

THE MEASUREMENT OF ATMOSPHERIC ELECTRIC FIELDS USING POLE MOUNTED ELECTROSTATIC FIELDMETERS

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Abstract

A pole mounted 'field mill' type electrostatic fieldmeter provides a simple and practical way for measurement, and for long term continuous monitoring, of ground level atmospheric electric fields. The paper describes a number of studies of this measurement method. These show how atmospheric electric field values are derived from the response of the fieldmeter when earth bonded and its height above ground level. The response of the fieldmeter is calibrated via the linear variation of its response to voltage applied during the set up procedure. The studies confirm a linearity of fieldmeter response with height above ground.

Keywords: Atmospheric electric field measurement, Electrostatic fieldmeter, Calibration

1. Introduction

A 'field mill' type electrostatic fieldmeter mounted at the top of a pole provides a simple way to measure atmospheric electric fields that has proved suitable for long term continuous monitoring observations. Figure 1 shows a practical example that formed part of a lightning warning system installed at Benbecula in the Outer Hebrides [1]. The main advantage of pole mounting is the simplicity of mounting.

Direct measurements by fieldmeters at ground level require mounting under a large plane earth level surface and are susceptible to ingress of insects and to wind blown ground level dust and dirt. Electrostatic fieldmeters are available (for example the JCI 131) that are suitable for upward pointing observations during even very adverse and wet weather conditions [2,3]. Alternative arrangements, in which a weather-shielded fieldmeter is mounted to look downwards, have proved effective over extended periods of operation (for example the JCI 180 Lightning Warning System).

The pole mounted fieldmeter approach is a practical alternative to the horizontal wire antenna system – for example as described by Harrison [4]. It is simpler to install and can be used in adverse weather conditions with appropriately constructed fieldmeter instruments [2,3].

It is not immediately obvious is how a pole mounted fieldmeter, measuring the electric field at its sensing aperture at a height above ground, provides proper measurement of the ambient atmospheric electric field. This paper is concerned with establishing the validity of measurements by pole mounted fieldmeters for monitoring of atmospheric electric fields. No studies are included on the use of this measurement method for studies of atmospheric field effects.

2. Background

Back in the early 1970s it was reported that a fieldmeter suspended on a cable would provide a response that related directly to the local space potential in its vicinity [5]. This approach provided a valuable way to examine the potential distributions and ignition risks created during, for example, the washing of the cargo tanks of very

large crude oil tankers [5,6]. For such applications, and for long term unattended measurement of atmospheric electric fields, it is essential to use instrumentation that is immune to the impact of water and to weather conditions [2,3]. It is also desirable to include operational health monitoring in such instrumentation [7]. This demonstrates and supports confidence in observations made over long periods in adverse conditions.

An earthed projection into a large scale uniform electric field will locally distort the potential distribution - as is illustrated in Figure 2. This distortion creates an electric field at the top of the projection much greater than the ambient, unperturbed electric field. The response of a cylindrical bodied fieldmeter has been found [5,6] to relate to the local potential in its vicinity as:

$$E = f V / d \quad (1)$$

- where E is the electric field created at the fieldmeter sensing aperture ($V m^{-1}$), V the local voltage (volts) and d is the effective diameter of the fieldmeter (meters). The factor f is usually about unity. Its value will have some dependence on the distribution of electric field sensitivity over the effective diameter of the fieldmeter structure.

The electric field at the fieldmeter sensing aperture will, of course, be zero when there is no difference in potential between the fieldmeter and its local surroundings¹.

¹ For a fieldmeter the electric field reading will be zero when the fieldmeter is at the local surrounding space potential. For the horizontal wire antenna approach [4] the potential is measured as that at which the current to the antenna is zero.

The response of a particular fieldmeter to the local space potential in a particular mounting support arrangement can be established by electrically isolating it, and any associated external power supply and data display equipment, from ground and applying to it a measured voltage. This enables the relationship between fieldmeter response and the voltage applied to it to be established. This approach, importantly, provides a route to formal calibration. It will be shown that values of atmospheric electric fields obtained using this approach depend only on having a fieldmeter with linear response, an accurately adjustable source of high voltage and a tape measure to measure the height of the fieldmeter sensing aperture above the local ground level. It is not necessary to use an independently calibrated fieldmeter [8].

