ISSN : 0974 - 7451 Volume 8 Issue 11

Environmental Science
An Indian Journal

Current Research Paper

ESAIJ, 8(11), 2013 [442-452]

Design and fabrication of an electrometer for the measurement of atmospheric potential

S.Manu, C.Panneerselvam*, K.U.Nair, S.Gurubaran
Equatorial Geophysical Research Laboratory, Indian Institute of Geomagnetism,
Krishnapuram, Tirunelveli 627 011, (INDIA)
E-mail: panneer.iig@gmail.com

ABSTRACT

The vertical atmospheric electric field may be sensed by using a passive antenna, which is charged slowly by exchanging the charges in the atmosphere. The potential of the atmosphere is obtained by the measurement of potential difference between the antenna and earth's surface, which is same as the atmospheric potential. In case of a passive antenna at 1m above the surface, the voltmeter system attached with the antenna system and it is operated over a typical input range of ± 500V. This voltage is generated by a floating voltage generator. The input bias current used in this system is of the order of nearly 10^{-14}A with an input resistance of $\sim 10^{15}$ Ω. This combination must be considered in this circuit is to provide an appreciably higher resistance than atmospheric resistance. In this passive antenna system a high voltage guard is also desirable. A direct method for measuring the atmospheric electric field is used by Electric Field Mill (EFM -100) and Field Mill. The Field Mill needs 230 V AC for running the motor, regular maintenance is required. The above instruments coast high and cannot be used during severe weather condition like high wind speed, rain, lightning snowfall and drifting sand. The passive antenna can be operated any meteorological conditions with 24V battery-powered in any remote place with minimum maintenance. Damages to the electrometer due to severe electrical storms can be cheaply repaired.
© 2013 Trade Science Inc. - INDIA

KEYWORDS

Atmospheric electric field;
Global electric circuit;
Fairweather;
Air-earth current.

INTRODUCTION

The scientific study of atmospheric electricity began in the 18th century, with investigation into the electrical nature of thunderstorms such as that famously undertaken by Benjamin Franklin, producing a spark from his aerial apparatus in 1750. Realisation that the atmosphere was electrified even in fair weather was made by the French botanist and physicist L.G. Le Monnier[21] who reproduced Franklin's experiment with an aerial in 1752 (although he removed the grounding pole from the aerial and placed some dust particles near the apparatus to investigate electrostatic attraction). This positive atmospheric charge was also found by John Canton in 1753. Le Monnier later went on to demonstrate the clear-sky electrification of the atmosphere and the diurnal variation of atmospheric electricity, by observing changes in the electrostatic attraction of a suspended wire insulated from the ground and exposed to the atmosphere. The English physicist Benjamin Wilson visited Le Monnier in Paris in 1753, who stated in a letter to the President of the Royal Society: The regular diurnal variation of electric field found by Le Monnier was also found by the Italian physicist Giambatista Beccaria[2]. An advocate of the scientific ideas of Benjamin Franklin, Beccaria determined that the atmosphere was positively charged with respect to the Earth during fair weather in 1775. Ten years later the French physicist Charles Coulomb discovered that atmospheric air was not a perfect electrical insulator as previously thought, but was in fact weakly conductive. Unfortunately however, this aspect of his work was ignored at the time.

In the 1860s William Thomson (later Lord Kelvin) invented the water-dropping discharger[19]. With this instrument it was possible to transport charge induced by an insulated tube in equilibrium with the atmosphere on water droplets from a reservoir, being collected by a metal funnel that was connected to an electrometer. That way charge could be measured from a collector whilst still being electrically isolated from the ground, allowing the atmospheric potential (and therefore electric field, given a further reference potential) to be determined. Kelvin recognized the necessity for regular recordings of atmospheric electricity, preferably simultaneously at different locations in the study of atmospheric electricity, following what was described by Kelvin as the "incessant" recordings by Beccaria a century before[20]. Almost fifty years later, C.T.R. Wilson developed a method to measure the air-earth conduction current density (J_C) at the surface in Kew Observatory, London[22]. By this time the presence of ions in the air was known and the Wilson instrument could also measure total air conductivity (σ) and potential gradient (PG) simultaneously, as described in detail by Harrison and Ingram[9]. This invention permitted the beginning of regular measurements of all three major variables in atmospheric electricity in the United Kingdom: air-earth current density, potential gradient and air conductivity. In addition to knowledge that natural radioactivity had sources in the ground that ionized the air, a balloon flight in 1912 by Austrian physicist Victor Hess carrying an ionization chamber demonstrated that ionization rate actually increased with height (after an initial decrease), demonstrating that the ground was not the only source of ionization[11]. The extra-terrestrial source of this ionization was determined to be cosmic radiation, with ionization rate increasing with height as the absorbing mass of atmosphere above decreased. The cosmic origins that produced an increased ion production rate (and therefore air conductivity) with height offered an explanation in addition to decreased aerosol concentration with height for the results from previous balloon flights measuring atmospheric electrical parameters (e.g. Gerdien[5,6]), that noticed an increase in conductivity and decrease in potential gradient with height.

Worldwide thunderstorm activity is believed to maintain the global electric potential between the ionosphere and the earth's surface[24]. Tropical thunderstorms are considered as the main source for the electric field in the lower atmosphere, drawing current upward to the ionosphere. In this way, the global thunderstorm activity is able to maintain a time varying electric potential difference of nearly 300 kV, directed downward between the equipotential surfaces of the ionosphere and the ground[1]. The atmospheric vertical electric field, conductivity and total current density are the three closely related parameters of atmospheric electricity that are required to obtain an adequate description of the fairweather atmospheric electric circuit[12].

The study of Global Electric Circuit (GEC) can help in understanding the electrical environment of the earth's atmosphere. This approach can provide a good framework for exploring interconnections and coupling of various regions of the atmosphere. It can also provide information on the solar-terrestrial weather relationship and offers possibilities for exploring one of the traditional scientific problems, namely, that of associating changes in surface weather with the solar output[10]. Thunderstorms are electrical generators whose global activity provides a current output that maintains a vertical potential difference between the ground and ionosphere. Willson's classical model of global electric circuit is shown in Figure 1.

