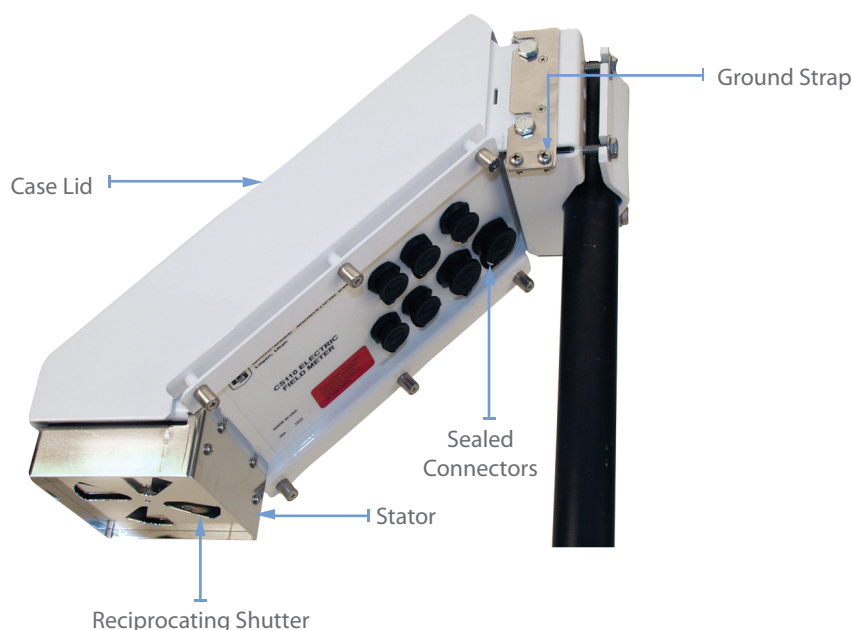


CS110 Electric Field Meter Overview

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Introduction

Lightning poses a serious threat to both people and equipment in most areas of the world. Although humans are equipped with fairly good lightning warning sensors (eyes and ears), data from electronic lightning hazard warning devices have proven valuable in lightning hazard warning.



Electronic lightning warning devices can be grouped into two classes: lightning detectors and electric-field monitors. Lightning detectors provide information about past lightning flashes, providing advanced warning of incoming storms. Yet lightning detectors provide no warning until a detectable lightning discharge has occurred, which may be too late for storms developing overhead.

Electric field monitors provide information about the local atmospheric electric field from which the likelihood of future lightning flashes can be inferred. Consequently, electric-field monitors can provide warning prior to the first strike. While electric-field monitors provide warning of incoming storms, lightning detectors are generally considered superior in this regard because of greater detection range with distance to strike estimates available in some instruments. As a result, both lightning detectors and electric-field monitors are employed in high-risk applications.

Atmospheric Electric Field

Electrical charges exert forces on each other; like charges repel and unlike charges attract. An electric force field, referred to as an electric field, is said to exist around electrical charges. Analogous to a gravitational field g defining the force F acting on a mass m ($g = F/m$), the electric field defines the force F acting on a charge q ($E = F/q$).

The electric field E is a vector quantity, having both a magnitude (field strength) and direction (direction of force exerted on a positive test charge). The units of electric field are Newtons/Coulomb, which are equivalent to the more commonly expressed units of Volt/meter (V/m). The magnitude of the electric field is equivalent to the potential (voltage) gradient.

Because large quantities of separated electrical charges are associated with thunderstorms, the vertical component of atmospheric electric field E at the earth's surface is useful for studying electrified clouds and for lightning warning. By convention, the sign of the electric field is considered positive (positive test charge would be pulled upward) if the overhead charge is predominantly negative, and defined as negative (positive test charge would move down-ward) if overhead charge is predominantly positive.

On a clear day (fair weather), a relatively small number of positive ions exist in the atmosphere that give rise to an electric field on the order of -100 to -200 V/m. These fair weather ions are thought to be generated by means of world-wide thunderstorms and distributed globally by the conductive electrosphere. The local electric field during a 24 hour fair weather period as measured with a CS110 electric-field meter is illustrated in Figure. 2.

The fair weather diurnal pattern is believed to be caused by variations in world-wide thunderstorm activity which affects a global electric circuit.