The questions examined in the present study are:

- is the response of the fieldmeter linear with the voltage applied relative to ground?
- does the potential of the fieldmeter support have any significant influence on the readings?
- is the atmospheric electric field uniform over heights up to a few meters?
- what is the influence of the direction of the fieldmeter and its sensing aperture in relation to the ambient electric field?

3. Experimental Measurements

A small self-contained electrostatic fieldmeter (JCI 140) was mounted at the top of a thin pole. The response of an electrostatic fieldmeter to the electric field at its sensing aperture can be checked to be linear during formal calibration up to fields near the

breakdown strength of air [8]. The tube of the mounting pole was in sections that socketed together so the fieldmeter could be easily mounted at a number of different heights above ground. The overall arrangement of the mounting pole is shown in Figure 3.

The fieldmeter was insulated from its support and the pole from ground so that the voltage of the pole could be set either to earth or to the same potential as that applied to the fieldmeter. This enabled estimation of the influence of the pole mounting when voltages were applied to the fieldmeter and the pole either held at the same potential or held at earth potential.

The 'height' of the fieldmeter was measured from the surface of its sensing aperture to the ground on which the pole base was standing. With the mounting location shown in Figure 3 (a domestic garden) it was not expected that measurements would show a particularly linear variation with height because of the shielding effects of nearby shrubbery, fences, etc. To avoid such influences measurements on the variation of readings with height were made in a nearby large and fairly flat open park area.

The signal output from the fieldmeter and connection to the mounting pole were linked by separate cables to a remote position for measurement and for application of calibration voltages. Measurements of fieldmeter output signals were made using an Extech multimeter, EX330. Defined voltages were applied using a Monroe 241 Reference HV supply unit. This enabled voltages of either polarity to be applied in steps of 1V, 10V, 100V and/or 1000V up to $\pm 3\text{kV}$.

Measurements were made under blue, or nearly blue, sky conditions so that atmospheric electric fields remained fairly stable throughout the each period of test. A check was kept on the level of the ambient atmospheric electric field and readings only used that related to stable conditions.

Figure 4 shows a photograph of the experimental arrangement used to examine the influence of the direction of the ambient atmospheric electric field in the vicinity of the fieldmeter in comparison to the electric field created by the difference in voltage between the fieldmeter and its surroundings. The fieldmeter was mounted on a light horizontally supported tube that could be rotated on an inner supporting rod to point up or down.

4. Results

Figure 5 shows that there is a linear variation of output with the potential of the fieldmeter. This applied both for the pole at the same potential as the fieldmeter and also with the pole held at ground potential. The difference in slopes shows there is a definite but modest influence of the potential of the mounting pole on the fieldmeter response. In practical measurements, when the fieldmeter is bonded to earth, the pole will be at the same earth potential. Hence it is logical to assess the response of a fieldmeter to applied voltage using the mounting pole at that same potential.

Figure 6 shows that the variation of signal output with applied voltage remains essentially constant for different mounting heights. It also shows that when the effective diameter of the fieldmeter was increased to 105mm (with an external shroud as shown in Figure 7) the slope of this variation decreased. The ratio of the slopes is

about 1.8.

Although the measurements were made under clear blue sky conditions it was evident that atmospheric electric field values were drifting a bit with time. This was probably associated with the exhaust pollution from the passage of vehicles nearby. The drift during the time of the measurements is evident in Figure 6 from comparison of the voltage needed to be applied to the fieldmeter alone and to the fieldmeter with its shroud while at the same height (2.44m) above ground.

