A Fieldmill for measuring Atmospheric Electricity

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Introduction

Every time we walk outside we are bathed in Force Fields. These are the gravitational, magnetic and electric fields. In the on-line text "Motion Mountain", volume III, page 209, Christopher Schiller makes the following statement about electric fields:
"every physicist should know that there is a vertical electric field of between 100 and 300 V/m on a clear day, as discovered in 1752; the earth is permanently negatively charged and, on a clear day, current flows downwards (electrons flow upwards) trying to discharge our planet."
Whereas we all know about gravitational and magnetic fields and can easily measure them [1], [2], the electric field is more of a mystery and this is largely to do with the fact that the electric field does not ***"come indoors"*** so this is a major obstacle to detection. An illustration is given in Fig 1:

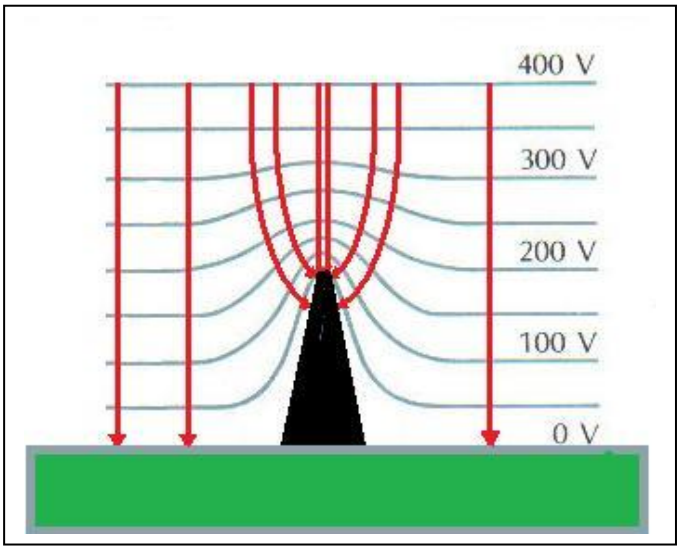


Figure 1 Distortion of field lines round a conducting object (blue – potential, red – field)

Any conducting object at ground level will distort both potential and field lines of an electric field as shown in Fig 1. Houses, trees, people.... all have relatively good conductivity when compared to the surrounding air and therefore electric fields will not be present ***inside*** artefacts at ground level.
It was taken as a challenge to measure this field and in doing so it was hoped that students would be made more aware of the vast topic of Atmospheric Physics.
It may be worthwhile visiting the website from Reading University:
http://www.met.reading.ac.uk/weatherdata/Reading_daily_AWS_graphs.html (note PG, potential gradient, denotes electric field)
Graphical data, listed under the heading "Atmospheric Electricity", shows the electric field values for the particular location of Reading, UK.

Apparatus

A little background reading showed that a Fieldmill was the most common arrangement for this field measurement and a typical layout is shown in Fig 2

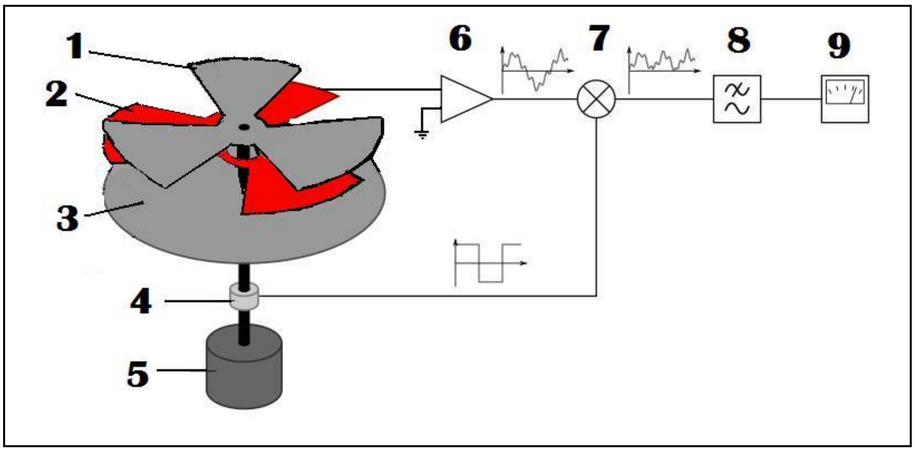


Figure 2 Diagram of a typical Fieldmill with electronic circuitry

The key for Fig 2 is as follows:

