# 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

$\varepsilon_0$ – 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.

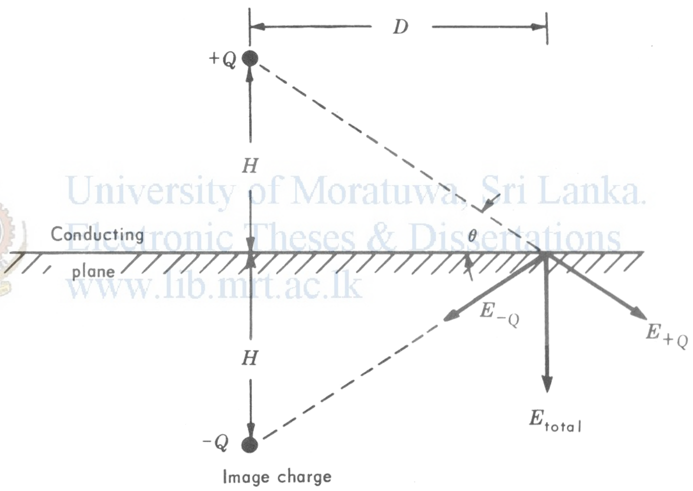




**Figure A.1** – The electric field intensity calculation [5].

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.



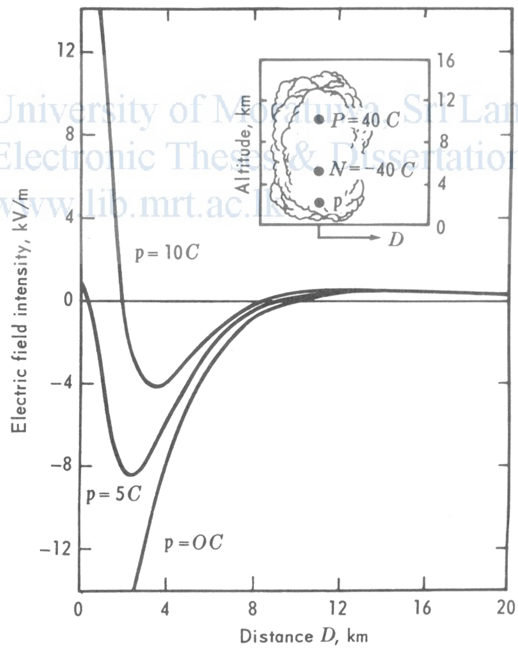



**Figure A.2** – Electric field intensity at the ground vs. distance [5].

# 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,

$$V_g = V\frac{C_c}{C_c + C_g} \qquad \textbf{(B.1)}$$

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

$$V = Eh\frac{C_c + C_g}{C_c} \qquad \textbf{(B.2)}$$

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.



$$v = V\frac{C_c}{C_c + C_g + C} \qquad \textbf{(B.3)}$$

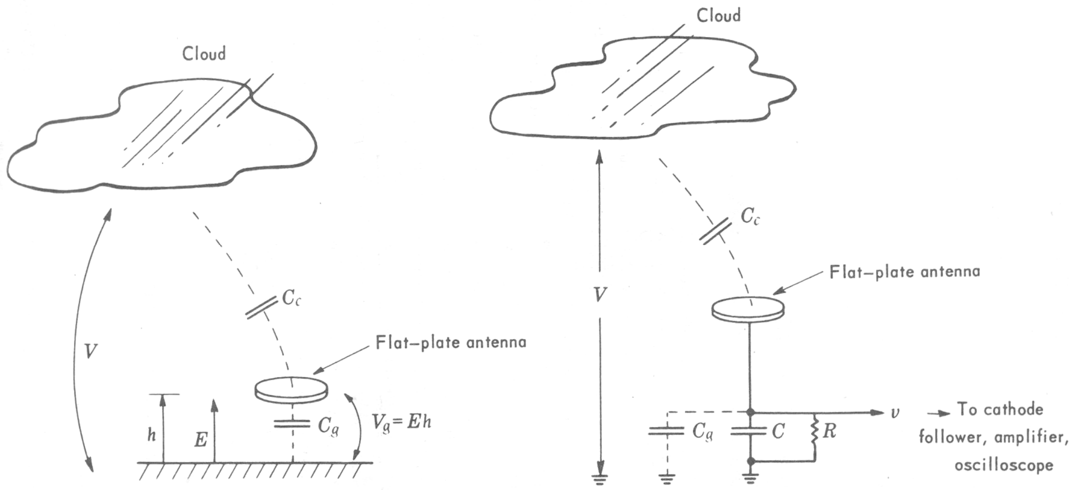
By substituting the value for $V$ from equation (B.2)

$$v = Eh\frac{C_c + C_g}{C_c + C_g + C} \qquad \textbf{(B.4)}$$

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

$$v \approx Eh\frac{C_g}{C_g + C} \qquad \textbf{(B.5)}$$

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.




(a) (b)

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

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

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