It is not entirely fair to estimate the effective diameter of the non-circular fieldmeter (see Figures 3 and 7) using the relation $E = fV / d$ with a value of $f = 1.0$ because this is only a reasonable approximation where the fieldmeter sensing aperture covers essentially the whole of the end of a cylindrical bodied fieldmeter. An estimate may, however, be made of the effective diameter by noting that the electric field sensitivity of the fieldmeter itself at its sensing aperture was about 23 V m^{-1} per mV output. Taking data from Figure 6 as an example: at a height of 2.44m the signal output of the fieldmeter at earth potential was 170mV. The field at the sensing aperture was hence about $23 \times 170 = 3910 \text{ V m}^{-1}$. The local voltage around the fieldmeter (from the voltage needed to be applied to give a zero fieldmeter output) was about 235V. In terms of the relationship $E = V / d$ the effective diameter of the bare fieldmeter is estimated to be about 60mm (from $235/3910 = 0.06\text{m}$). This is plausible in relation to the overall cross-section of the fieldmeter instrument body, 65 x 33mm. Applying the same approach to the fieldmeter with the shield (shown in Figure 7) the effective diameter may be estimated to be about 98mm. This is plausible agreement with the actual 105mm - bearing in mind the odd geometry of the shielded fieldmeter

arrangement!

Figure 8 shows the variation of the fieldmeter output with the height of the sensing aperture above ground. These measurements were made on a large fairly flat open park area. The nearest tree was over 80m away. The fieldmeter and the mounting support were both at earth potential. The variation with height is essentially linear. This is as would be expected in a uniform atmospheric electric field. Variations from linearity are attributed to minor variations in the atmospheric electric field over the time taken in making the observations.

In the above studies no account is taken of the contribution of the ambient atmospheric electric field around the fieldmeter in comparison to the field generated at its sensing aperture by the difference in voltage between the sensor and its local environment. In the example noted above, the electric field at the sensing aperture was 3910V m^{-1} with an atmospheric ambient electric field of $235/2.44 = 96\text{V m}^{-1}$. This ratio of the field created by the difference in potential to the ambient level of the electric field (a ratio about 40) shows that the influence of the ambient atmospheric electric field is quite small in comparison to the influence of the local potential for the geometries and sensing heights used.

Figure 4 shows a mounting for the fieldmeter that enables it to be easily changed from pointing up to pointing down by rotating its horizontal support tube. Figure 9 shows observations made at different heights with the fieldmeter pointing up and pointing down. It was not easy to rotate the pointing direction of the fieldmeter with its sensing aperture at a constant height. Nor was it easy to do the rotation in a time suitably short

in relation to the time of variation of atmospheric electric fields. However the observations made may be assessed as follows:

- the fieldmeter voltage at which the output is zero provides a measure of the local atmospheric voltage at that time and height ($V_{S=0}$)
- we know that in a uniform atmospheric electric field the response of an earthed fieldmeter, $S_{V=0}$, is linear with field and with height
- we can hence compare observations by looking at the ratio $S_{V=0} / V_{S=0}$ for the fieldmeter looking up and looking down at different heights.

The results, in the following table, show that the response of the fieldmeter is not significantly affected by its pointing direction. This is as would be expected from the above results that showed that the main factor determining the fieldmeter signal output was the local potential around the fieldmeter - with only a small influence from the local ambient electric field. If an independent check had been available on the value of the atmospheric electric field at the time of each measurement (for example with an independent reference fieldmeter at a constant height) then it is expected that the small influence of the direction of the atmospheric would have been revealed.

	Fieldmeter pointing up		Fieldmeter pointing down	
Sensing aperture height h (m)	2.11	2.31	1.73	1.93
V for zero output ($V_{S=0}$)	112	158	64	107
Atmospheric E field ($V m^{-1}$) from ($V_{S=0}$) / h	53.1	68	37	55
$S_{V=0}$	72	101	40	70
$S_{V=0} / V_{S=0}$	0.643	0.639	0.625	0.654

The values shown in the last line of this table are essentially the same as the values of the slopes shown on the graph in Figure 9 – which are based on ‘best fit’ equation lines rather than direct individual readings.

Calculation of the voltage in the vicinity of the fieldmeter sensing aperture, V , is obtained from the fieldmeter signal, when the fieldmeter is held at earth potential, S_0 , and the slope of the variation of the fieldmeter signal with voltage, $\Delta S / \Delta V$, established during the set up and calibration procedure as:

$$V = S_0 / (\Delta S / \Delta V) = S_0 (\Delta V / \Delta S) \quad (2)$$

While it is desirable, when calibrating the variation of fieldmeter signal with voltage, to check the fieldmeter reading at voltages up to those that give zero fieldmeter signal this it is not a necessary requirement – only the slope is needed.