There is no thunderstorm activity at high latitudes; therefore atmospheric currents at these regions can be regarded as a closure segment of the global electric circuit. The global circuit involves lower atmosphere generators and the upper atmospheric generators, the most important of which are in polar caps. It is a desert like climate with clear skies, very low atmospheric aerosol content. In summer the prevailing winds are light, flowing in a nearly constant direction, and are relatively free of turbulent and convective motions[13]. Thus the sources of conductivity fluctuations that produce space charge fluctuations and meteorological noise on the measured atmospheric electrical parameters when moved by winds are minimized compared to low-latitude measurements. The vertical atmospheric electric field leads to a potential difference between the surface and any point in the air vertically above. In fair weather the atmospheric electric field is nearly 150 V/m at 1m above the surface and the potential increases positively with increasing in height.

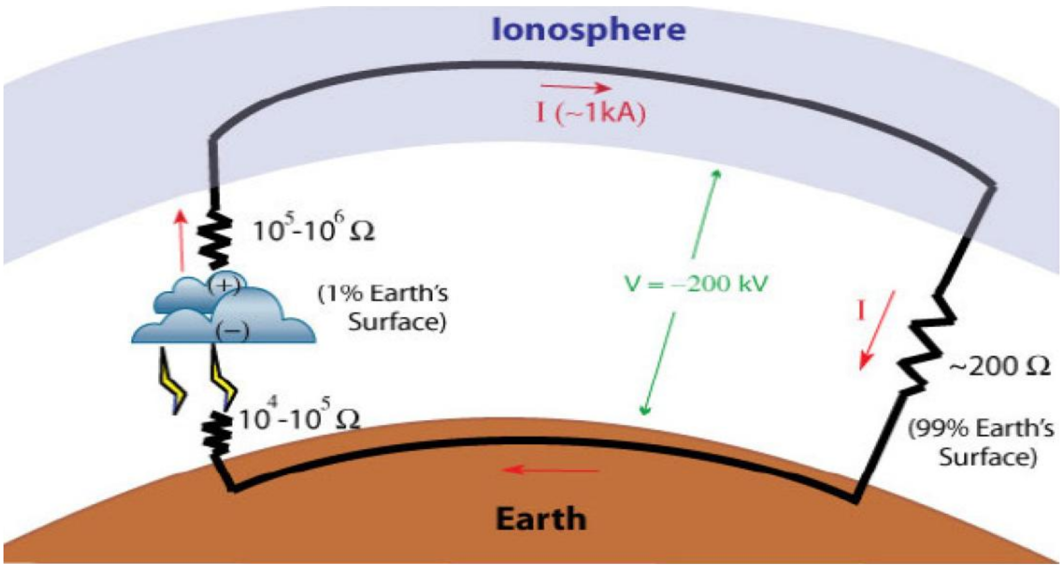

Figure 1 : The global electric circuit model by C.T.R.Wilson.

A device for sensing the atmospheric potential close to the surface is called passive antenna system. This introduces very little distortion only. This is a tensioned, long (20m) and fine (1mm diameter) horizontal wire, which is well insulated at each end. The passive antenna offers spatial averaging and requires no geometrical corrections. But it requires an ultra high input impedance and low leakage current from the measurement circuitry attached.

SITE DESCRIPTION

The passive antenna system initially tested at Equatorial Geophysical Research Laboratory (EGRL), Indian institute of Geomagnetism, Tirunelveli. After successful satisfactory functioning of the system we have installed the passive antenna system at Tirunelveli and at Maitri, Antractica, which is a high latitude station. Presently we are operating the passive antenna system simultaneously at both the stations.

Measurements of the potential gradient (PG), air-Earth conduction current density (J_C) and total conductivity (σ) made at Equatorial Geophysical Research Laboratory (EGRL), Tirunelveli (8.7°N, 77.8°E), which is a regional center of Indian Institute of Geomagnetism, Mumbai under Department of Science and Technology, Government of India. All of these parameters have been recorded simultaneously since 1995 onwards[17]. The environmental and meteorological conditions at the measuring site and the orography relevant observation on atmospheric electricity and data selection reported below One of our experimental site is EGRL (35 m above mean sea level) is more than 12 km from the twin towns of Tirunelveli and Palayamkottai towards the southeast. The site is about 35 km from the Bay of Bengal and the nearest hills of Western Ghats are at distances of nearly 45 km towards the west. The crustal part of the earth over the site is fixed on solid rocks, and hence does not support vegetation. The landscape is nearly flat and there are no trees in the vicinity of the sensors. The experimental site receives rainfall normally during the months of October and November when the northeast monsoon is active. Occasional rains occur during the summer when the southwest monsoon prevails in the Indian subcontinent. Scanty rainfall over most of the year in this region permits a large number of atmospheric electricity measurements to be made. Being in the tropics, this region is under the influence of convection that is expected to be severe during the late spring and early summer months (April–June).

In 1999 we have started GEC experiments at Maitri, Antarctica with the same instruments which is operational at EGRL. The Indian Antarctic station, Maitri is located in the Schirmacher oasis in the Dronning Maud Land, East Antarctica (117 m above the mean sea level). Antarctica has only around 2% of its area that is free from ice. The nearest steep cliff of the east-west trending glacier on the southern side of the station is more than 700 m away from the station and is 300 m in height. The snow-covered surface during summer season was more than half a kilometer away from the station. The instruments were installed on barren land near the station. The surface of the station area is mainly covered by sandy and loamy sand types of soil. The solar zenith angle at Maitri varies from 48° to 88° during summer months. There was no sunset till the third week of January, but periods of short nights slowly increased during February. The variations in surface meteorological parameters were measured by automatic weather station which is installed during this expedition. The cloud cover over the station occurs mainly under the influence of subpolar low-pressure systems and shows an alternating sequence of the sky changing from overcast to clear as the system moves away[3]. The passive antenna system installed at Maitri during 2008 and it is operated continuously round the year. From these atmospheric electrical measurements and those of standard meteorological parameters using Automatic Weather Station (AWS) data, it is possible to resent both an electrical "climatology" of the EGRL and a comparison work carried out between electrical and meteorological parameters. Additionally, inter-comparison of electrical parameters will be made and results compared to other instruments which one is measuring the same parameters with some other technique.

