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.

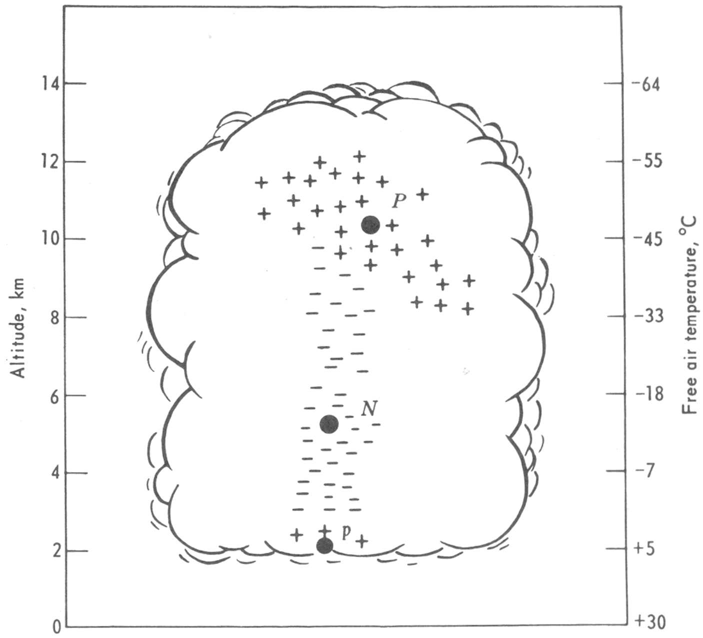


Figure 2.1 – Probable charge distribution of a thundercloud [5].

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.

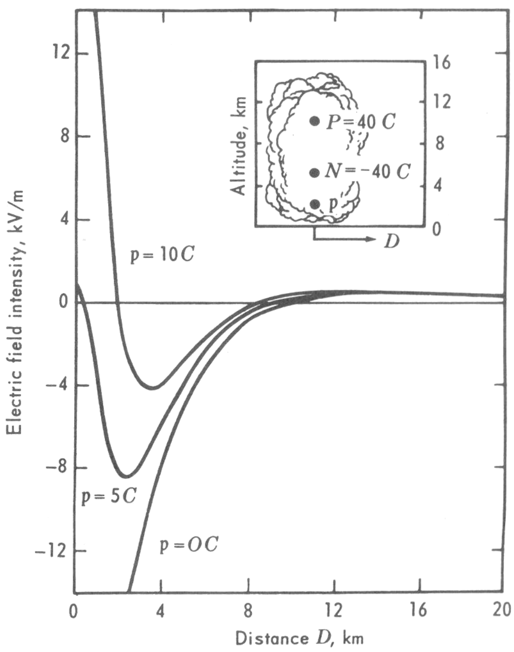


Figure 2.2 – Electric field intensity at the ground vs. distance [5].

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.

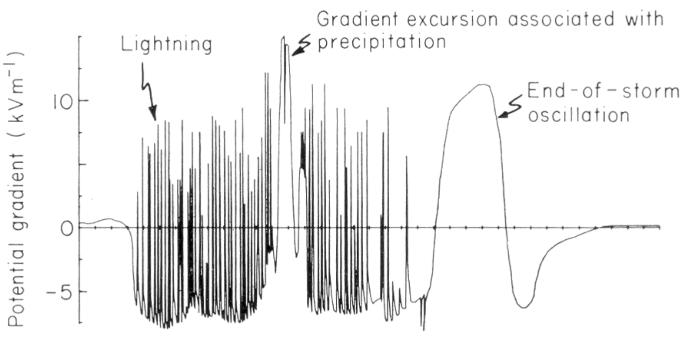


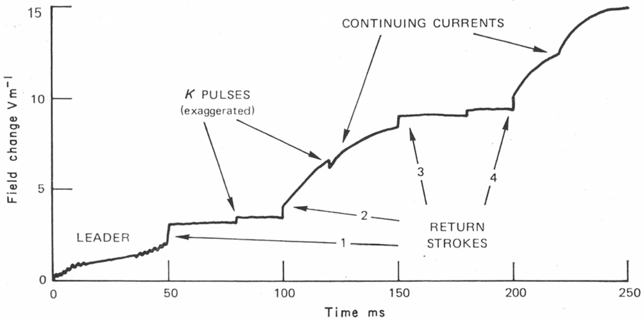
Figure 2.3 – Electric potential gradient beneath an isolated, horizontally stationary thundercloud [4].