In practice it has been found convenient to work with a fieldmeter mounting height of about 2m. This allows easy manual set up and servicing and is adequately high to minimize ground level dust, dirt and insects. It is necessary to avoid too high a mounting to avoid risks of corona at the edges of the fieldmeter in thunderstorm conditions where ambient electric fields might be up around 10kV m^{-1} . In such a field a 100mm diameter fieldmeter mounted on a 2m high pole would experience an average electric field across its sensing aperture around 200kV m^{-1} . To avoid the risk of distortion of linearity in the fieldmeter response by corona discharges in such situations it will be wise to radius the edges of the fieldmeter body. The ability of a pole mounted fieldmeter to avoid influence from corona can be tested by checking for linearity in response as the system is raised to a suitably high voltage – for example, at least 20kV

In practical work it may be necessary to measure atmospheric electric fields with instrumentation that is in a situation where observations may be affected by the proximity of trees, buildings or ground topography. In such situations observations may be normalized by determining, during initial set up, the relationship between observations at the chosen location and simultaneous measurements made on a nearby large scale flat area during electrostatically stable blue sky conditions. 'Blue sky' conditions should give essentially the same ambient atmospheric electric field at both locations. Provided the two locations are close enough (perhaps within $\frac{1}{2}$ km or so) and on a blue sky day this will enable a factor to be determined which will convert the readings at the chosen location to the value that would apply in the absence of the field distortions arising from local topography. It is, of course, best to site the pole mounted fieldmeter well away from any structures likely to occasion corona in high ambient atmospheric electric fields – such as arise during thunderstorms. Thus it is wise to avoid mounting on top of a building. This is likely to give much greater enhancement of the ambient field and also to be near structures likely to experience corona discharging. It is also wise to avoid a mounting where ground level vegetation might experience corona in high ambient fields. Such situations should also be avoided so there is a stable well defined height for the fieldmeter observations.

5. Conclusions

The variation of output of a pole mounted electrostatic fieldmeter is:

- linear with applied voltage relative to earth
- linear with mounting height

- affected to only a modest extent by whether the potential of the mounting support is held at the fieldmeter or at ground potential.

Furthermore the variation of the fieldmeter response to applied voltage:

- is linear
- is the same at different heights
- relates to the effective diameter of the fieldmeter structure
- is little influenced by whether the fieldmeter is pointing up or pointing down.
- relates the signal observed with the fieldmeter at earth potential to the potential at which the observed signal is zero.

The present studies confirm that measurement of the variation of the fieldmeter output with its potential provides a direct way to measure the potential in the vicinity of the fieldmeter from the reading when the fieldmeter operates at earth potential. From this the atmospheric electric field can be obtained simply by dividing the calculated potential at the fieldmeter sensing aperture by its height above local ground level.

It is worth noting that atmospheric electric field measurements with a pole mounted fieldmeter do not rely upon any electric field calibration of the fieldmeter itself. They depend solely upon the linearity of response to electric fields and upon good quality measurement (during initial set up of the system) of the variation of output with applied voltage.

It will be good to make direct comparison of measurements using a pole mounted fieldmeter with measurements using a horizontal wire antenna [4]. It is expected the measurements will agree – but this needs to be demonstrated.

