Chapter II

2. MEASUREMENT TECHNIQUES AND INSTRUMENTATION

The present investigation is aimed to understand the reasons for diurnal variation of atmospheric electrical conductivities near surface. It has been noticed in an earlier study that the conductivity variation could have a relationship with atmospheric pressure variation. Hence the approach or methodology of the investigation was to look for cause effect relationship if any between atmospheric electrical conductivity, atmospheric pressure, weather elements other than pressure, the source of ion production and the main sink of small ions namely the atmospheric aerosols.

2.1. ION SOURCE AND SINK

The atmospheric electrical conductivity can be affected by variations in the small ion concentration. The small ion concentration is affected by ion production and recombination or attachment. The ionising agencies near surface controls ion production. The ionising agencies near surface of earth are Galactic Cosmic rays and surface radioactivity (see 1.4.2 & 1.4.3). Cosmic ray intensity variations in the region of this investigation have been studied extensively and it is known that the variation is of the order of ±0.2% over the mean (Sarabhai et. al, 1953). The contribution to conductivity near
the surface from cosmic rays is only 20% (Bricard, 1965). Hence a variation of ±0.2% in cosmic ray intensity which contributes to 20% of ionisation can bring about a change of only 0.04% in total ionisation. This means surface radioactivity only is important of the two ionising agencies. Hence variation of environmental radiation due to surface radioactivity only was monitored. For this an environmental radiation monitor ER4576A manufactured by Electronics Corporation of India Limited was used. This instrument is capable for continuous monitoring of γ radiation. It can measure very low level (10 μR/h) of gamma radiation present in the atmosphere.

As mentioned earlier (in sec 1.6) aerosol is one element capable of modifying the electrical conductivity of atmosphere. Therefore, aerosols were monitored in collaboration with Space Physics Laboratory of Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram. Two types of equipments were used. One was an aerosol counter capable of making counts within a specified interval of about 15 minutes. The counter gave counts of a spectrum of particles of different diameters (K. Parameswaran, 2001). The second equipment was a high volume sampler (HVS) for collecting aerosols by using a filter attached to the inlet. The high volume sampler essentially consists of an aspiration device and a filter paper. The filter paper attached to the inlet of the instrument is previously weighed. Air is drawn in through the filter paper for a specified time say, an hour. The filter paper is then removed and weighed to find the amount of aerosol collected. The difference in the
weight is the measure of the aerosol mass loading in the atmosphere. Measurements were repeated after a 15 minutes lapse.

2.2. Weather Parameters.

Weather parameters were monitored using an Automatic weather station (AWS) installed at the terrace of the laboratory of Atmospheric Sciences Division, Centre for Earth Science Studies, Thiruvananthapuram where the investigations are carried out. The height of the terrace above mean sea level (AMSL) was 25m.

Table 2.1 gives the weather elements monitored, type of sensors, their type of output, sensitivity/resolution and range of weather elements measured. The sensors (except the rain gauge) are mounted on top of a stainless steel mast of 4 metres height erected a few metres distant from the Gerdien Condensers (GC) on the terrace. Cables run from the sensors to the Data acquisition System (DAS) kept in the Electronics Laboratory immediately below the terrace.

Of the weather elements being monitored, the accepted pattern of pressure variation has already showed a relationship with conductivity (sec 1.8). Hence, more attention is to be given to the pressure data. It is not easy to differentiate a mal function, if any, of the pressure sensor from an unusual variation. Therefore, another crude sensor useful for cross checking was made. It consists mainly of a 5 litre glass bottle used in chemical laboratory.
This bottle has an outlet at the bottom. The outlet is closed with a cork and a brass tube is introduced through the cork. A polythene tube of 3 mm diameter was connected to this tube and attached to a vertical scale of 1 mm resolution fixed to the side of the bottle. The bottle is filled with about 2.5 litres of water and closed tightly. The bottle is closed at about 7 AM or 1:00 PM so that the water level in the tube will correspond to the median level of atmospheric pressure.

<table>
<thead>
<tr>
<th>Weather element</th>
<th>Sensor</th>
<th>Output</th>
<th>Sensitivity/Resolution</th>
<th>Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature (AT)</td>
<td>Platinum Resistance (PT100)</td>
<td>0-2.5 V</td>
<td>0.1°C</td>
<td>0°C - 50°C</td>
<td>&lt; 0.5°C</td>
</tr>
<tr>
<td>Wind Speed (WS)</td>
<td>3 Cup Rotor Frequency-Reed switch</td>
<td>0.1 m/s</td>
<td>0.1°C</td>
<td>0-50 m/s</td>
<td>± 2%</td>
</tr>
<tr>
<td>Wind Direction (WD)</td>
<td>Potentiometer Resistance 1 deg.</td>
<td>1 deg.</td>
<td>0-360°</td>
<td>± 2.25%</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity (RH)</td>
<td>Thin film capacitance Frequency</td>
<td>1% RH</td>
<td>0-100%</td>
<td>±5% (10 to 90%)</td>
<td></td>
</tr>
<tr>
<td>Rain (RF)</td>
<td>Tipping bucket Switch contact</td>
<td>0.1 mm</td>
<td>0.1 m -</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Pressure (P)</td>
<td>Strain gauge bridge Analogue voltage</td>
<td>0.1 m hPa</td>
<td>800-1100 hPa</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1. Sensitivity/resolution and range of measurement of sensors used for measurement of weather elements.
Later this was calibrated against the pressure data obtained from the data acquisition system (DAS). This system has a sensitivity of 4.5 cm/ hPa of pressure. This has been in use throughout the study to cross check for pressure sensor output.