INSTRUMENTATION

The vertical atmospheric electric field may be sensed by using a passive antenna, which is charged slowly by exchanging the charges in the atmosphere. The potential of the atmosphere is obtained by the measurement of potential difference between the antenna and earth's surface, which is same as the atmospheric potential. In case of a passive antenna at 1m above the surface, the voltmeter system attached with the antenna system and it is operated over a typical input range of ± 500V. This voltage is generated by a floating voltage generator. The input bias current used in the system is of the order of nearly 10^{-14} A with input resistance of ~10^{15} Ω. This combination must be considered in this circuit is to provide an appreciably higher resistance than atmospheric resistance. In this passive antenna system a high voltage guard is also desirable. The output is given to the ADC and thus the potential can be measured. This system can be operated at a remote place with minimum power consumption. Damages to the electrometer due to severe electrical storms can be cheaply repaired.

The antenna consists of 20m of 1mm diameter tined copper wire, suspended horizontally between short metal masts. At each end there are porcelain egg insulators, and PTFE fixing under steady compression at the masts. Sketch diagram of passive antenna shown in Figure 2. The insulators are regularly cleaned with isopropanol. A guard potential, which is close to the potential on the wire, is applied to the support wires at each end. This is to minimize the leakage through the insulators, which would occur if the support wires were merely grounded. As a precaution against the guard potential influencing the potential sensed by the antenna, the parallel cable that is carrying the guard signal to the far end of the antenna has an earthed screen.

SYSTEM DESCRIPTION

The antenna is connected, with a short wire made of same material as that of the antenna, through a UHF male connector to operational amplifier LMC 6042, which is configured as a unity gain follower. LMC 6042 is a low input bias current operational amplifier, which is the input amplifier, and OP-97 is used as driver stage for the source amplifier. The input potential is connected, via a PTFE standoff, to the input of LMC 6042. A 9V battery powers LMC 6042, with the 0V reference set at 1.2 V above the battery negative supply by TC04. This ensures an adequate performance by LMC 6042 around 0 V. The data sheet of the LMC 6042 shows that for positive input voltages, the ultra low bias current (nearly 1fA) is maintained which can otherwise increase 9by the order of magnitude) for negative input voltage. Thus, by ensuing that the input voltages to LMC 6042 will always be positive at start-up (for input voltages within the range ± HT), no large current will be drawn from the high-impedance source, which could otherwise lead to oscillation. If the input does fail due to large transients from nearby lightning discharges, for which its voltage slew rate and dynamic range will be inadequate, LMC 6042 may fail and can be cheaply replace. Instead of relying on a push-pull unity-gain output buffer stage, the output stage is taken directly from the internal integrator of the LMC 6042, which provides low output impedance and large gain. It is quite common to use large values of feedback resistance with amplifiers with ultra-low input bias current, like LMC 6042. When high input impedances are damaged, guarding of the IC is suggested. Guarding input lines will not only reduce leakage, but lowers stray input capacitance as well. Simplified block diagram shown in Figure 3.

To provide a low impedance output to a voltmeter or logging system the operation potential of LMC 6042 is reduced by a 100: 1. 100 MΩ potential divider (trimmed by high voltage transformer T1), and presented to the input of MAX 430, also a follower stage. Max 430 is a chopper stabilized amplifier (with a 1pA input bias current) so that any additional dc error is minimized. A low pass filter (C210 and R211) protects Max 430 from external short circuits. The negative supply of the output amplifier (Max 430) is taken from a voltage inverter ICL 7661. This work by first accumulating charge in a bucket capacitor connected between pin 2 and 4 and then transfers it into reservoir capacitor connected between pin 5 and ground. A third power supply bypass capacitor is recommended (0.1 μF to 10 μF). Internally there is a main signal path amplifier and a separate nulling amplifier in MAX 430. The main amplifier is in the primary signal path and is continuously connected to the external inputs. The nulling amplifier alternately corrects its own offset, and then of the main amplifier, as its input switches between the two compensating FETs in the input stage's bias circuitry. The offset values that drive these trim FETs are stored for the duration of the correction cycle on two internal capacitors. It also provides correction for CMRR, PSRR, and A_{vol} at low frequencies. Internal compensation and internal chopper removes all offset voltages and drift.

An isolated, high-tension supply generates approximately ± 500V (designated +-HT), which is supplied to two high-voltage MOSFETS Q1 and Q2 is wired as a source follower, operated at constant current (generated by Q2) to improve the linearity. OP-97 is a unity gain driver stage, which has frequency compensated for phase shifts caused by driving the considerable input capacitances of Q1, and the capacitance of the cable