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Figure 1: Pole mounted fieldmeter for continuous long term measurements

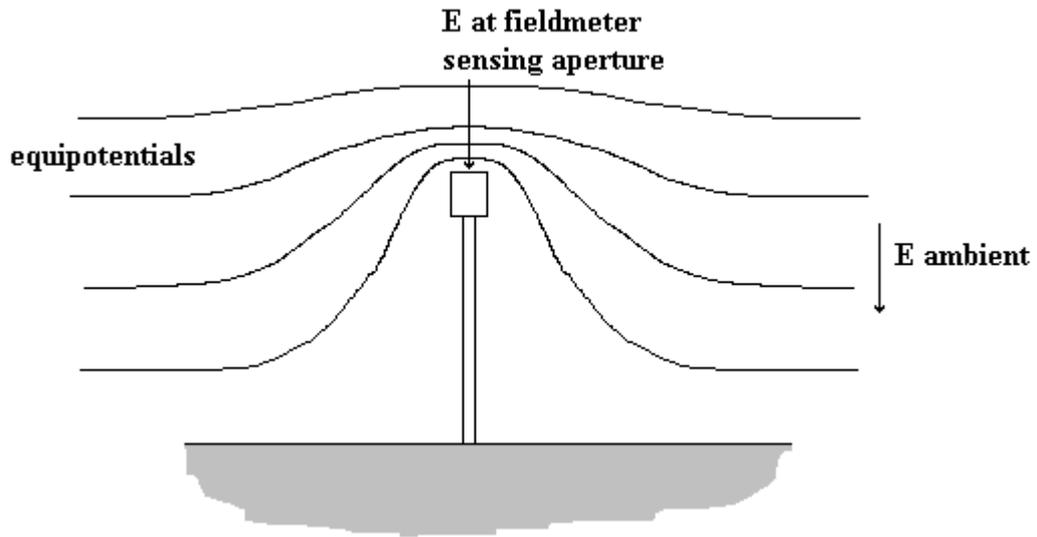


Figure 2: Perturbation of a uniform potential distribution by an earthed projection



Figure 3: Pole mounted fieldmeter



Figure 4: Photograph of the experimental arrangement for examining the influence of the fieldmeter pointing direction and height

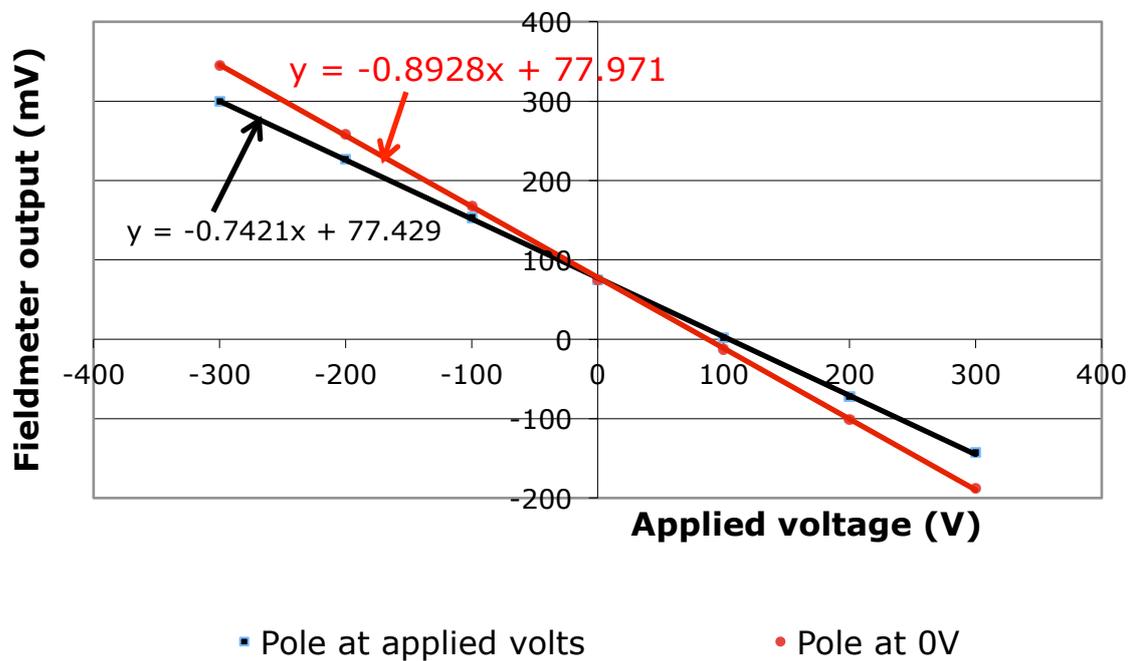


Figure 5: Comparison of variation of fieldmeter output with applied voltage with mounting pole at same potential as fieldmeter and at earth potential

