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Atmospheric point discharge current measurements using a temperature-compensated logarithmic current amplifier

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Marlton, G., Harrison, R. G. ORCID: https://orcid.org/0000-0003-0693-347X and Nicoll, K. A. ORCID: https://orcid.org/0000-0001-5580-6325 (2013) Atmospheric point discharge current measurements using a temperature-compensated logarithmic current amplifier. Review of Scientific Instruments, 84 (6). 066103. ISSN 0034-6748 doi: 10.1063/1.4810849 Available at https://centaur.reading.ac.uk/32898/

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Published version at: http://dx.doi.org/10.1063/1.4810849
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Citation: Rev. Sci. Instrum. **84**, 066103 (2013); doi: 10.1063/1.4810849
View online: http://dx.doi.org/10.1063/1.4810849
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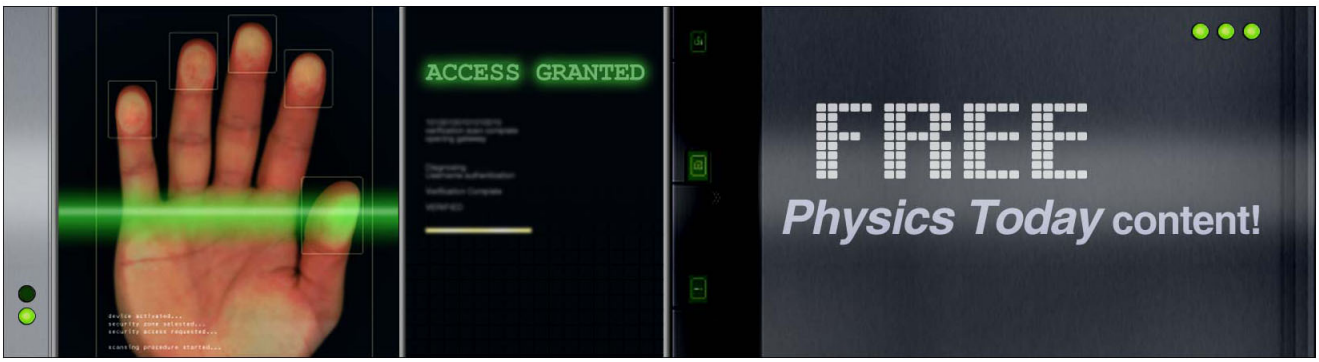

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Note: Atmospheric point discharge current measurements using a temperature-compensated logarithmic current amplifier

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(Received 19 December 2012; accepted 27 May 2013; published online 11 June 2013)

Measurements of atmospheric corona currents have been made for over 100 years to indicate the atmospheric electric field. Corona currents vary substantially, in polarity and in magnitude. The instrument described here uses a sharp point sensor connected to a temperature compensated bi-polar logarithmic current amplifier. Calibrations over a range of currents from ±10 fA to ±3 μA and across ±20 °C show it has an excellent logarithmic response over six orders of magnitude from 1 pA to 1 μA in both polarities for the range of atmospheric temperatures likely to be encountered in the southern UK. Comparison with atmospheric electric field measurements during disturbed weather confirms that bipolar electric fields induce corona currents of corresponding sign, with magnitudes ∼0.5 μA.
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Corona currents or Point Discharge Currents (PDC) occur in the atmosphere when the ambient electric field around a grounded upward-pointing sharp ended-conductor is sufficient to allow air around the point to break down, allowing a current to flow through the point.[1] Such a discharge may also be visible, such as blue wisps (St Elmo's Fire) emanating from the masts of sailing ships during thunderstorms, observed since the late 1700s.[2] In the early 1900s the PDC provided important quantitative atmospheric electrical data, such as with an elevated metal spike connected to a galvanometer[3] or condenser electrometer.[4] In atmospheric applications, the current measuring device will encounter a range of temperatures as well as a large range of currents. Here a bi-polar logarithmic current amplifier, designed originally for space applications,[5] is evaluated with upwards-pointing discharge electrode for PDC measurements.