In the DAS, the data from the sensors are sampled, averaged and stored in a memory module. The sampling interval and averaging time are selectable. The sampling interval can be selected to vary between 1sec and 99 sec. The averaging time also is selectable form 1 minute to 99 minutes. A sampling interval of 1 sec and averaging frequency of 5 minutes was selected. Hence each weather element data point stored was an average of measurements for the past 5 minutes. The sampling frequency and averaging interval are so selected to look into the finer aspect of weather elements variation.

2.3. POLAR CONDUCTIVITY MEASUREMENT

A simple method that was often used in earlier times for measuring conductivity of air is the dissipation technique (Israel, 1971). A spherical or cylindrical charged body kept insulated in air dissipates charge and the rate of dissipation is measured. The conductivity is calculated from the rate of dissipation. This simple method gives correct results when the movement of air is sufficient. Every ion moving in an electric field gives rise to “electrode effect” near the boundary surface that gives rise to very low values of conductivity when measured in air at rest. This electrode effect, discussed in
detail later in this section can be neglected if air flow rate is more than 0.20 km/s (Israel, 1971). In earlier days when information on conductivity was sparse, spot measurements were useful. With highly sensitive electronics being available today, spot measurements using dissipation technique is not generally used.

The atmospheric ions classified as described in section 1.4.5 falls under three categories: small, intermediate, and large ions. In Table 2.2 is given the values of number density, mobility, and size ions near the surface of earth. The values shown are indicative of the order of magnitude and are not exact.

<table>
<thead>
<tr>
<th>Type of ion</th>
<th>Number density /m$^{-3}$</th>
<th>Mobility (m$^2$/Vs)</th>
<th>Size (radial) m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small ion</td>
<td>$1.5 \times 10^9$</td>
<td>1 to $2 \times 10^{-4}$</td>
<td>$&lt; 10^{-9}$</td>
</tr>
<tr>
<td>Intermediate ions</td>
<td>variable</td>
<td>1 to $2 \times 10^{-5}$ to 1 to $2 \times 10^{-6}$</td>
<td>$10^{-9}$ to $10^{-7}$</td>
</tr>
<tr>
<td>Large ions</td>
<td>variable</td>
<td>1 to $2 \times 10^{-5}$ to 1 to $2 \times 10^{-8}$</td>
<td>$&gt; 10^{-7}$</td>
</tr>
</tbody>
</table>

**Table 2.2. Typical surface values of number density, mobility and size of ions of different types**

The values of concentration and mobility of ions near surface in the atmosphere range over 4 orders of magnitude. Therefore simultaneous measurement of these parameters in all the three categories is difficult with a
single apparatus. Hence measurements generally are limited to one category at a time. For example Missaki (1961a, 1964), Whipple (1960), Suzuki et al., (1982), and Cabane and Milani (1984) have used the GC to study the concentration/mobility spectrum of small or large atmospheric ions and Bricard et al., (1969b) and Takebe (1974) have used the drift tube to study the same at the ground surface. Dhanorkar and Kamra (1991) reported the development of an ion counter which measures mobility and concentration over the entire range of atmospheric ions by varying the aspiration rate and / or voltage of the condenser electrode.

2.3.1. GC Technology - Basic Theory.

To estimate the electrical conductivity of air, the charged particles in the air is aspirated through a cylindrical condenser. An electric field of sufficient strength is applied to the electrodes of the condenser. The charged particles or ions that enter the condenser are then subjected to two mutually perpendicular forces:

1) the force of air flow parallel to the capacitor electrodes and
2) force due to the electric field acting perpendicular to the air flow.

Consider a co-axial cylindrical capacitor having two cylindrical electrodes with radius \( r_1 \) and \( r_2 \), if the air flow rate across unit cross section is constant at \( u \), then

\[
  u = \frac{dx}{dt}
\]
Where \( x \) is the position of the ion from the inlet and \( dx \) is the displacement of the ion parallel to the axis of the cylindrical electrode during a time interval \( dt \) sec.

If the electric field \( E \) applied across the capacitor electrodes causes the ion to be accelerated to the internal electrode with a velocity then,

\[
\frac{dy}{dt} = E \mu \quad 2\ (2)
\]

Where \( dy \) is vertical displacement perpendicular to the axis of the electrode during the time interval \( dt \) sec, and \( \mu \) is the mobility of the air ion.

\( E \), the electric field at any point at a distance \( r \) from the axis of the cylinder is given by

\[
E = -\frac{V}{r \ln (r_2/r_1)} \quad 2\ (3)
\]

Where \( V \) is the voltage in Volts applied to the outer electrode having radius \( r_2 \) with respect to the inner electrode of radius \( r_1 \).

By combining 2(1) and 2(2) with 2(3) to eliminate time, we get

\[
u \ r \ dy = -\mu \ V \ dx / \ln (r_2/r_1) \quad 2\ (4)
\]

The equation of the path of the ion which enter at the distance \( r = r_2 \) from the axis is given by the relation,

\[
dx = \left(\frac{u}{\mu} \ V \right) \ln \left(\frac{r_2}{r_1}\right) \int_{r_2}^{r_1} r \ dy
\]

That is,

\[
dx = u \left(\frac{r_2^2}{r_1^2} - 1\right) \ln \left(\frac{r_2}{r_1}\right) / (2\mu V) \quad 2\ (5)
\]
This expression indicates that the path of the ion entering the cylindrical condenser is parabolic in nature.

If the length of the inner electrode is L then the smallest mobility or the limiting mobility $\mu = \mu_g$ of ions which gets collected by the inner electrode for the given aspiration rate and potential applied to the electrodes is given by equation 2(5) as

$$\mu_g = u (r_2^2 - r_1^2) \ln (r_2/r_1) / (2VL) \quad 2(6)$$

![Figure. 2.1](image)

_Schematic drawing of GC showing the path of ions with $\mu = \mu_g$.  