1 is a rotor blade at earth potential, **2** is a fixed plate isolated from earth - this is called the sensor plate, **3** is a ground plate, also held at earth potential, **4** is a tachometer with three equally spaced partitions, **5** is a motor providing power to the rotor blade, **6** is a charge amplifier, **7** is a mixing device and in the present apparatus it is a multiplier AD 633, **8** is a low pass filter and **9** is a centre-zero meter.

A photograph of the motor and tachometer is given in Fig 3

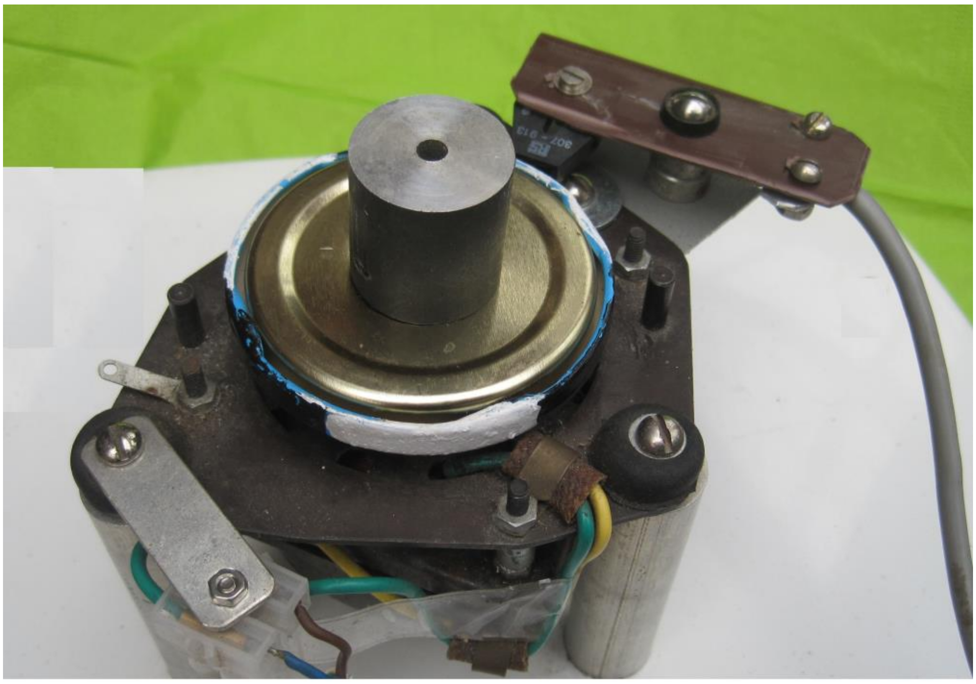


Fig 3 Photograph showing the motor plus tachometer

In the present work, item **5** is a small motor and a disc is attached to the spindle as shown in Fig 3. Black and white stripes were painted on the rim so that the reflective opto-switch (RS Components Ltd, RS 307-913, or Optek Opb 704w-z supplied by Amazon) gave a square wave output signal. The motor also turns blade **1**.
Plate **3** is fabricated from a biscuit tin so that the upper part of the spindle passes through. The charge sensor (plate **2**) is supported by this tin on insulated pillars and is alternately ***exposed to*** or ***shielded from*** the incident field by the rotor blade **1**.

The instrument/apparatus, positioned at gound level, is shown in Fig 4. Both the stationary and rotating blades are enclosed in a biscuit tin so allowing the instrument to be zeroed when the lid is placed on the tin. It also provided electrical shielding as extraneous noise from the motor was quite high.