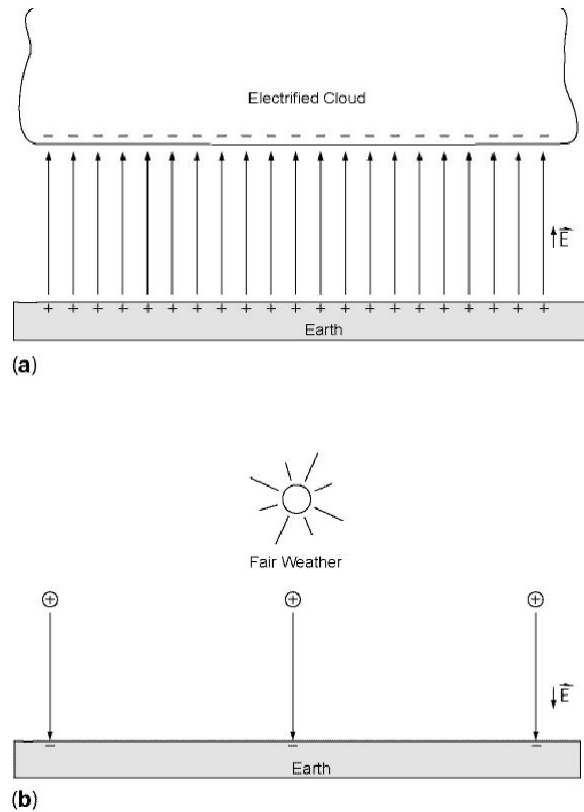


Figure 1. Sign convention of electric field at the Earth's surface.

(a) Positive electric field induced by negative charge at the cloud base.
(b) Negative electric field induced by positive ions in the fair weather conditions.

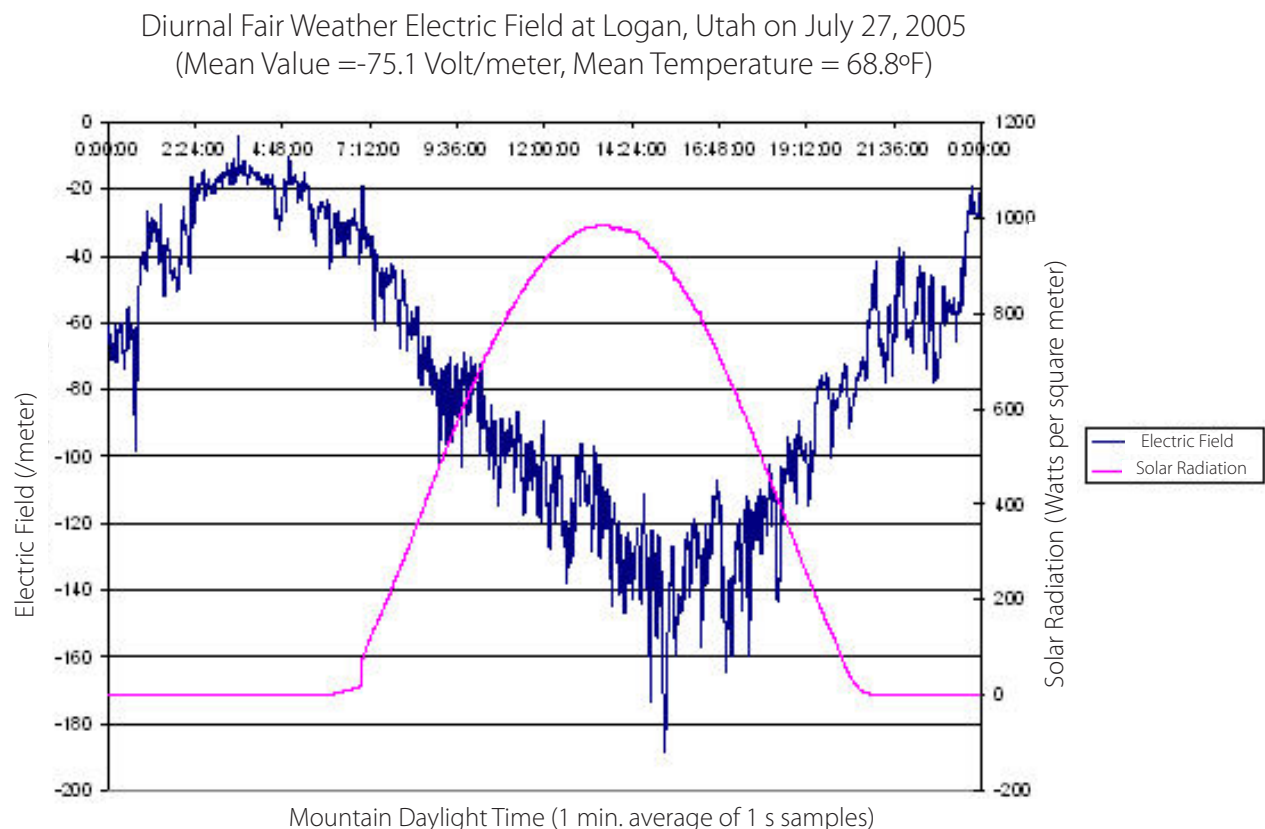


Figure 2. Electric-Field Measured with CS110 During 24 Hour Period of Fair Weather.