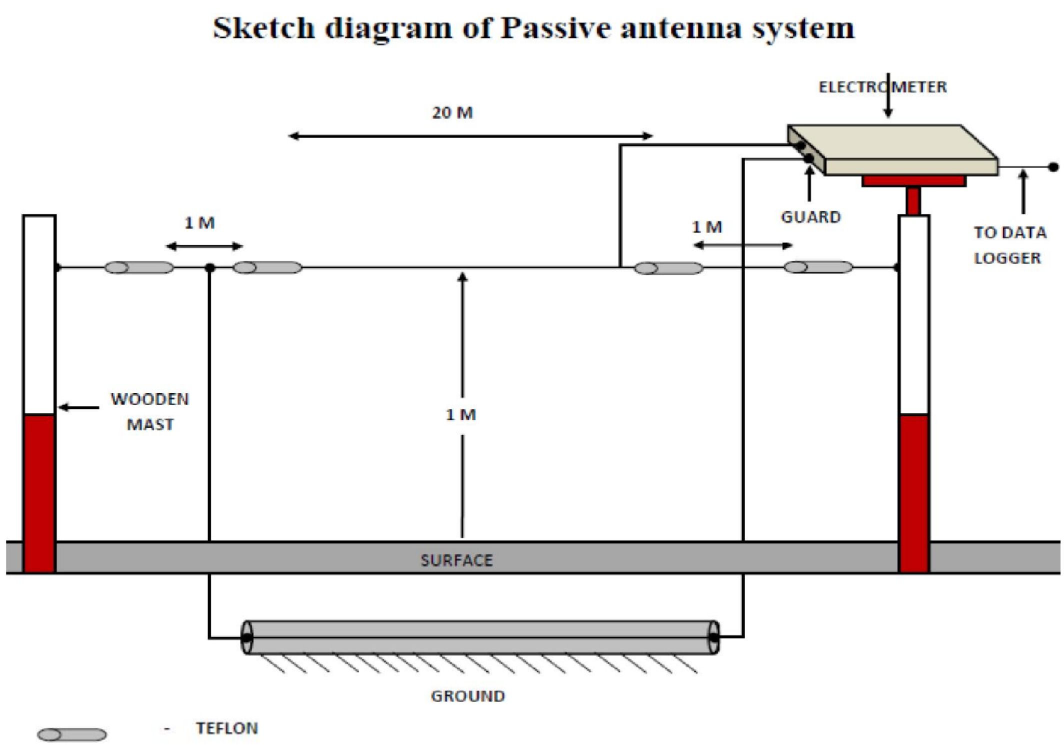

Figure 2 : Sketch diagram of passive antenna

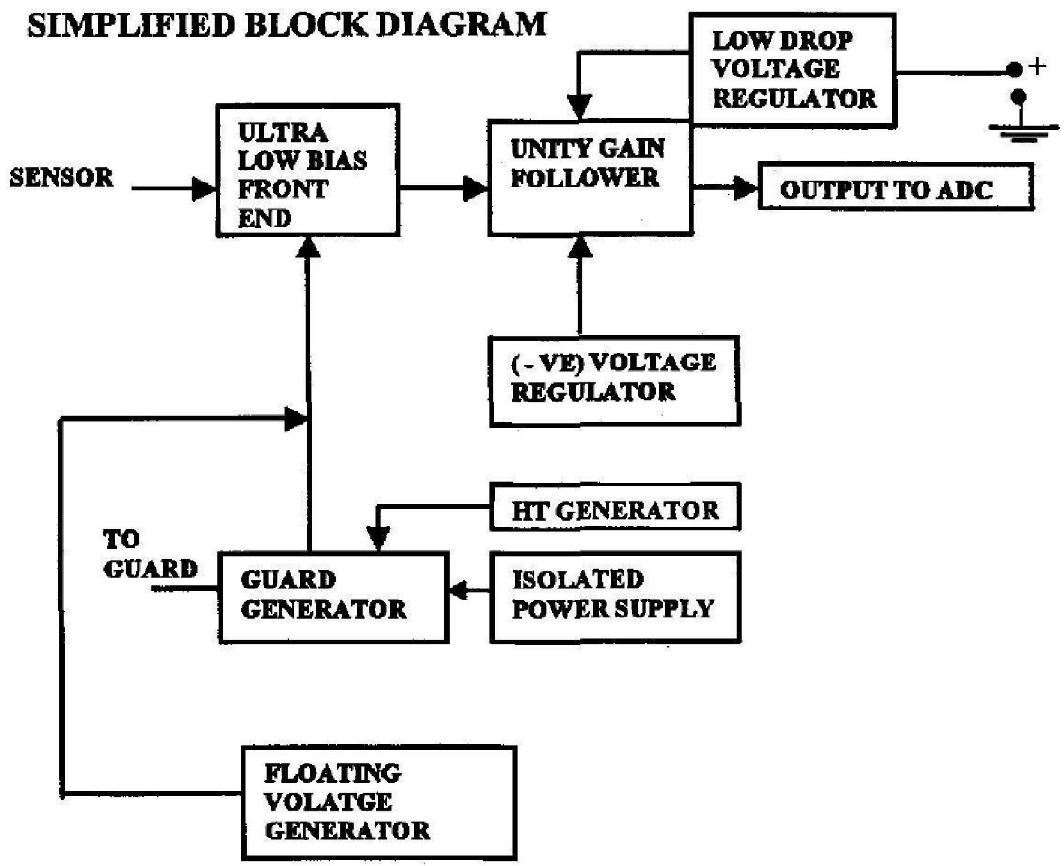

Figure 3 : Simplified block diagram of passive antenna system

to the antenna support wires (auxillary guard). To maintain the extremely high input impedance of OP-97, care must be taken in circuit board layout and manufacturing. Both surfaces must be clean and free of moisture. Even a clean PC board can have 100pA of leakage currents between adjacent traces. So that the guard rings should be used around the inputs, so that the leakage currents become minimal. OP-97 is powered from a transformer derived supply, but shares 0V connection with LMC 6042. This arrangement ensures that LMC 6042 (which has poorer power supply rejection than OP-97 at high frequencies) is powered from ultra-smooth supply, and OP-97 has adequate supply current to drive the capacitance load. OP-97 drives the gate of Q1, which is operated at a fixed drain-source current of 100 micro ampere set by the high-voltage constant current source of Q2 and LM334. (This is also serves to safely limit the current if the guard connections are accidentally grounded).

Constant current is established in LM334 with one external resistor and no other parts are required. The sense voltage used to establish operating current is 64mV at 25^0C and is directly proportional to absolute temperature (K). It generates a current with nearly +0.33 %^{o}C temperature dependence. The follower stage has a high effective gain: Q1 was observed to switch on at Vgs = 3.3V, i.e., an output swing of approximately 1kV for a Vgs variation of 0.2V. This high-voltage gain ensures good dc precision for the unity-gain combination of LMC 6042, OP-97, Q1, but requires a low pass filter for satiability. At start up, the potential on LMC 6042 and the input of the supply can differ by the full bipolar HT voltage (1kV). This can cause damage to LMC 6042. And hence a series resistor of 100 MΩ is connected to LMC 6042 to restrict the input current under voltage overload. A stable voltage offset is generated by the circuitry around TC04-LM7555 (IC 201). By adjusting the potentiometer T2, the output at pin 1 of LMC 6042 can made to precisely track the input 5. This output can also used to provide a local guard (body of the UHF female connector) potential for LMC 6042's input connection. The amplifier section circuit is shown in Figure 4. The main power for the unit is supplied from two 12V (7AH) rechargeable batteries, from which a 9V (± 4.5) is obtained using a 9V fixed regulator and is given to LM 6042. 10.5V supply is derived from, such as load dump (60V), when the input voltage to the regulator exceed the specified maximum operating voltage (33V type), the regulator will automatically shut down to protect both internal circuits and the load. The LM 2931 cannot be harmed by temperature mirror-image insertion. The power supply circuit is shown in Figure 5. The output of the output amplifier is connected to a PC based data logger with a 12 bit ADC to record the field variations continuously. From the circuit, the tracks are drawn using software called, PROTEL EASTEDIT 2.0. A printout of tracks is taken and from this printout the tracks is taken and from the printout the tracks are transplated into the PCB using screening technique. After this the PCB is etched using ferric chloride e copy of the printer output is shown in Figure 6.