When $\varepsilon_0$ is the permittivity of free space, for a cylindrical condenser the capacitance $C$ is given by the relation,

$$C = 2 \pi \varepsilon_0 \ L / \ln (r_2/r_1) \quad 2(7)$$

and  

$$\varphi = u \pi (r_2^2 - r_1^2) \quad 2(8)$$
is the air flow rate through the condenser. Then by combining equations 2(7) and 2(8) in 2(6), the limiting mobility takes the form

\[ \mu_g = \frac{\phi \varepsilon_0}{C V} \quad 2(9) \]

The relation 2(9) indicates that for a given flow rate \( \phi \) and potential \( V \) applied between the electrodes of a condenser all the ions with mobility equal to or greater than the limiting mobility \( \mu_g \) are collected by the electrode. Or the limiting mobility of a given apparatus is decided by the potential applied between the electrodes as well as the flow rate.

2.3.1.1. Organisation of Electrodes in a GC.

Named after H.Gerdien (1905) the GC instrument has been in use for a long time for the measurement of atmospheric electrical conductivities, ion densities and mobility. Basically the instrument is a cylindrical capacitor through which air is made to flow. Usually the outer electrode is designated as the driving electrode and the other as collector. The voltage maintained at the driving electrode with respect to the collector, is known as the driving electrode voltage (DEV). This DEV drives ions in the air to the collector. The ions give up their charges at the collector constituting a current which is measured using a suitable electronic circuitry. For low DEV values the collector current is proportional to the applied voltage. For sufficiently high DEV all ions in the incoming air get collected after which the current
becomes independent of applied voltage and the condenser is said to be saturated. Details of working are given below.

2.3.1.2. Theory

The discussion below largely follows Conley (1974) and Farrokh (1975). The following assumptions are made in analysing the operation of GC.

1) The air flow through the condenser is parallel to the axis and streamlined.
2) In comparison to the motion of ions due to the applied electric field the thermal diffusion of ions is small and hence neglected.
3) The ion density does not change due to production and destruction during the time of flow through the GC.
4) The concentration of negative and positive ions is equal in the ambient air or the air is electrically neutral.

The general equation of motion for any one type of ion can be written as follows:

$$J = -eD \left( \frac{dn}{dr} \right) + \mu ne \left( \frac{d\psi}{dr} \right) + neu$$  \hspace{1cm} (2.10)

Where $J$ is the current density per unit length at the collector, $D$ is the diffusion coefficient, $n$ is the number density of the type of ion, $\psi$ is the potential at any point inside the condenser, $d\psi/dr$ is the gradient of potential
at a distance $r$ from the axis and $dn/dr$ is rate of variation of number density, $u$ is the convection velocity of the ions inside the condenser and $e$ is the electronic charge. The first term in the above equation is the contribution to the current from thermal diffusion. This can be neglected as per our second assumption. The third term represents the contribution from convective motion. This also can be neglected if our first assumption is satisfied. Assuming cylindrical symmetry the two dimensional equation of (10) takes the form:

$$J = \mu n e (d\psi/dr)$$  \hspace{1cm} (11)

Where $r$ is the radial distance. The potential gradient is then:

$$\frac{d\psi}{dr} = \frac{V}{r \ln (r_2/r_1)}$$ \hspace{1cm} (12)

Substituting (12) and then (7) in (11), we get:

$$J = \left( \frac{\mu n e V}{r \ln (r_2/r_1)} \right) = \left( \frac{\mu n e V C}{(2 \pi \varepsilon_0 L r)} \right)$$ \hspace{1cm} (13)

The current per unit length of the collector is $i = 2 \pi r J$ so that the total current $I$ to the probe is given by:

$$I = 2 \pi r J L = \frac{\mu n e V C}{\varepsilon_0}$$ \hspace{1cm} (14)

The equation (14) describes the current-voltage characteristic in the conductivity mode. That is only a part of the ions entering the condenser gets
collected by the collector. Here, for a given flow rate the collector current is proportional to the driving voltage. This region of the characteristic is the Ohmic region. As the DEV is increased, the limiting mobility of the condenser is reduced as in equation 2(9) so that all the small ions that enter the GC get collected and collector current gets saturated at the value $I_s$ as given by:

$$I_s = \mu e \phi \quad \text{or} \quad I_s = \mu e u \pi (r_2^2 - r_1^2)$$

2(15)

(the air flow rate through the condenser $\phi = u \pi (r_2^2 - r_1^2)$ where $u$ is the cross sectional air flow rate per unit area)

Thus the collector current is directly proportional to the driving voltage in the conductivity mode [equation: 2(14)] and constant in the saturation mode [equation: 2(15)].

The driving voltage at which collector current gets saturated is known as saturation voltage designated as $V_s$ and is obtained from equation 2(9) as:

$$\mu_g = \phi \varepsilon_0 / C V_s \quad \text{or} \quad V_s = \phi \varepsilon_0/ \mu_g C$$

2(16)

The theoretical I-V characteristic of a GC should therefore look as shown in Fig.2.2.b
Fig. 2.2. Schematic diagram of operation of GC & Theoretical Current-Voltage characteristic of a GC.