2.5 Electromagnetic Fields Radiated by Lightning Discharges

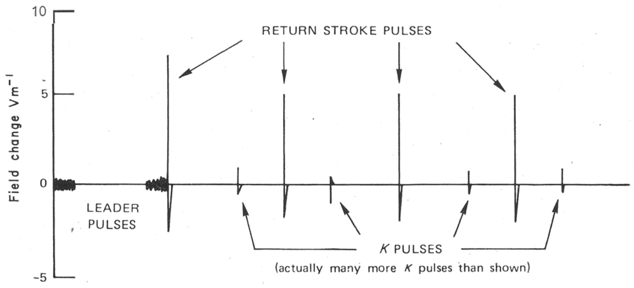
The transient electrical activity in thunderstorms generates electromagnetic radiation events known as atmospherics or spherics. The emitted radiation ranges from ultra low frequency (ULF) through ultra high frequency (UHF) [6]. A typical return stroke produces radiation with peak energy around 10 kHz [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].

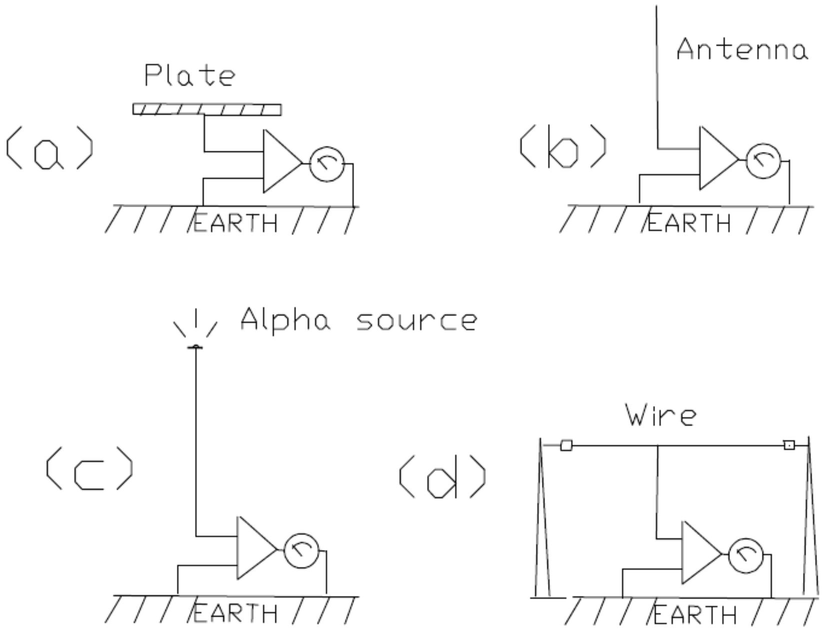
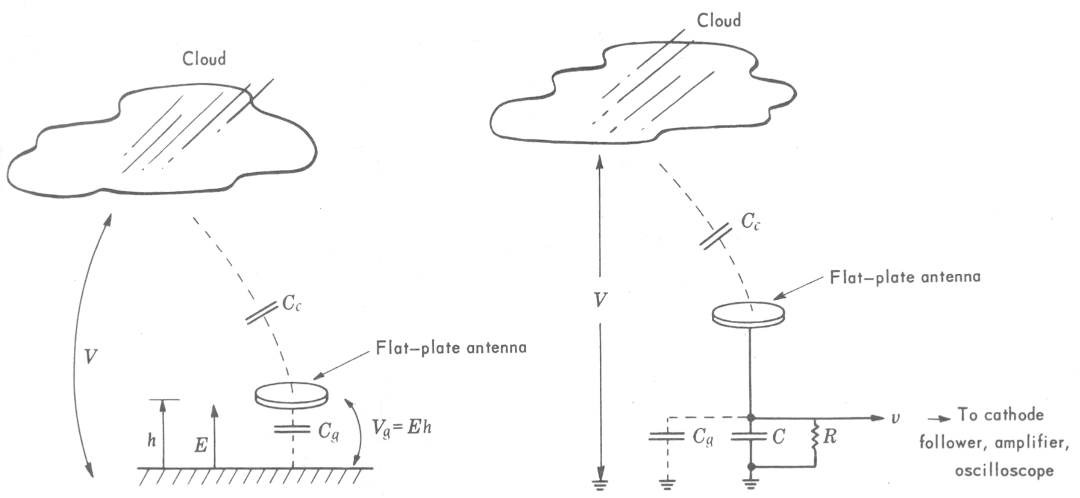


Figure 2.5 – Different antenna configurations for electric field measurements in the atmosphere [9] (a) Disc antenna (b) Whip antenna (c) Whip antenna with radioactive probe (d) Long wire antenna.

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.