RESULTS AND CONCLUSION

This system was tested by using a variable voltage supply operating over the range ± 500 V, and by high-impedance operation on the antenna. The measurement were compared with Keithley electrometer and is shown in Figure 7, which allows the ± 5 V span compared to ±500 V on the antenna and the frequency response curve shown in Figure 8. The measurements were taken

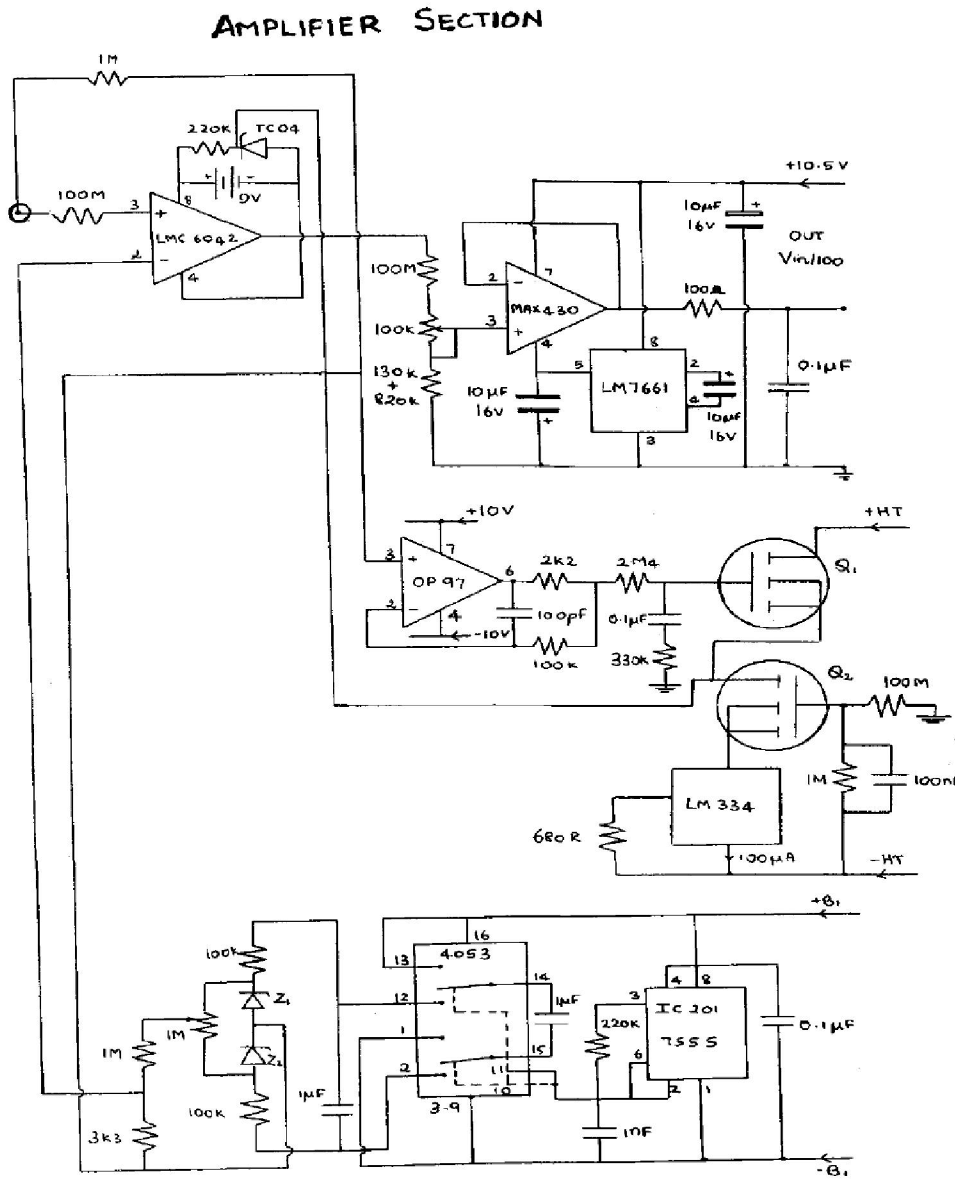

Figure 4 : The amplifier section circuit

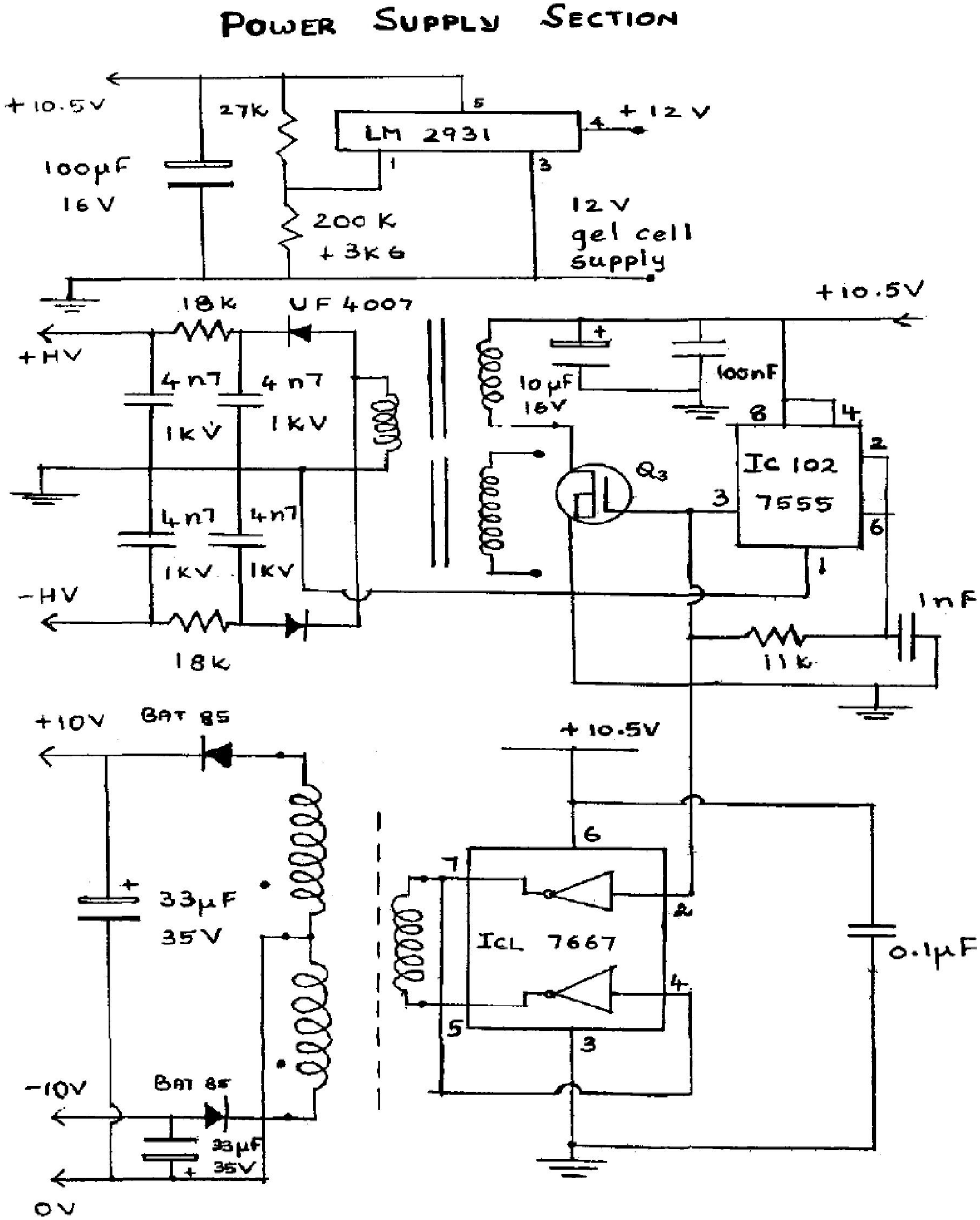

Figure 5 : The power supply section circuit

in the field during the clear sky days and meteorologically disturbed days and the measured atmospheric field compared with the other device which is measuring the same atmospheric electric field and have similar variation. These measured atmospheric electric field compared with the other atmospheric electrical parameters and it shows during the fair-weather days the atmospheric electric field and current shows similar variation that means the atmospheric conductivity during the fair weather days more are less table or constant, but in meteorologically disturbed days the variation of field and current always not similar because of atmospheric conductivity. During blizzard conditions due to high wind speed, falling and drifting snow brings different charges