Fig. 2.2.a

Fig. 2.2.b

Schematic diagram of operation of GC & Theoretical Current-Voltage characteristic of a GC.
The point at which the GC gets saturated may be considered to be still in the linear region of the characteristics, thus the relation for polar conductivity, mobility and ion concentration can be deduced from Equation 2(9), 2(14) and 2(16) as:

\[ \sigma^\pm = \mu^\pm n^\pm e = \varepsilon_0 I / (VC) \]

(where the superscripts + and – stands for the positively and negatively charged ions respectively)

When the GC is operated in the conductivity mode

\[ \sigma^\pm = (\varepsilon_0 / C) (dI^\pm / dV^\pm) = [\ln (r_2 / r_1) / 2\pi L] [dI^\pm / dV^\pm] \quad 2(17) \]

\[ \mu^\pm = \varphi \varepsilon_0 / V^\pm C = u (r_2^2 - r_1^2) \ln (r_2 / r_1) / (2L V^\pm) \quad 2(18) \]

and

\[ n^\pm = \Gamma^\pm / e \varphi = \Gamma^\pm / e u \pi (r_2^2 - r_1^2) \quad 2(19) \]

since \( \varphi = u \pi (r_2^2 - r_1^2) \), \( C = 2\pi \varepsilon_0 L / \ln (r_2/r_1) \) and \( \sigma^\pm, \mu^\pm, n^\pm \) are conductivity, mobility, and ion concentration respectively of positive or negative ions.

2.4. SOURCES OF ERRORS

The discussions given above of the principle of GC is valid only in ideal condition. In other words assumptions given in section 2.3.1.2 may not be valid in practice. This can lead to errors in measurement that has to be taken in to account so that the errors do not become too large.

In the first assumption that the flow of air through the GC is laminar necessitates the Raynold’s number of the configuration remains below a certain value
that is dependent on the configuration. For two very long co-axial cylinders the Raynold’s number is given by:

$$R_e = (r_2 - r_1) \frac{u}{\eta}$$  \hspace{1cm} 2(20)

Where $u$ is the average flow velocity across the section and $\eta$ is the kinematic viscosity. The critical value of such a system is 2000. The exact value for a given condenser has to be determined experimentally. In the GC used in the present study the flow rate is determined by the flow generator used and ensured that the Raynold’s number remains below the critical value. However there is bound to be turbulence at the inlet end of the condenser. This does not affect the measurement because as a practice certain portion of the inlet is left to stabilise the flow. Care has also been taken to see that the ions that enter this portion are not lost.

The second assumption is that thermal diffusion of ions does not contribute significantly to the current. By Einstein’s equation, $D/\mu = kT/e$ where $k$ is the Boltzman’s constant and $T$ is the ambient temperature. $D/\mu$ is less than 0.03 for normal surface temperature. Thus the contribution of thermal diffusion is less than 3% which is within tolerable limits.

According to the third assumption that ion pair production and loss rate inside the sensor are negligible. Life time of small ions in air are of the order of 50 to 300 sec (Chalmers, 1956) which is significantly larger than the time the air sample takes to move from the inlet to the outlet of the sensor. Ion production will be taking place inside the sensor due to radioactive elements present in air. However ion balance will
remain the same inside and outside since the condition do not change when the air enters the sensor.

The equation 2(3) for the field inside the sensor has been derived on the assumption of charge neutrality. This gives the variation of electric field inside the sensor. In the presence of space charge the electric field variation could be different. In order to determine the extent to which this could affect the measurement, Conley (1974) assumed a uniform charge distribution of one polarity inside the condenser and solved the corresponding Poisson’s equation. According to that, for charge densities as high as $10^{11} \text{ m}^{-3}$, the perturbation to the field is very small. Hence this effect can be ignored for most purposes.

The last assumption that all the ions that enter the condenser have the same mobility is also not strictly valid. Intermediate and large ions with considerably different mobility also will enter the GC. However, the ions that are detected by the GC are the small ions which have mobility values with in a narrow range. The effect of having a range of mobility will modify the linear portion of the I-V characteristic of the condenser. If ions with mobility $\mu_1, \mu_2, \mu_3, \ldots$ are present in the air, there will be saturation voltage for each of this ions. The region of the characteristic from the origin and the point corresponding to the saturation voltage of ions with smallest mobility will therefore consist of several short straight line segments. This would not affect conductivity measurements if the driving voltage used is sufficiently small.

Apart from the possibility of errors discussed above, error can occur due to fringing of electric field at the inlet of the condenser. These fringing of field lines also known as edge effect, can deflect some of the incoming ions to some portion of the
sensor other than the collector resulting a reduced value of current in measurement. This effect can be seen clearly if the driving voltage is gradually increased from a small value to a value much higher than the saturation voltage. The collector current can be seen to reach a broad maxima around $V=V_s$ and then decrease. For conductivity measurements near ground, when the driving voltage is small compared to saturation voltage, the error so introduced can be neglected. Moreover, near surface measurements keeps the errors due to fringing of electric field to very low values because of low mobility of ions close to the surface.

Modification to this basic design has been attempted by several workers. In the modified McClelland method, for instance the driving voltage is kept constant at high value and the collector current is measured for different flow rates. Whipple (1960) suggested a method to obtain a single characteristic from the current obtained by varying either the driving voltage or flow rate. This has been extended to include the capacitance of the sensor so that the characteristic becomes valid for any GC (Dhanorkar & Kamra 1991). The instrument used in the present investigation is the basic type with a degree of technical perfection as detailed below.