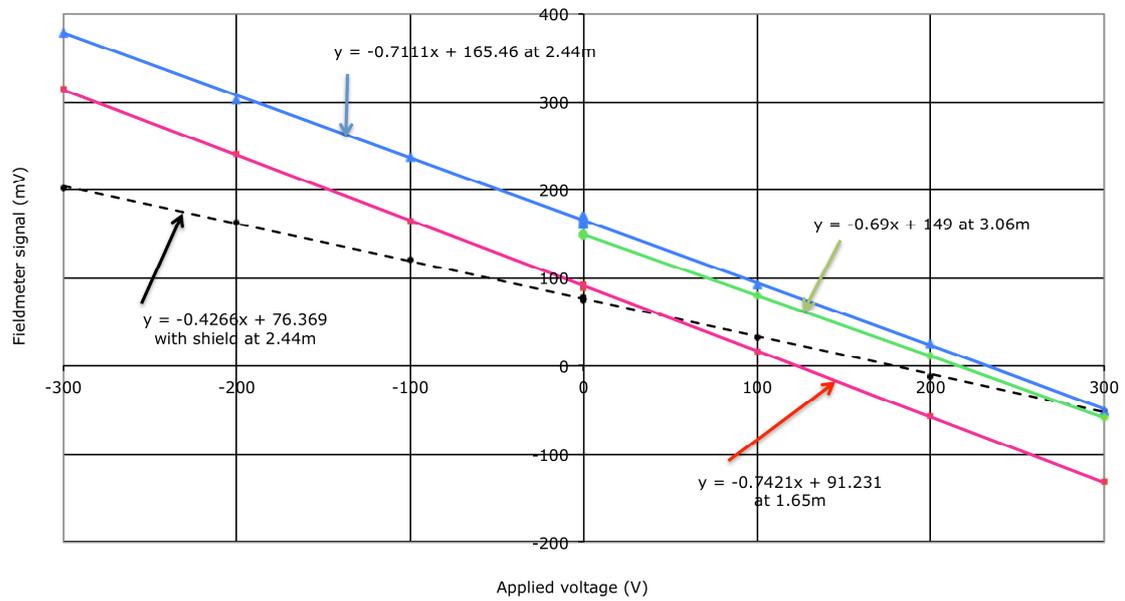


Figure 6: Fieldmeter output as a function of applied voltage at different heights and with its diameter increased by a 105mm diameter shield (dashed line)