The presence of charged clouds results in dramatic increases in the magnitude of the local electric field as compared with fair weather fields, with the sign indicating the dominating charge polarity. Figure 3 displays the local atmospheric electric during a local thunderstorm. Deviation from and return to fair weather field conditions are observed at the beginning and end of this storm. The abrupt electric field change observed at approximately 6:12 am was due to a cloud-to-ground lightning discharge within 1 mile of the electric-field meter.

Although no universal warning criteria based on electric-field measurements exists, two levels that have been used are ≤ 1000 V/m [NASA] and ≥ 2000 V/m [NAVSEA]. Obviously the lower the level used the more risk reduction available, at the expense of increased down time for operations suspended for lightning hazard warning.

August 2, 2005 Thunderstorm at Logan Utah

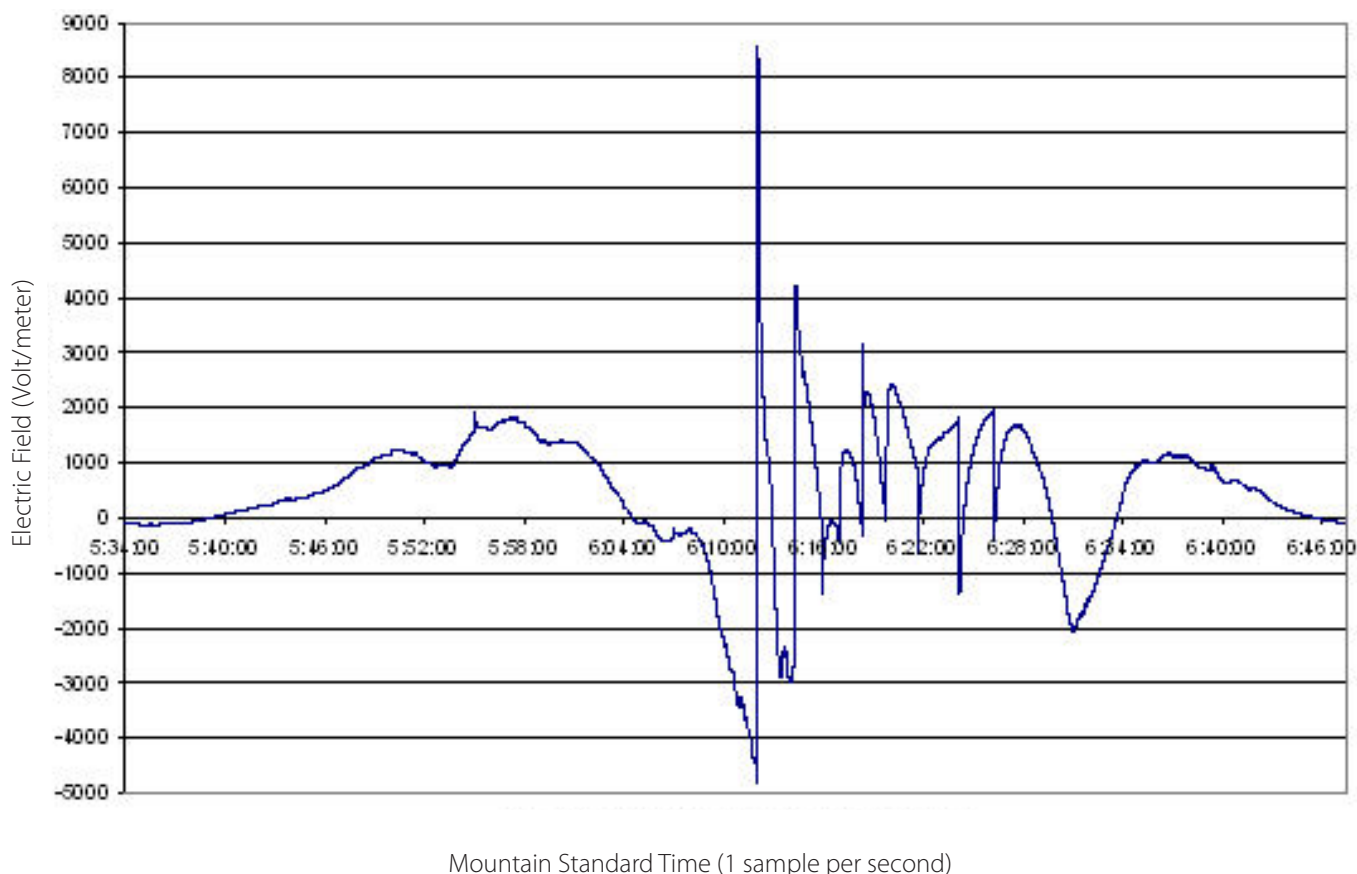


Figure 3. Atmospheric electric field monitored by a CS110 during a local thunderstorm.