2.5. GC ASSEMBLY- DESIGN AND FABRICATION

The GC Assembly consists of the sensor and a support structure. The sensor shown in Fig 2.3 consists mainly of the collector and driving electrode. A voltage is applied to the driving electrode and current due to collection of ions at the collector is measured. The driving electrode of the GC is a tube of 0.065m diameter and 0.5m length. A few layers of thin, high voltage synthetic insulation sheet is wound over the driving electrode and it is slipped into another tube of 0.067m inside diameter and
0.66 m length. This tube is the Shield and has two circular windows near its ends, covered by metal lids. These Windows are for removing the collector for periodical cleaning. The collector is a silver plated copper wire of radius 0.00045 m supported by two P.T.F.E. (Poly Tetra Fluro Ethylene known by the trade name as Teflon) insulators at the ends. The collector is held taut co-axially to the driving electrode using two cross Bolts fixed at the ends of the Shield. During operation, accumulation of dirt on the insulators can cause leakage currents to flow. Because of air flow through the condenser dust settle on the Teflon insulators. This can lead to leakage current and so periodic cleaning is essential to minimize the error caused by this current.

Collector assembly consisting of collector and P.T.F.E. insulators at its ends are made such that the assembly can be replaced easily every week. Without dismantling the sensor, the collector assembly alone is substituted with a fresh cleaned one through the windows in shield. The removed one is conveniently cleaned in the laboratory for replacing next week. After the change, the windows are closed and bolted.

The P.T.F.E. insulated cable connects the collector to a Current to Voltage Converter (E. M. Assembly) mounted on the GC itself. The E. M. Assembly is fitted laterally to facilitate free downward air flow through the sensor. An adaptor and a fan tube are used to couple the sensor to a fan of 0.2 m diameter mounted at the bottom of the sensor. During operation, the fan draws air through the sensor. An Extension tube of same diameter as the Shield and mounted above it makes the air flow laminar. All parts of the GC except the collector are made of Brass and electroplated with Nickel. All joints are made air tight using rubber washers. A hood made of painted
Figure 2.3.
The Gerdien Condenser Sensor
Aluminium protects the sensor inlet from rain and vertical electric field of the atmosphere. During operation the effect of the hood in modifying the conductivity was checked by measuring the output of the sensor with the hood in position and also without it for a number of times. No change in the sensor output was noticed. Hence it is assumed that the hood does not modify the ion density to interfere with the measurement of conductivity.

The GC assembly is shown in Fig. 2.4. A triangular structure made of 0.025m angle irons and 3mm mild steel plates supports the GC vertically. The support is zinc plated and painted to prevent corrosion caused by exposure to sun and rain. In addition, stainless steel bolts and nuts were used for the same reason. The support is made such that it independently supports the three main parts of the sensor assembly. Such a structure facilitates easy maintenance of any one of the parts without dismantling others.
Figure 2.4
Plan and elevation drawings of the GC assembly showing the details of support structure.
2.5.1. The Electronics.

The block diagram of the system for measurement of positive conductivity is shown in Fig. 2.8, and complete circuit diagram of the same for measuring the positive polar conductivity is shown in Fig. 2.15. Before describing the details of the system as a whole, details of the input amplifier and other details of significance in measurement of collector current are detailed through circuit diagrams in Fig.2.5 to Fig.2.14

2.5.1.1. The Current to Voltage Converter or the E. M. Amplifier.

The E.M. Amplifier is the most important element of a GC system. The collector current due to collection of ions is converted to voltage by a current to voltage converter (E.M. Amplifier) wired around an AD 549L operational amplifier. This is an operational amplifier manufactured by M/s Analog Devices, U.S.A and has a typical bias current of 40 fA. The circuit diagram of the E.M. amplifier is shown in Fig.2.5. Each of the GC systems has an E.M. Amplifier as the input stage after the collector of the sensor. Both the E.M. Amplifiers are identical.

Noise error currents or voltages are of serious consideration in the design and fabrication of E.M. Amplifiers. Therefore at this stage where the collector current of the order of a fraction of a pA is converted to a voltage that should be of a level more than the normal noise level of electronic circuits and amplifiers. As the pin of most of the IC devices are very close together (2.5mm), when used on PCB can introduce surface leakage current which are of much concern especially when the current to be measured is of the order a fraction of a pico ampere. The Virgin P.T.F.E. (Teflon) stand offs marked in Fig.2.5 are terminals insulated with P.T.F.E, and mounted on FRP printed circuit board. Virgin P.T.F.E is high quality insulators whose surface can be polished and cleaned to minimise surface leakage.
Figure 2.5.
Circuit diagram of the E.M amplifier used in both positive and negative GC systems.
The use of virgin P.T.F.E stand offs on the PCB has been found to be very effective in preventing the leakage current from entering the input terminals of the EM amplifier. Moreover M/s Analog Devices, the manufacturer of the operational amplifier used in this EM amplifier system also recommends the use of P.T.F.E as an insulator.

Because of the insulation by Teflon stand offs, surface leakage of the PCB does not reach the input terminal of the E.M. amplifier. Also the input lead does not have a shield. This is because the E.M. Amplifier is mounted on the GC and so the lead is routed inside. Since it is run inside the shielded GC it does not require a separate shield. The presence of shield on the input lead can cause a leakage current between the centre conductor and shield upon dust collection during operation also.

In Fig.2.6 is shown the details of the mounting of E.M. Amplifier on the GC and in Fig. 2.7 is shown the details of the routing of the input wire from the collector to the E.M. Amplifier. In Fig. 2.6 the shape of the insulator at the lower end of the collector wire and to which the collector is attached can be seen. This shape facilitates reduction of leakage current. The shape is that of an inverted cup from the centre of which protrudes a stem. To the stem is attached the collector anchor wire. The collector anchor wire is attached to the bolt used for anchoring the collector to the shield tube.
Figure 2.6.