Figure 7: Fieldmeter with shield increasing diameter to about 105mm

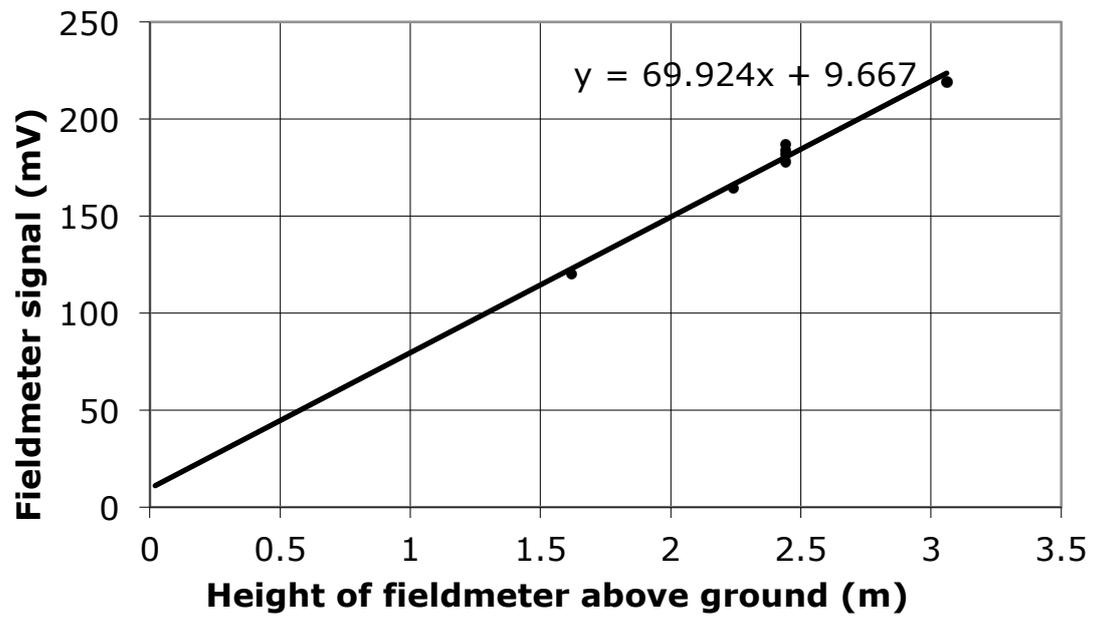


Figure 8: Variation of fieldmeter output with height of the sensing aperture above surrounding ground in a large fairly flat open area.

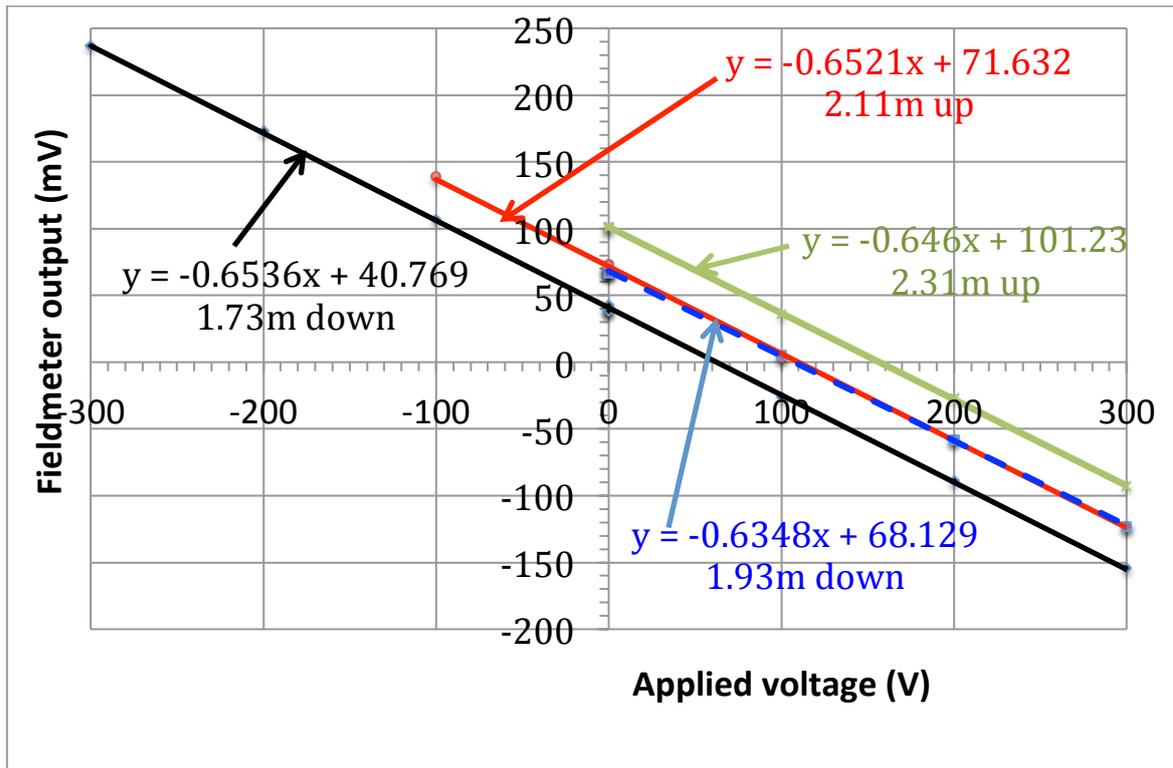


Figure 9: Variation of signal output with applied voltage for a bare fieldmeter at different heights with the fieldmeter pointing up and pointing down.