The PDC instrument uses a stainless steel needle of length 4 cm protruding vertically through the top of a die cast box which acts as the discharge electrode. The box has dimensions 10 cm in length, 5 cm in width, and 2.5 cm in depth. The box is mounted at the top of a vertical mast, at a height of 3 m. Within the die cast box is mounted the bi-polar logarithmic current amplifier,[5] insulated from the grounded metal box by Polytetrafluoroethylene (PTFE) fixings. A conical PTFE cap of 5 cm diameter is fitted around the lowest part of the needle to prevent ingress of precipitation between the needle and the box. The end of the needle is air-wired to the electrometer circuit to minimise leakage currents.

The operation of the electrometer circuit is summarised for this application in Figure 1. Current generated in the elevated discharge point enters op amp A, which gives an output voltage proportional to the logarithm of the input current. This response is achieved by two chains of light emitting diodes (LEDs) mounted in inverse parallel directions in the feedback path of the op amp, one for either polarity of the input current. To minimise the reverse leakage current, green LEDs are used, with reverse leakage currents of I_0 of 10^{-21} A,[6] and the box is light-proofed. The LED reverse leakage currents are compensated using a second logarithmic amplifier stage, with polarity switching employed to select the appropriate polarity. The locally generated compensation current is summed with the measurement current to achieve compensation. However, because the LED characteristics show a remaining temperature response, a further temperature-compensated stage is employed, comprising a further amplifier with a thermistor in its feedback loop.

To calibrate the device, a range of input currents was generated from ±10 fA to ±3 μA, using a Time Electronics 2003S DC voltage calibrator (accuracy 0.01%) and known value resistor connected to the input needle electrode. The needle was shielded during the calibration to minimise the effects of electrostatics generated in the laboratory including space charges. The resistor calibration was checked by applying a known voltage across the resistor and measuring the current using a Keithley 6512 programmable electrometer.

The equations of the fitted lines in Figure 2 are summarised by Eq. (1), where i is the detected current (in amps) and a and b are constants which vary with the polarity of the output voltage V_{out} (in volts). For positive PDC $a = 1.225$ and $b = -0.233$ and for negative PDC $a = 1.243$ and $b = -0.234$, showing the instrument has similar response to both polarities of PDC:

$$i = 10^{\left(\frac{|V_{out}|+a}{b}\right)}. \quad (1)$$

Since the PDC instrument will be exposed to a range of temperatures, evaluating the effectiveness of the temperature compensation is important. Figure 3 compares the responses for calibrations performed in the same manner as described previously, but with and without the temperature compensation, in an environmental chamber where the temperature was varied from −20 to +20 °C.

The uncompensated output from the PDC instrument (dashed line) at very low temperatures is up to one order of magnitude greater than that in the compensated case. However, using the compensated output the temperature variation is greatly reduced for currents of ∼nA and pA. For fA currents

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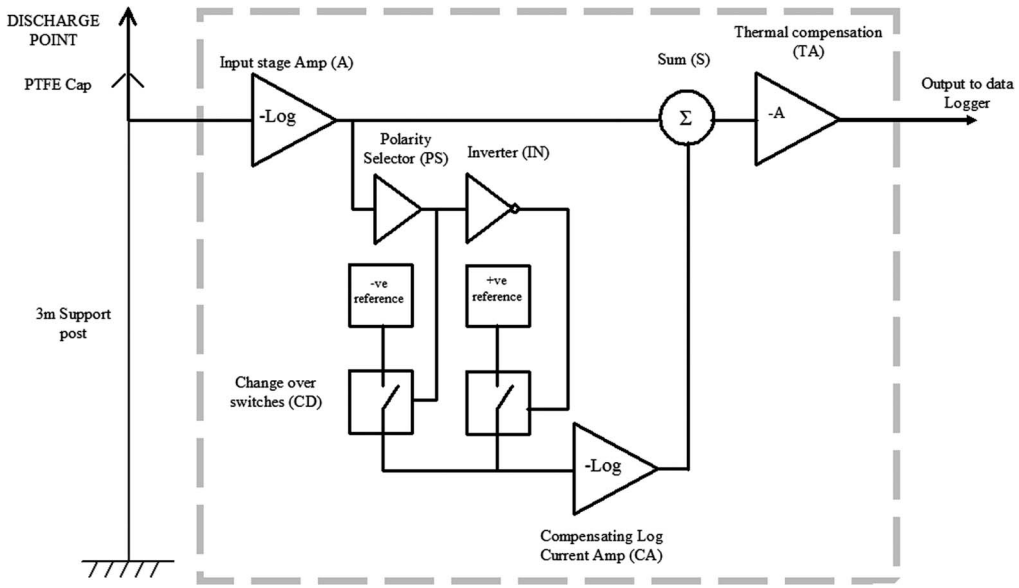

