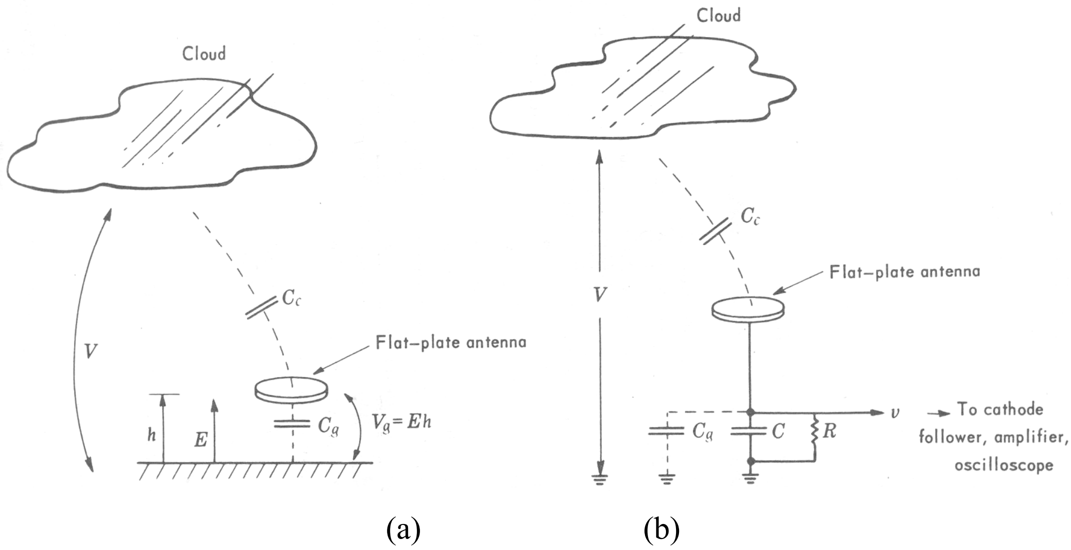

Figure B.1 – (a) Flat-plate antenna not attached to electronics

(b) Flat-plate antenna with associated electronics [5].

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