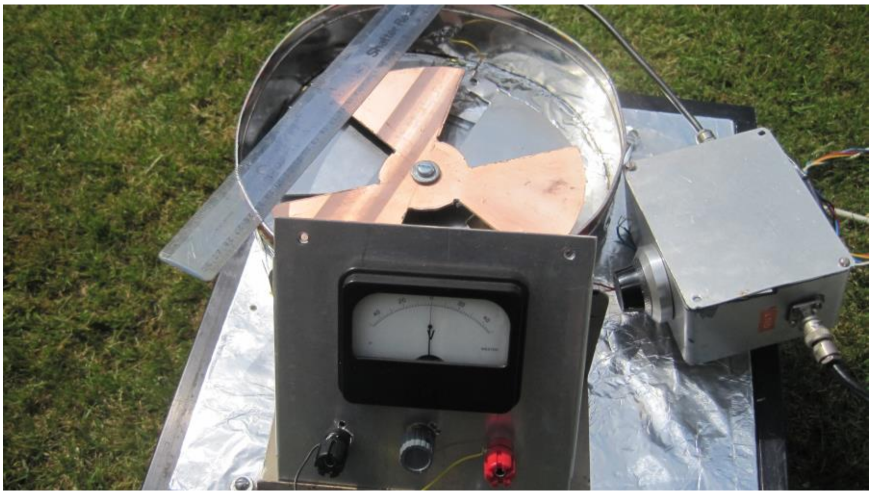


Fig 4 Fieldmill with separate charge amplifier and meter resting and on the case (ruler indicates the size of the apparatus)

The charge amplifier, encased in a separate metallic box, rests on the case of the apparatus and is connected to plate **2**. If the signal from this amplifier were to be rectified then only the magnitude of the field would be measured and whether the field was incoming or outgoing would not be determined. But, by using ***a mixer*** (item **7**) we have synchronous demodulation which gives the sign of the field and. a significant noise reduction. Commercial instruments are available for these measurements (e.g. Model 410 Scitech Instruments Ltd) and Fig 5 shows a low cost alternative.

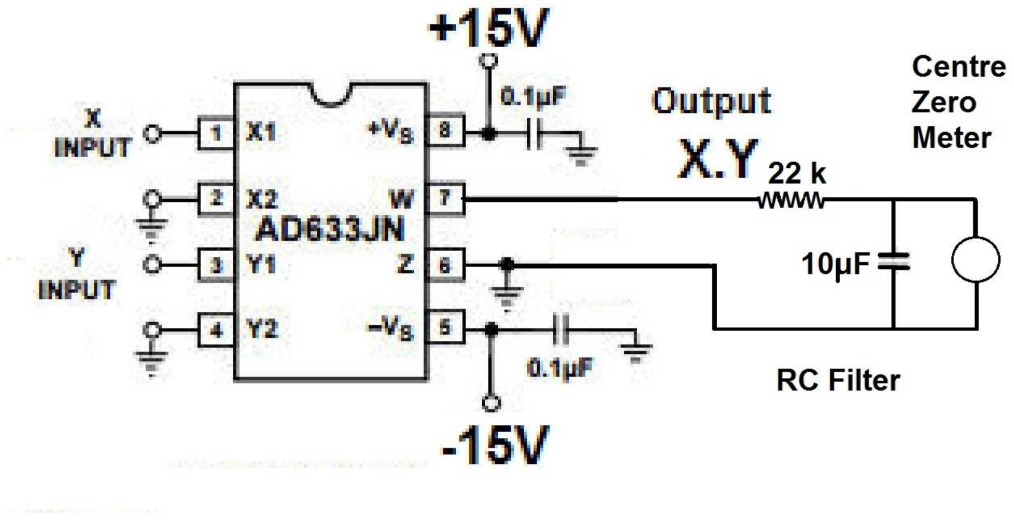
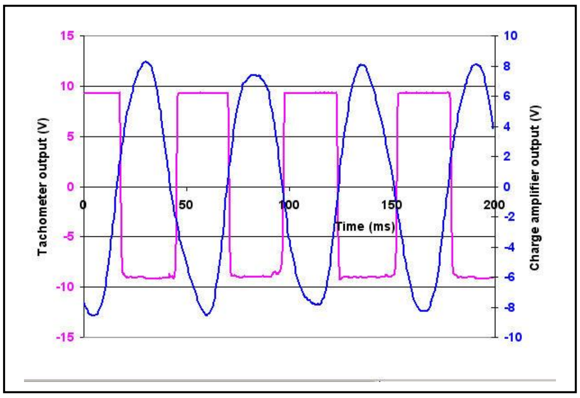
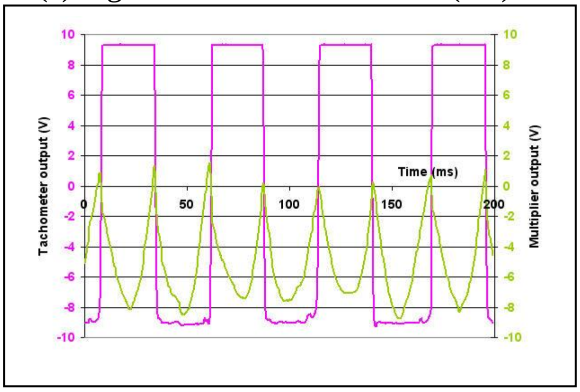