FIG. 1. Block diagram showing the major components of the point discharge current instrument in use for atmospheric measurements, employing an elevated point electrode at height 3 m, connected to bipolar logarithmic electrometer current amplifier. A polarity-dependent leakage compensation current is provided to the input logarithmic stage (A) via a Polarity Selector (PS) and Inverter (IN). The output from the compensation amplifier (CA) is of the opposite sign to that from A, which are summed to achieve compensation. A further amplifier stage (TA) provides thermal compensation.

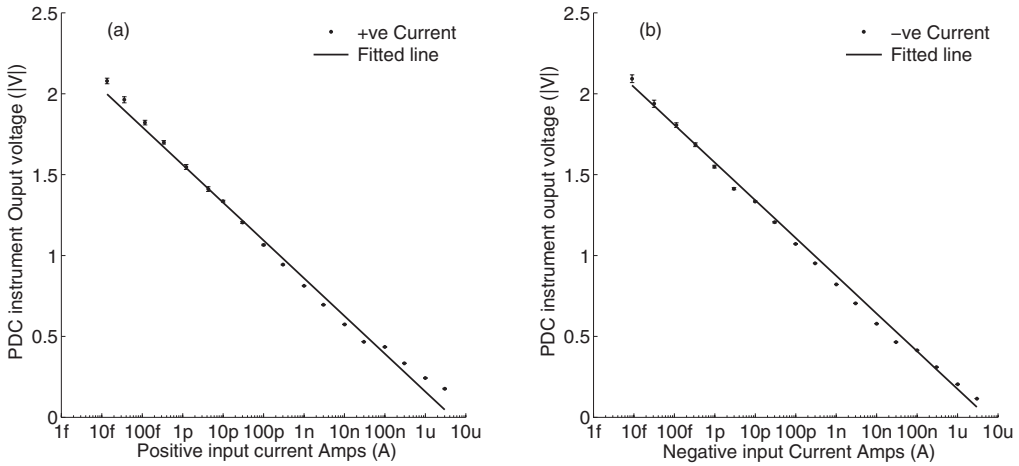

FIG. 2. Output voltage of PDC instrument for a range of generated positive (a) and negative (b) input currents. The solid lines are fitted regression lines to the data points.

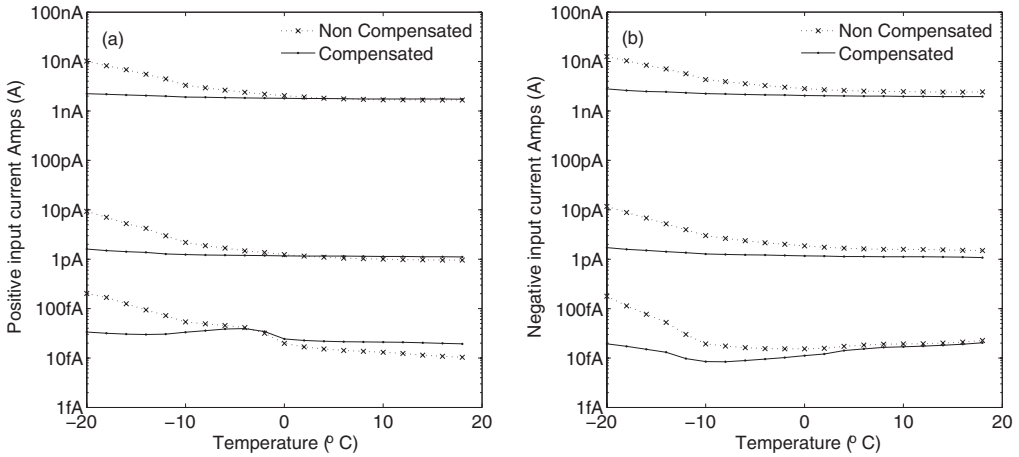

FIG. 3. Response of the PDC instrument to fixed currents (10 fA, 1 pA, and 1 nA) for uncompensated (dashed lines) and compensated (solid lines) outputs over the temperature range between −20 and +20 °C for (a) positive and (b) negative induced currents.