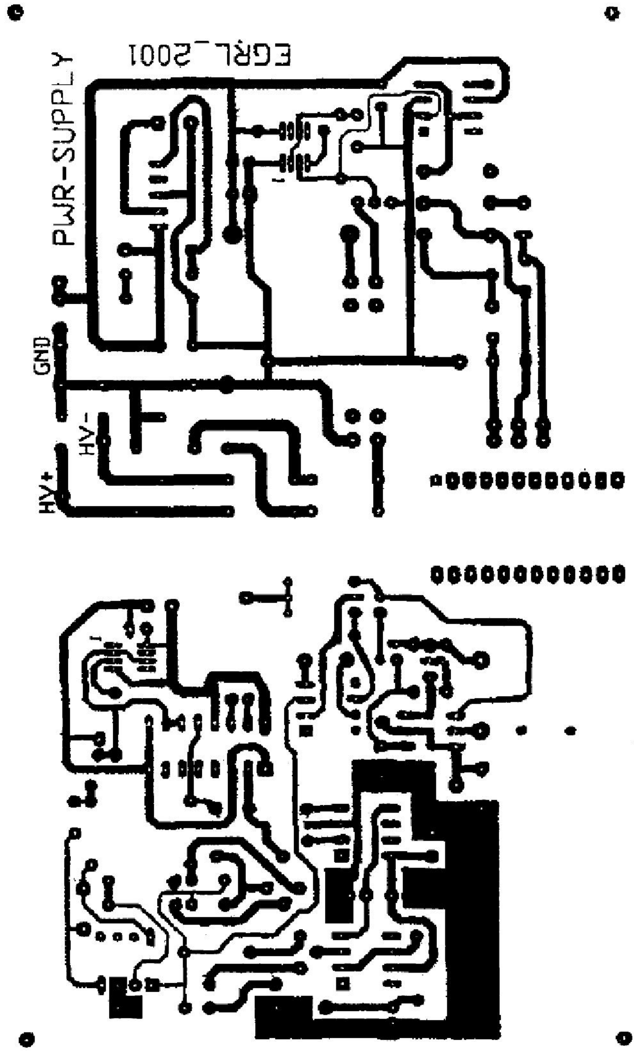

Figure 6 : Printed circuit board

near to the sensor complex. And hence, the conductivity changes according to the polarity of the charged particles. Due to the change of the conductivity the current and field changes occur. Diurnal variation of atmospheric electric field and current during fairweather day as well meteorologically disturbed days shown in Figure 9(a) and 9(b).

The relationship between observed in atmospheric current (I) and electric field (E) and column resistivity (*R*), given by $E = wV/R = w.I$, where w is the resistivity at the observation point, V is the total potential difference between the earth's surface and the atmospheric electric equalization layer, and I is the current. Though the field intensity depend strongly on the meteorological processes through its dependence on the local resistivity w, the current, given by $I = V/R$, is less sensitive to local changes in conductivity. However, changes in