Figure 5 Multiplier circuit for **mixing** the tacho and charge signals (X and Y)
(detailed circuits of the tachometer and charge amplifier are available on request)

In setting up the Fieldmill one can place a charged object over the sensor plate and the following signals were observed, Fig 6 (a), (b):



(a) signals from the tachometer (red) and the charge amplifier (blue)



(b)signals from the tachometer (red) and the mixer (green)

Figure 6 Signals obtained when a charged PTFE rod is positioned over the Fieldmill

The output from the multiplier circuit is then passed through a low pass filter and displayed on a centre zero meter. The above readings in Fig 6 were taken with an ADC-100 Picoscope (Picotech Ltd) and copied to EXCEL sheets.

Preliminary results

The output voltage from the filtered signal is directly proportional to the earth's field and a typical, fine day, outdoor graph is given in Figure 7.

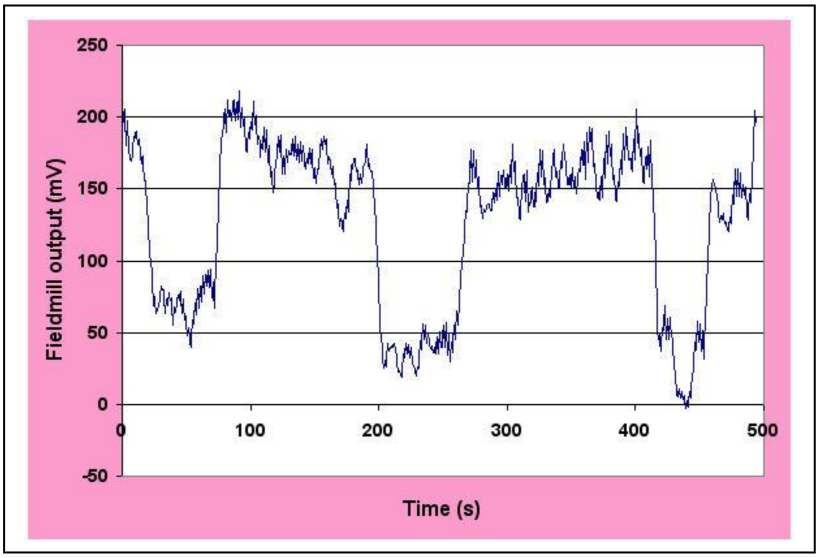


Figure 7 Output from the Fieldmill (rotor covered with earth plate during low readings of about 50 mV – this is an instrumental off-set error)

As a very approximate calibration (carried out at the Meteorological Dept., Reading University) the output readings in mV could be converted directly into field readings in V/m. Thus, the Fieldmill gives the earth's electric field as 120 (±20) Vm^{-1} as the covered reading of approximately 50 mV is subtracted from the uncovered reading of 170 mV.

Further measurements were made with the Fieldmill on 22 June 2017; a thunder storm had been forecast so there was a possibility of variability in the earth's electric field. The apparatus was placed in an open space at about 8.15 am and the trace (Fig, 8) was obtained. At approximately 8.30 am both the meter and the trace were "off-scale" indicating a large negative signal. Lowering the gain by a factor of 10x restored an "on-scale" signal and, for several periods a "zero signal condition" was tested by placing the tin lid over the rotor. The changes in the signal were quite rapid as Fig 8 shows.