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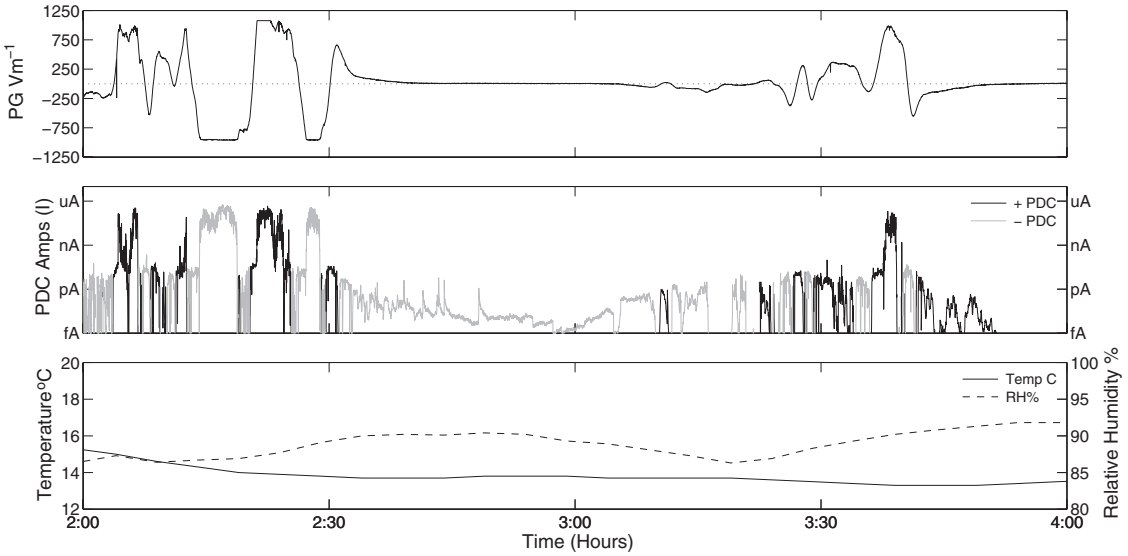

FIG. 4. (Upper panel) Variation in atmospheric potential gradient (PG); (middle panel) positive (negative) PDC in black (grey); and (lower panel) temperature (solid line) and relative humidity % (dashed line) during passage of electrified cloud during disturbed weather between 02:00 and 04:00 on September 11, 2011.

some temperature variation remains in the compensated output, which is likely to be due to incomplete compensation at current levels where a variety of small leakage contributions are present.

A characteristic of the onset of PDC in the atmosphere is that it occurs rapidly on timescales of a few seconds.[4] To ensure that the device was capable of responding rapidly, fixed currents were applied to the sensor in the same manner as before, but with the output voltage recorded by a chart recorder to determine transient responses. The time response at each current was calculated as the time taken for the output to reach 1/*e* of the final steady value. It was found that the instrument had a similar time response for both polarities of input current; for PDC $<$ 10 pA the time response varied from 2 s at 10 pA to ∼500 s at 10 fA. At PDC $>$ 100 pA, the time response varied between 0.2 s at 1 nA to 0.1 s at 1 μA, which is sufficient for the atmospheric measurements anticipated.

The PDC instrument was deployed next to an upward-facing field mill (JCI Instruments model JCI140), calibrated as described by Bennett and Harrison.[7] This allows the Potential Gradient (PG) (potential gradient is defined as PG $= -E_z$, where E_z is the vertical electric field component) to be compared to PDC currents. Figure 4 shows a period where a large PG was recorded during the early hours of September 11, 2011. The PDC instrument responds to large PG of either sign, with large negative PG associated with negative PDC of magnitude ∼0.5 μA and likewise positive PDC of the same magnitude for positive PG. From Figure 4, no response of the PDC to relative humidity (RH) % and temperature is apparent, furthermore, the variability in the PG dominates.

An upwards-facing needle point connected to a temperature-compensated bipolar logarithmic current amplifier provides effective technique for measuring atmospheric point discharge currents. Because of its low component cost (∼£50) and wide dynamic range, it provides an alternative to field mill devices for the observation of the atmospheric electric field during disturbed weather events. It also has the potential for use in space science as a robust, wide-range instrument to measure the electrification widely found[8] in planetary atmospheres.

The authors thank the Department of Meteorology Technicians for the construction, assistance with calibrations, and the maintenance of the instrument.

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