Drawing of the relevant portion of GC assembly showing the details of mounting of E.M. Amplifier and connection of collector to it.
Figure 2.7.
Part of the drawing of the GC showing details of collector wire connection to E.M. Amplifier.
The routing of the connection from the lower end of the collector to the E.M. Amplifier assembly is shown in Fig.2.7. It can be seen in the figure that three parts designated as insulator cup are put on the P.T.F.E wire connecting the collector to E.M. Amplifier. They are made of virgin P.T.F.E and have an inverted cup shape. Shown in the circle is a zoomed view of the insulator cup which has a through hole as the Teflon wire diameter. As the air flows through the GC dust settles on all parts including the P.T.F.E insulated wire. Leakage being a non linear phenomenon, a continuous coating of dust can cause a leakage current from the collector to shield in the presence of humidity and an error can get introduced in the measurement. The cup shaped insulator prevents dust settling on the portion covered by the cup. This helps in having a discontinuity in the dust coating and hence reduces the possibility of leakage current occurring.

2.5.1.2 Voltage Amplifier System.

Referring to the schematic block diagram of the GC system for measuring positive polar conductivity shown in Fig.2.8, the circuit diagram of the E.M amplifier and three voltage amplifiers of gain 1, 7 and 7 in cascade is shown in Fig.2.9. The output of the E. M. amplifier is fed to a non-inverting buffer wired around a 741C operational amplifier. This constitutes the unity gain amplifier. Output of the buffer is further amplified by two cascaded non-inverting amplifiers of approximate gain of 7 each so that a total gain of approximately 49 is available. The outputs of any of these three amplifiers are connected through a three pole three-way selector (band switch) to an adder amplifier of unit gain so that the gains namely 1, 7 or 49 can be selected.
Figure 2.8.
Block diagram of the system for positive polar conductivity measurement
Figure 2.9.

Circuit diagram of the Current to Voltage converter and three amplifiers of gain 1, 7, and 7.
2.5.1.3. **Output Level Control.**

The second input of the adder is a variable voltage derived from power supply and fed from a multi-turn preset potentiometer which is shown in the circuit diagram presented as Fig.2.10. This adder with the variable DC voltage input is designated as level control (LC) in the block diagram. LC is necessary to set the level of output fed to the recorder to desired level. This is because the Amplifier System output is fed to the analogue channels of the DAS. The analogue channels have an input range of 0 to 4 V only with a resolution of 0.1 mV, so the output of LC is fed to an output buffer and buffer output is fed to the recorder network. It is seen in the block diagram in Fig.2.8 and circuit diagram in Fig.2.11 that the input to the LC is fed through an N/C contact of a relay designated \( R_{L1} \). This relay helps in identifying the last gain change from the data.

As mentioned above, selection of gain is done by means of one pole of a three pole three way selector. Referring to the Fig.2.11 the contacts of second pole of the selector is connected to the supply and the wiper output is used to trigger a mono stable multi vibrator made of NE 555 timer. Whenever the gain is changed the wiper of this second pole goes through a zero to reach the next position. So a negative edge is created by the transit of the common terminal of band selector and this negative edge is used to trigger the monoshot.

When the averaging time of the DAS is set for 5 minutes, the monoshot is wired for an on time of 11 minutes. The monoshot drives the relay \( (R_{L1}) \) through necessary transistors to connect one of the three calibration voltages corresponding to
Figure 2.10.

Circuit diagram of the level control and output buffer along with relays for gain change indication and transient suppression.
Figure 2.11.
Circuit diagram of the system to automatically record selected gain when gain is changed.
the gain selected, which will help in identifying the gain in the data recorder. The calibration voltages of -1.4V, -2.52V and -3.8V (1.28, 2.42 & 3.43 for Negative GC) corresponding to 1, 7 & 49 gains are generated using a reference diode and a resistor network. Care, like selection of proper reference diodes and resistors, is taken to see that the voltages generated have low drift. Thus, whenever the gain is changed the recorder records for the next 11 minutes the calibration voltage corresponding to the new gain stage. In addition, a gain change is noted daily in the log book maintained by the operating personal also.

2.5.1.4. Driving Electrode Voltage (DEV) Switching

The most important part of the measurement electronics is the Current to Voltage Converter (E.M.Amplifier). This converts the current constituted by collection of ions at the collector of the GC to voltage for further processing / amplification and has a sensitivity of 0.084 V/pA. Very good care is necessary during fabrication and operation to avoid leakage currents caused by collection of dust and dirt in the sampled air. However, the current to voltage converter or other amplifiers may drift due to many reasons including temperature and leakage. This can introduce a shift in the zero or reference value resulting in measurement error.

The error can be reduced by evaluating the output periodically when the driving voltage is zero (zero or reference of the measurement system). This essentially eliminates the drift of the system. For this purpose, the driving electrode is connected to the driving voltage generator through a relay (R_{L3}) as shown in Fig.2.12.
Figure.2.12.

Circuit diagram of the clock, relay drive circuits, and relay for periodic grounding of driving electrode.
Figure 2.13.

Expanded view of circuit with relay $R_{L3}$ for grounding driving electrode
An expanded view of the relay circuit also is shown in Fig.2.13. The driving electrode is periodically switched to zero for a definite duration. The corresponding GC output gives the zero or reference value and difference of other readings with this value gives the collector current proportional to conductivity.

2.5.1.5. Transient Suppression

The GC is a capacitor and when the voltage applied to it is changed suddenly as mentioned above that is, switching DEV to zero and then zero to DEV, a transient appears at the output for a few seconds. The relay $R_{L2}$ is used for eliminating transients in the output by disconnecting the recorder when transients are generated. For this the LC is connected to the output buffer through the N/C contact of relay $R_{L2}$ as shown in the block diagram and circuit diagram in Fig.2.14.