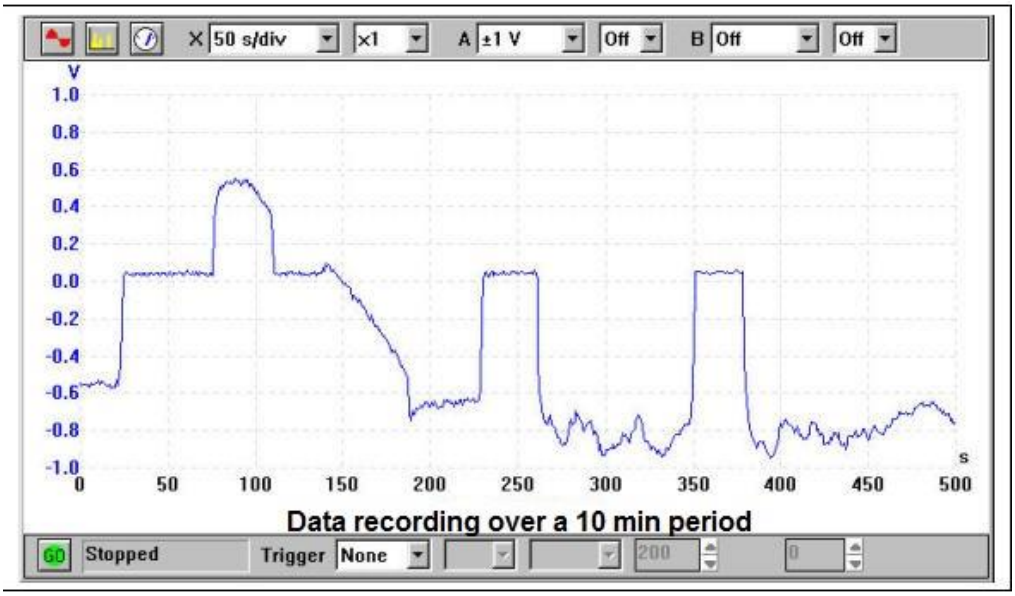


Figure 8 Earth's electric field changes as a thunder storm was approaching (rotor covered for periods 30 –70 s, 107-140 s, 230-260 s and 350-380s)

In Fig 8 we see that the earth's electric field changes from negative to positive in about 30 seconds and then the positive signal changes to negative in about 100 s. The instrument had to be moved indoors after 600s as rainfall had commenced and thunder an lightening occurred shortly afterwards. The electric field is seen to vary between +600 V/m and –1 kV/m.

Conclusions

On a fair-weather day, the Earth's electric field was found to be close to 120 V/m but the accuracy for these preliminary results was, at best, ± 20%. This agrees with the Schiller statement. The off-set error of approximately 50 mV is likely to result from imperfect blade dimensions and/or the black and white tacho divisions as these were hand painted .

Further readings were taken when storm conditions were approaching. In this case the Fieldmill indicated both positive and negative fields which were typically in excess of 500 V/m. In Fig 8 we see that the field changes from +400 V/m to –1000 V/m in approximately 100 seconds.

The variability of the Earth's electric field does pose a problem. On a fine day it will be close to 120 V/m but, when thunder is in the air, it can range from above +1000V/m to below –1000 V/m.

One could ask "is such a parameter worth measuring?". There is no right answer as Fig 6 shows the earth's electric field changes from moment to moment and sometimes by a factor of 10.An answer for this and all other measurements must lie in the immortal words of Rutherford - ***unless one can measure a quantity and put a number to it then one's knowledge is of a very meagre kind.*** So I believe Rutherford would have said, "yes" to the question and ***his*** is a sentiment with which I concur.

As a final point, the signal-to-noise performance of the apparatus is very low even with blade diameters close to 20 cm. If one could replace the simple mixer with a phase sensitive detector (PSD) then improvements would be possible. The PSD would greatly simplify the setting up procedure of the apparatus as both gain and phase of the charge signal could then be adjusted.

Acknowledgements

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The author would also like to thank the referees for making thoughtful and constructive comments.

References

[1] J Nunn (2014) "Educational inductive gravimeter" Phys. Ed. 49(1), p41

[2] F Thompson (2014) "An inductive Probe to measure the Earth's Magnetic Field" Phys. Ed., 49(5), p489.