CS110 Versus Traditional Field Mills

Atmospheric electric fields have been measured for decades by electric field meters dubbed field mills. Traditional field mills employ a continuously rotating vane (rotor) electrically connected to ground potential. The grounded spinning rotor alternately shields and exposes sense electrodes from the electric field to be measured, resulting in a modulation of induced electrical charge. A charge amplifier, or pair of charge amplifiers, convert the modulated charge into an ac voltage. Further signal conditioning results in a low frequency (≤ 10 Hz) voltage proportional to the electric field.

A variety of methods have been employed to make electrical contact with the spinning motor shaft of rotating vane field mills but all of them wear out over time. Furthermore, traditional field mills do not have an inherent way to compensate for electronic drift with time and temperature, along with changes in leakage currents across sense-electrode insulators, all of which induce measurement errors. Frequent scheduled cleaning of insulators is often necessary in critical field-mill applications, especially in coastal environments, to minimize measurement errors due to insulator leakage currents.

Unlike traditional rotating vane field mills, the CS110 uses a reciprocating shutter. A stepper motor opens and then closes the reciprocating shutter by 45° during measurements. The reciprocating shutter is electrically connected to ground potential by a flexible stainless steel strap operated below its fatigue limit, resulting in an ultra-reliable electrical ground connection (U.S. Patent No. 6,984,971). The stainless steel grounding strap and the motor assembly are illustrated in Figure 4; the 316-L stainless-steel electrodes and base plate are illustrated in Figure 5. An optical position encoder is used to determine the position of the shutter.

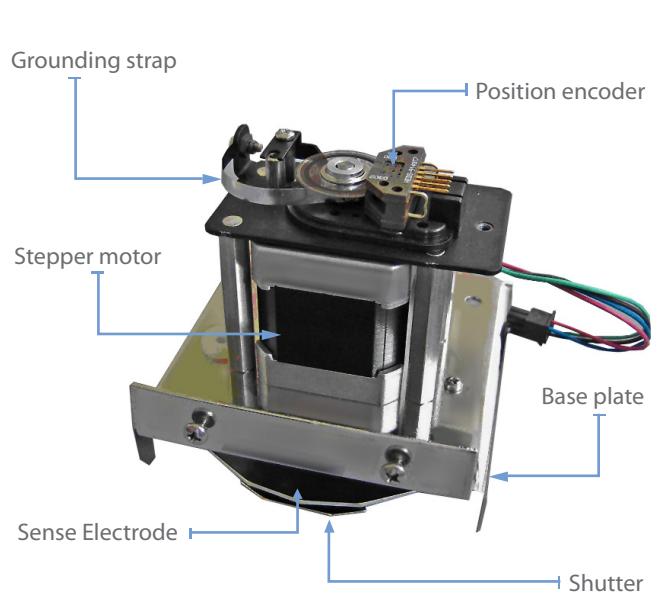


Figure 4. CS110 Motor Assembly

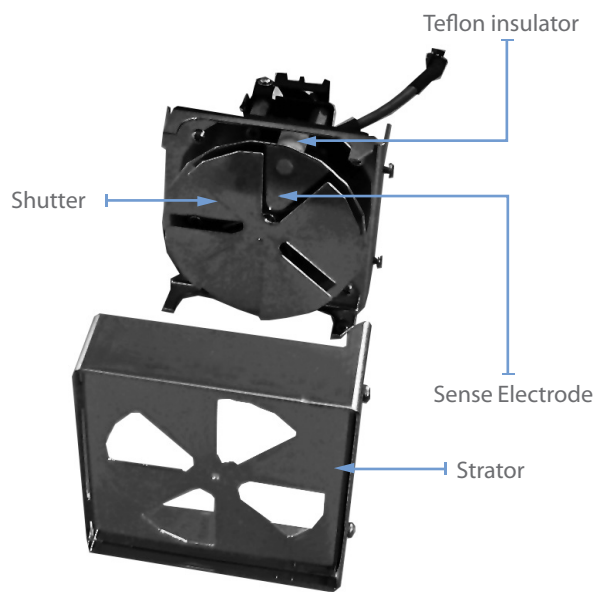


Figure 5. CS110 Polished 316-L Stainless Steel Electrodes

In the reciprocating approach, low-frequency measurement errors associated with electronic drift and changing insulator leakage currents are inherently compensated for by using the zero electric-field reference available when the shutter is closed (U.S. Patent No. 7,109,698). Traditional field mills typically consume many watts of power with their continuously operated motors. In the reciprocating approach, the stepper motor power is off much of the time, resulting in low power consumption and low