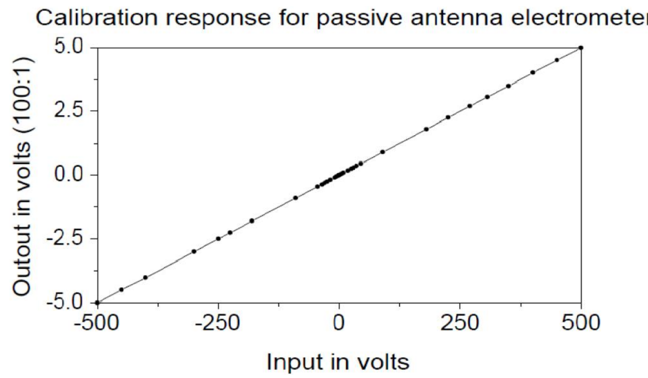

Figure 7 : Voltage response curve

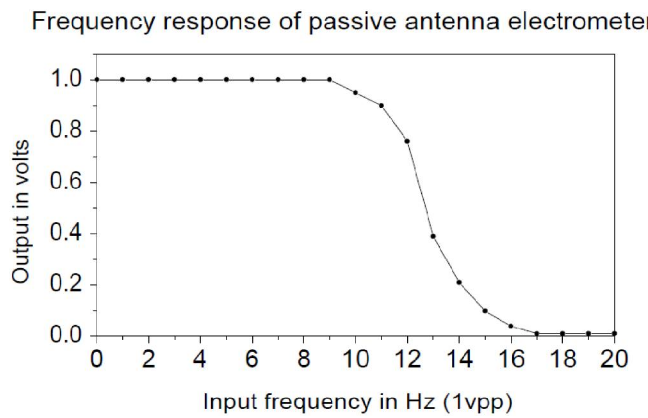

Figure 8 : Frequency response of passive antenna electrometer

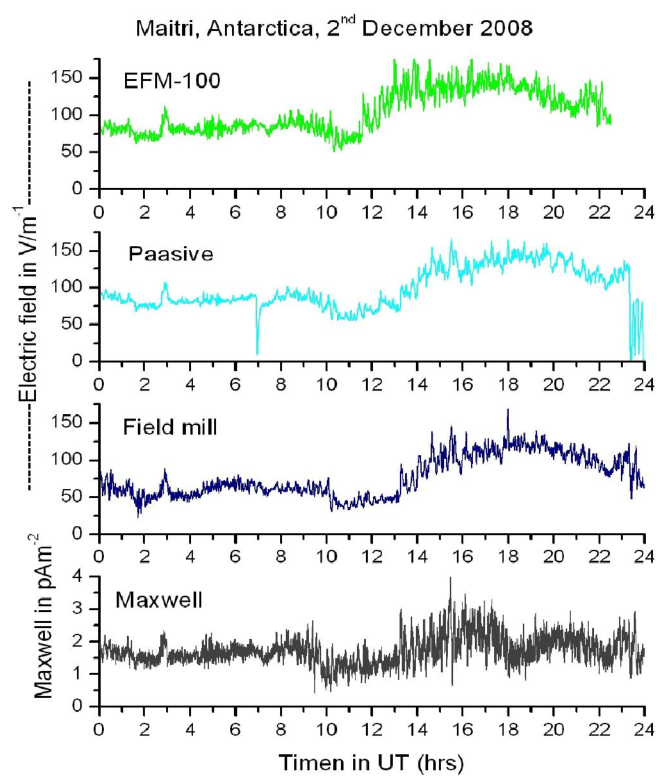

Figure 9(a) : Variation of GEC parameters during fairweather day

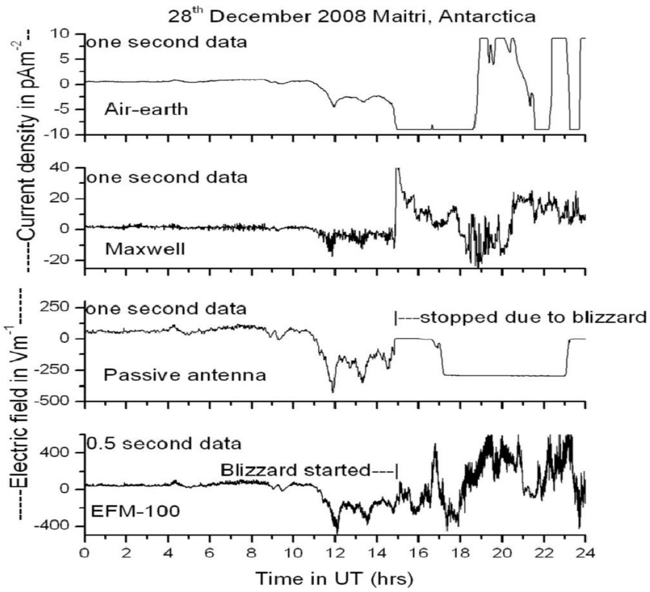

Figure 9(b) : Variation of GEC parameters during blizzard day.

the columnar resistance, induced by the atmospheric suspension content and its vertical transport, may be expected to dominate the vertical current and its variations. Thus the behavior of I depends on whether the percentage changes in *V* or *R* dominate. Over the continental stations one can expect that the changes associated with *R* are larger than those associated with *V*[12]. Gringel *et al.*[7] showed that the first two km of the atmosphere contribute about 50 percent to the total columnar resistance and the first 13 km about 95 percent. With observations conducted at Weissnau, Germany, Gringel *et al.*[7] measured a variation in *R* of about 30 percent, and attributed the variation to a changing ionization near ground and by varying aerosol concentrations in the lower troposphere. Muir[14,15] tried to explain it on the basis of sunrise effect at the height of electrosphere leading to build up of a potential through dynamic motion associated with tides.

Monitoring atmospheric electrical parameters during clear sky days has been achieved by this system Panneerselvam, et al.[16]. This present electrometer design can measure potentials safely at a height of up to 2m only. In future with suitable modifications in the electrometer front end, so as to measure the potential up to 60kms using electrometer as a play load in balloons and rockets. Making suitable modifications in the electrometer can be used to sense lighting clouds well in advance so as to make it as a lighting warning device. The potential of the atmosphere, at the same height as the antenna, is obtained by a measurement of potential difference between the antenna and the surface and thereby to measure the atmospheric electric field. The observations at several heights allow micrometeorological processes to be investigated. This battery-powered electrometer is preferable to a commercial laboratory device both because of cost and ability to cheaply replace the front-end amplifier chip damaged by transients. By setting up systems for the measurements of conductivity and current this system can be used to verify the Ohm's law J= σE.