The relay $R_{L3}$ used for switching the driving voltage is a DPDT relay and whenever the DEV is switched on or off, a mono stable multi vibrator is triggered using the second set of contacts of the same relay. The N/C and N/O contact of this relay are wired to +Vcc and so whenever the relay common traverses from N/O to N/C or vice versa a negative edge is generated. The mono shot is triggered using this negative edge. The relay $R_{L2}$ is controlled by this mono shot which has an on time of 40 seconds. Hence, whenever the driving voltage is switched the output buffer is disconnected for 40 seconds to eliminate transients.
Figure 2.14.

Circuit diagram of trigger, relay etc for transient suppression
Figure 2.15.
Circuit diagram of the system for positive polar conductivity measurement.
2.5.2. System for Negative Polar Conductivity Measurement.

Basically, there is no difference in the electronics between the two polar conductivity measurement systems. The block diagram and circuit diagram of the system of negative conductivity measurement are shown in Fig.2.16 & 2.17. The output buffer for this system is an inverting buffer and the calibration voltages are positive instead of the negative voltages in the other system. There is no clock here and the same clock that drives the positive system is used so that DEV of both the sensors are switched on and off simultaneously. The DEV is also negative.

2.5.3. Power Supply and DEVs

The circuit diagram of power supplies of positive and negative measurement systems are shown in Fig.2.18. Unregulated supplies were made with the usual transformer bridge rectifier combination. Power supplies of three voltages were made for each GC system. The voltages were +15V, -15V, +5V and 30V supply for the driving electrode. Three pin voltage regulators of 1 Ampere capacity have been used for low voltage supplies and zener-transistor combination has been used for generating DEV of both polarities. The current capability of both the positive and negative DEV supplies have a capability to deliver a current of 0.1 A. The only load which draws a small amount of current of the order of a milli Ampere is the circuit used for monitoring the DEV voltages. Hence the DEV supplies have negligible noise and ripple. Since the GC is a capacitor any noise or ripple will be seen in the E.M. Amplifier output. This aspect was checked with an oscilloscope of 2mV/div
Figure 2.16.
Block diagram of the system for negative polar conductivity measurement
Figure 2.17.

Circuit diagram of the system for negative polar conductivity measurement
RESISTANCE VALUES ARE IN KILO OHMS. CAPACITANCE VALUES ARE IN MICRO FARAD.

Figure 2.18.
Circuit diagrams of power supplies of both positive and negative polar Conductivity measurement systems
sensitivity and it was confirmed that that the DEV does not generate or introduce a noise or error signal in the E.M. amplifier output. In view of the possibility of cross talk between the positive and negative GC systems, independent power supplies were used for each of the systems. The ripples in both the supplies were close to a milli Volt only.

**2.6. Integration of the Two Systems.**

The weather data and the conductivity data are recorded in the DAS. This is an equipment made using a microcontroller. All inputs are sampled, averaged and stored into a location of a memory module. The data thus stored in the memory module is read into a computer using a dedicated software. The DAS has analogue, digital and frequency channels of input. The sampled data is averaged at the end of the averaging time and stored in a location of the memory module. Two analogue channels each and one digital channel were used for recording the data from the GC. The analogue channels have an input range of 0 to 4 V with a resolution of 0.1 mV and the digital channel responds to logic 0 and 1 levels. The 0 & 1 states of the digital channel correspond to input voltages of 0V & 5V respectively. The digital channel records the amount of time 1 state was present during the averaging period, in percentage. The Amplifier System output is fed to the analogue channels. The organisation of the whole GC and weather monitoring system is given schematically in Fig.2.16. Details of the positive GC system are shown in the figure. Final output from both positive and negative GC systems is fed to the data acquisition system. The weather elements data is also fed to the same DAS. It can be seen that the clock of the GC system is not fed to the DAS. It has an independent clock. These two clocks are not synchronised even though the data collection duration and sampling is controlled by the DAS clock.
Figure 2.19.
Block diagram of the complete system for measurement of polar conductivities and weather elements.
The DAS has two components. One is the main control module. The control module does the sampling and the sampled data is stored in a buffer memory of the module. Periodically the data is transferred to a second component of the system called the memory module. The memory module has a capacity of 128 kb. Two similar units were used. One module is connected to the main unit always. Once in two days the memory module is removed and data is transferred to the computer. Upon removal of the memory module for data transfer to the computer the second memory module is attached immediately so that data during the time of transfer is not lost. Data from the memory module is transferred to the computer with the help of a software through the parallel port of the computer.