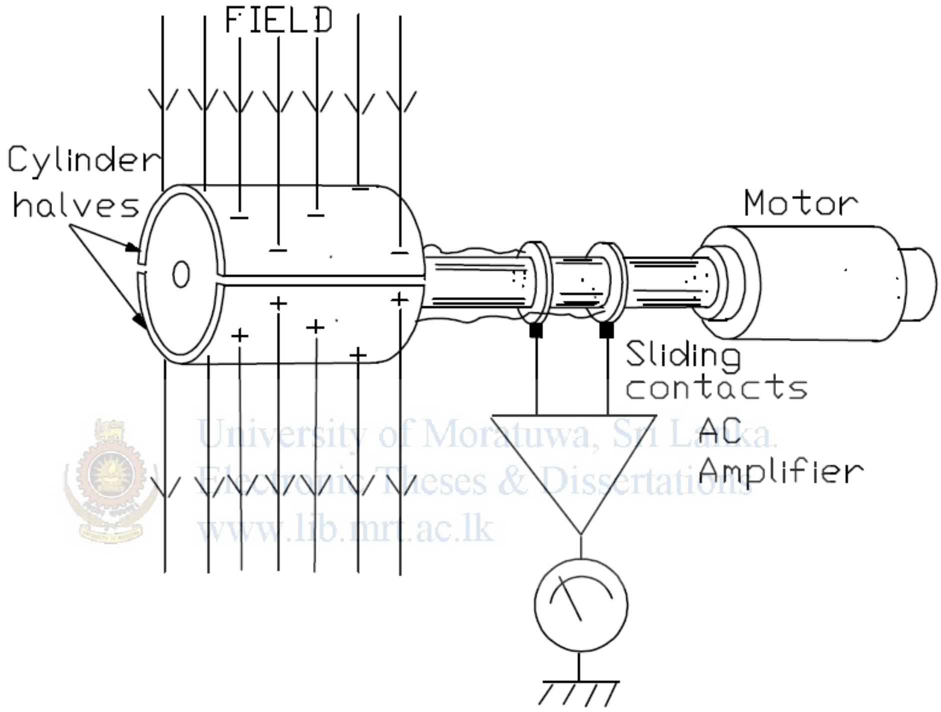


Figure 2.7 – Cylindrical electric field mill [9].

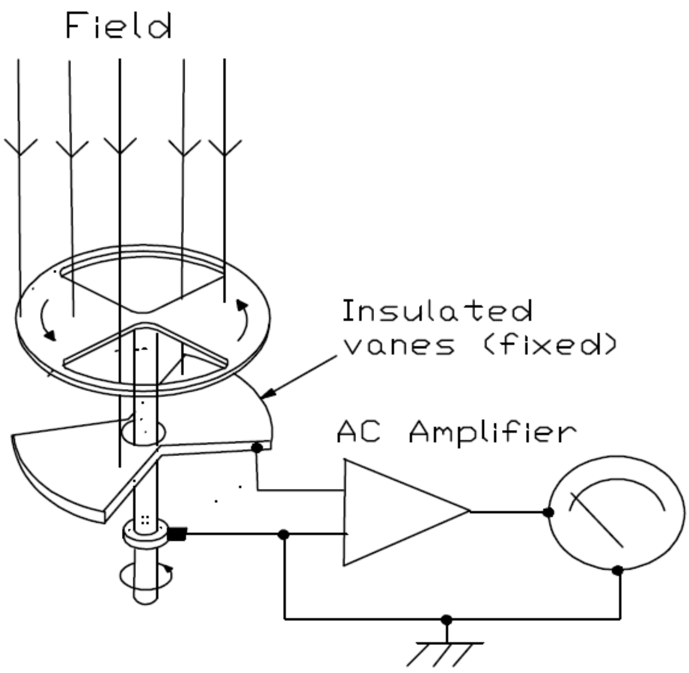


Figure 2.8 – Rotating shutter electric field mill [9].

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.

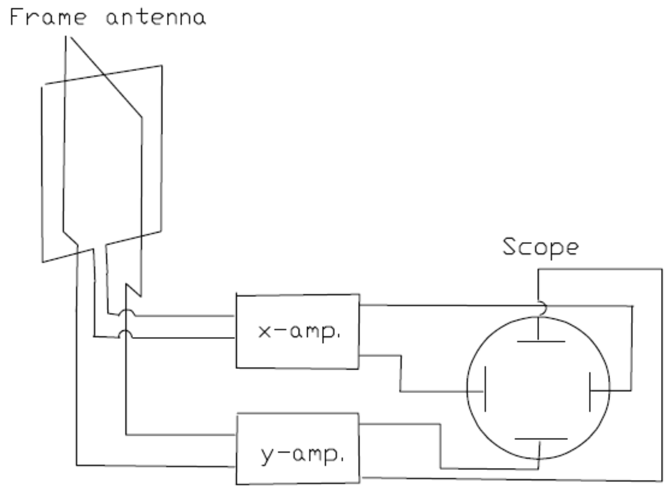


Figure 2.9 – Loop or frame antenna for lightning detection [9].

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.