Simpson[18] observed that blizzards are intensely electrified and produce high positive potential gradients on the ground. In our observations we observe that whenever high winds are accompanied with some snowfall, i.e., atmospheric Maxwell current, Air-earth-current, electric field of all the three categories begin to decrease about 3 – 4 hours before the appearance of blizzard. For example, on December 28, 2008, winds begin to strengthen at 1200 UT and blizzard started from 1500 UT shown in Figure 9(b). Devendraa Siingh, Vimlesh Pant and A K Kamra made similar observations at the same place in summer 2005 on atmospheric air-earth current density, temperature are below freezing point, positive ion concentration of all four categories begin to decrease 3-4 hours before the onset of blizzard. The decrease observed in all types atmospheric electrical parameters during snowfall indicates that snow particles effectively scavenge the ions. The fact that the air-earth current density and electric field almost reduces to zero value indicates that scavenging of atmospheric ions is almost total at that time. The observations that the decrease in different ion categories is not always parallel to each other are likely to result from the non-uniform rate of scavenging of the ions of different sizes. This observation can be used as a forecasting for the convoy persons and other activities around Maitri for human safety and preliminary percussions. The detailed mechanisms underlying the formation of severe blizzards are not yet well understood and form one of the interesting topics for future polar research.

Surface atmospheric electrical parameters were found to be sensitive to convective clouds, fog, rain and snow. The variations of electrical parameters will always be in the positive side, and goes to well in negative side at about 3 hours before the onset of a blizzard at the measuring site. Hence at high latitude station

Maitri, it may perhaps be used as a tool for forecasting the onset of blizzards. With the continuous measurements of atmospheric electrical parameters and geomagnetic field variations, there is scope for addressing the problems related to the modulation of GEC by the influence of magnetosphere-ionosphere-lower atmosphere coupling processes on the near-surface electrical parameters in the polar caps. And also help to understand lightning activity in globe and regional, global warming problems and micrometeorological studies.

REFERENCES

[1] E.J.Adlerman, E.R.Williams; Seasonal variation of the global electric circuit, J.Geophys.Res., **101**, 29,679-29,688 **(1996)**.

[2] G.Beccaria; Della elettricite terrestre atmosferica a cielo serno, Turin, **(1775)**.

[3] C.G.Deshpande, A.K.Kamra; Diurnal variations of the atmospheric electric field and conductivity at Maitri, Antarctica, J.Geophys.Res., **106**, 14,207-14,218 **(2001)**.

[4] Devendra Siingh, V.Gopalakrishnan, R.P.Singh, A.K.Kamra, Shubha Singh, Vimlesh Pant, R.Singh, A.K.Singh; The atmospheric global electric circuit: An overview. Atmos.Res., **84**, 91-100 **(2007)**.

[5] H.Gerdien; Messungen der Dichte des vertikalen elektrische in der freien Atmosphäre bei der Ballonfahrt am 11 V 1905 Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen 1905, 258-270 **(1995a)**.

[6] H.Gerdien; Messungen der Dichte des vertikalen elektrische in der freien Atmosphäre bei der Ballonfahrt am 30 VIII 1905 Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen 1905, 447-458 **(1905b)**.

[7] W.Gringel, J.M.Rosen, D.J.Hofmann; The Earth's electrical environment, Ch. 12, Studies in Geophysics. National Academy Press, U.S.A., **(1986)**.

[8] R.G.Harrison; An atmospheric electrical volymeter follower, Rev.Sci.Instrum., **67(7)**, July **(1996)**.

[9] R.G.Harrison, W.J.Ingram; Air-earth current measurements at Kew, London, 1909-1979, Atmos. Research., **76(1-4)**, 49-64 **(2005)**.

[10] J.R.Herman, R.A.Goldberg; Sun, weather and climate, Scientific and Technical Information Branch, National Aeronautics and Space Administration, Washington, D.C, **(1978)**.

[11] V.F.Hess; Über Beobachtungen der durchdringenden Strahlung bei sieben Freiballonfahrten, Phys.Zeitschr., **13**, 1084 **(1912)**.

[12] H.Israel; Atmospheric electricity, Isr.Program for Sci.Transl., Jerusalem, **2**, **(1973)**.

[13] A.K.Kamra; Measurements of the electrical properties of dust storms, J.Geophys Res., 5856-5869 **(1972)**.

[14] M.S.Muir; The ionosphere as the source of the atmospheric electric sunrise effect, J.Atmos.Terr. Phys., **37**, 553-559 **(1975)**.

[15] M.S.Muir; The potential gradient sunrise effect in atmospheric electricity, J.Atmos.Terr.Phys., **39**, 229-233 **(1977)**.

[16] C.Panneerselvam, K.U.Nair, K.Jeeva, C.Selvaraj, S.Gurubaran, R.Rajaram; A comparative study of atmospheric Maxwell current and electric field from a low latitude station Tirunelveli, Earth Planets Space, **55**, 697-703 **(2003)**.

[17] C.Panneerselvam, K.U.Nair, C.Selvaraj, K.Jeeva, C.P.Anil Kumar, S.Gurubaran; Diurnal variation of atmospheric Maxwell current over the low-latitude continental station, Tirunelveli, India (8.7°N, 77.8°E), Earth Planets Space, **59**, 429-435 **(2007)**.

[18] G.C.Simpson; British Antarctic Expedition 1910-1913. Thacker, Spink and Co., 326 **(1919)**.

[19] S.P.Thompson; The Life of William Tomson, MacMillan, **1**, **(1910)**.

[20] W.Thompson; On the necessity for incessant recording, and for simultaneous observations in different localities, to investigate atmospheric electricity, 29th Meeting, British Association for the Advancement of Science (Aberdeen), **(1859)**.

[21] W.M.Watson; Observations upon so much of Monsieur Le Monnier the Younger's Memoir, Lately Presented to the Royal Society, as Relates to the Communicating the Electric Virtue to Non-Electrics, Philosophical Transactions (1683-1775), **44**, 388-395 **(1746)**.

[22] C.T.R.Wilson; On the measurement of the earth-air current and on the origin of atmospheric electricity, Cambridge Proc.Phil.Soc., **13(6)**, 363-382 **(1906)**.

[23] C.T.R.Wilson; On some determinations of the sign and magnitude of electric discharges in lightning flashes. Proc.Roy.Soc.Lond.A, **92**, 555-574 **(1916)**.

[24] C.T.R.Wilson; The electric field of the thundercloud and some of its effects, Proc.Phys.Soc.London, Sect.A 111 32D, **(1925)**.