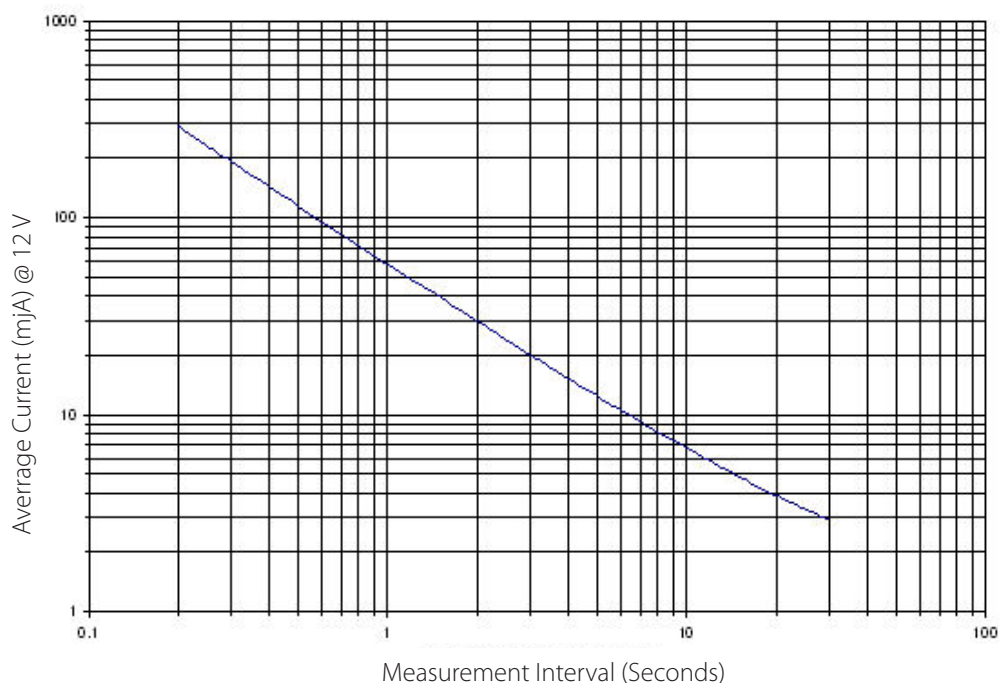


Figure 6. CS110 Average Current Consumption versus Measurement Interval

noise. The current required by the reciprocating electric-field meter powered from 12 Vdc is shown in Figure 6. As depicted in the Figure 6, the average electric-field meter current is a function of the desired measurement rate, which is under user control.

Variable sample rates based on measured results can be implemented to conserve power in solar powered applications. For example, the CS110 can be programmed to measure electric field at a 10 s rate during fair weather conditions, and then automatically switch to faster measurements during threatening conditions.

The reciprocating motion of the CS110 electric-field meter is limited to approximately 5 Hz, which is adequate for lightning hazard warning, where 1 minute averaged data is often used. For applications desiring greater than 5 Hz, the CS110 reciprocating electric-field meter can be configured as a slow antenna (MacGorman and Rust). The shutter would typically be left open indefinitely in slow antenna mode and a resistor electronically switched into the charge amplifier providing a 66 ms decay time constant. In the slow antenna mode, the CS110 is a field change meter with the charge amplifier having a high-pass filter frequency response with the lower cutoff frequency defined as $f_{3dB} = (2\pi R \cdot C)^{-1} = 2.4$ Hz. In slow antenna mode the charge amplifier output can be sampled by the datalogger as fast as every 20 ms (50 Hz), using 250 μ s integration durations for the analog integrator.

The CR1000 datalogger embedded within each CS110 can be used to extend the capability of the CS110. The CR1000 provides measurement and control functions, data processing and storage, a user interface language (CRBasic), and flexible communications options. LoggerNet datalogger support software (purchased separately) provides versatile networking and data collection capabilities.

References

[Space Shuttle Weather Launch Commit Criteria and KSC End of Mission Weather Landing Criteria](#) (NASA)

NAVSEA OP 5, Vol 1, Seventh Rev. Para 6-2, pg 6-1 and 6-2, 2001.

MacGorman D. R., and Rust W. D, The Electrical Nature of Storms, pp. 143-144, 1998.