2.6.1 Synchronisation in Absence of a Common Clock.

As has been mentioned above that the DAS does not have a clock output and so synchronous operation of the conductivity measurement system with the DAS is not possible. However, it is necessary that the time at which the driving voltage is switched off and on is known. In order to know the time at which the DEV is switched, the clock controlling the relay $R_{L3}$ is given to one of the digital channels of the DAS. Normally the DAS is operated with a sampling interval of 1 second and averaging interval of 5 minutes. With 5 minutes averaging time the duration for which the driving voltage is switched off for reference estimation is set at 11 minutes. The 11 minutes off time ensures that at least one 5 minutes averaged value of output corresponding to the driving voltage zero is recorded. This is not ensured if the off time is less than 10 minutes as there is no synchronisation with averaging time of DAS.
Table 2.3 shows a print out of a few hours of data collected where time and duration of DEV switching off can be seen in the channel designated 26-LW. The columns 03-VLT and 04-VLT correspond to analogue channels where positive and negative conductivity data inputs respectively are given and 26–LW correspond to digital channel where the clock input is given. The entry at 00:38 h in the column indicates that at about 0:41:11 h the driving voltage has been switched off. This is inferred from reading 36.3% in 26–LW channel. The 36.3 entry in LW channel indicates the percentage of the total averaging time for which the channel was in 1 state. 36.3% of averaging time of 5 minutes is 1 min 49s. That is the DEV was switched off 1min 49 s before the end of the 5 min averaging time. In other words the DEV was switched off after 3 min 11s. In absolute time it was at 0:41:11 h. Similarly the DEV was switched on at about 0:46:12 h (64.3% in 26–LW channel). The reading in 03–VLT and 04-VLT corresponding to 00:43 h (100% in 26-LW channel) gives the reference value when the DEV is zero for the full five minutes of the averaging time. The two values before and after this value in 03-VLT and 04-VLT are averages of two groups of samples when DEV was off partially during the averaging period, and has to be discarded. It is to be mentioned here that the calibration voltages are recorded, during a gain change, also for 11 minutes for the same reason only; that is to ensure that the calibration voltage exists for one complete 5 minutes period of averaging.
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Table 2.3. A sample record of the data retrieved from the DAS. AT is the air temperature, WD is the wind direction, PRS is the atmospheric pressure, WS is the wind speed, RF is the rain fall, and RH is the relative humidity. 03-VLT and 04-VLT columns correspond to the conductivity data recorded. 26-LW is a digital channel used for recording the duration and time of switching of the DEV to zero for estimating the reference. Abbreviated unit of each measured parameter is shown in the column header.
The Electronics including the power supply is housed in a console containing three racks with front panels. The drawing of the console is shown in Fig.2.20. Positive and negative conductivity measurement systems. Controls and indicators for positive conductivity system on the right hand side of top rack are marked. The left hand side ones are identical and are for negative system.

The Thumb Wheel Switch (TWS) and the DPM help in monitoring the status of the Conductivity measuring systems daily. The Following voltages are fed through the decimal TWS to the DPM.

![Schematic drawing of the electronics console containing both](image)

**Figure.2.20.**

Schematic drawing of the electronics console containing both
0. Adder Voltage
1. +ve Supply
2. -ve Supply
3. +5 V Supply
4. DAS input (Final output)
5. Attenuated DEV
6. E.M. Amplifier Output
7. X 1 Gain Output
8. X7 Gain Output
9. X49 Gain Output.

These voltages are noted twice daily so that any error/malfunction can be traced at any time. In addition, the faulty part or element can be identified with ease. For example if there is leakage in the GC creating a short circuit with the collector the E.M. Amplifier Output will immediately show a large value. The GC and E. M Amplifier can then be checked for cause of leakage and corrective measures can be taken. Three LEDs by the side of the band switch indicate the gain at which the system is operating. Another LED mounted above the band switch indicates the overload or over voltage at the output of the selected amplifier. On finding this lit the gain can be reduced using the band switch.

In addition to the Digital Panel Meter (DPM), two sockets with a switch are also provided in the middle rack to monitor the DPM input with an external Digital Multimeter to cross check if necessary. The switch selects between Positive and Negative systems.
The array of illuminated switches on the middle rack indicates the power supply position to all systems. Four Led indicators under each DPM indicate the status of three power supplies and DEV of both positive and negative systems.

The lower most rack contains the power supply distribution to all systems including the GC. Conductivity data from the system was collected and processed on a daily basis.

2.7. Calculation of Conductivity.

As mentioned before in 2(17), the atmospheric electrical conductivity is given by

\[ \sigma = \frac{\ln \left( \frac{r_2}{r_1} \right)}{2\pi L V} I \]

Where I is the collector current measured for the applied DEV. The applied DEV and all the other parameters except I are known.

The measured current \( I = \frac{v}{AR} \) \hspace{1cm} 2(21)

Where \( v \) is the output voltage of the amplifier of the GC system, A is the amplification factor of the voltage amplifier which amplifies the output of the current to voltage converter (E.M. Amplifier) and R is the value of the feedback resistor of the current to voltage converter.

By calculating the difference between the output voltages obtained during DEV off and DEV on, from the DAS record, the value of \( v \) is obtained. All the other values are known and the polar conductivity for each GC is calculated by substituting the DEV value and magnitude of \( v \) of the corresponding systems.
Here

\[ r_1 = 0.00045 \text{m} \]
\[ r_2 = 0.0325 \text{m} \]
\[ L = 0.5 \text{ m} \]
\[ V \text{ (DEV)} = +30 \text{ V for positive GC and -30.1 V for negative GC} \]
\[ R = 10^{11} \text{ Ohms.} \]
\[ A = 1, 7, \text{ or 49 depending on the output selected.} \]

2.8. SELECTION OF OPERATING POINT OF THE GC.

It is well known that the GC should be operated in the conductivity mode for measurement of conductivity. This is achieved by applying a voltage well below the saturation voltage of the GC for a given air flow rate. This ensures that the GC doesn’t change over to saturation mode even if a considerable reduction in flow rate occurs. For ensuring this aspect it is necessary that the current –voltage characteristic of the GC is taken. Shown in Fig.2.21 is the Current – Voltage (I-V) characteristic of the GC used for negative conductivity measurement.

![GC Characteristics](image)

**Figure. 2.21.**

I-V Characteristics of the GC.
The characteristic was taken up to 85 Volts. The positive conductivity measuring GC is exactly same in dimensions. The characteristics show a tendency to saturate after about 70V. The performances of the other sensor is the same.

The system characteristics were estimated and a DEV of 30 V selected for operation. The EM Amplifier system was calibrated using Keithly current source. This is a secondary current source which is calibrated against international standard. The sensitivity of EM Amplifier measured was 84mV/pA. Shown in Fig.2.22 is the EM Amplifier calibration curve. After calibrating for current sensitivity, the system was test run and found satisfactory.

![EM Amplifier Calibration Curve](image)

**Figure.2.22.**

EM Amplifier Calibration curve.