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Sandia Lightning Early Warning Network: Digital-Based Upgrade

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Abstract

This report describes the layout and operation of the recently upgraded Sandia Lightning Early Warning Network, which was upgraded from an analog-based to a digital-based telemetry system.

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Acknowledgment

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Sandia Lightning Early Warning Network: Digital-Based Upgrade

Introduction

Because of the danger to operating personnel from the frequent afternoon thunderstorms that occur in the Coyote Canyon Test Field (CTF), operated by Sandia/NM, the original analog-based lightning early warning (LEW) system was established.

The CTF is a 40-square-mile test complex at which a wide variety of testing activities, from rocket sled shots to explosive testing, are performed. The topography at CTF ranges from desert on the west side to mountains on the east side. During July and August, afternoon thunderstorms frequently develop over the mountains on the east end of the range or move in from offrange, producing hazards to operational personnel from cloud electrification. Reference 1 contains a detailed description of this cloud electrification process.

In FY 1993, the system was upgraded from an analog-based to a digital-based Telemetry System. This was a major effort that required redesign of the entire system, from the sensors used to measure the potential gradient (PG) to the communications and control software used to acquire data and distribute that data to PC display units located throughout Sandia/NM.

This report:

- Describes the operation of the new digital LEW system
- Documents the hardware and software used
- Documents calibration and performance verification procedures.

The purpose of this documentation is to enable Department 2761, to:

- Share technical data with organizations interested in acquiring PG data.
- Provide the users of the Sandia LEW network a better understanding of how the data is collected and displayed.

Description of LEW Digital Network

The Sandia LEW system (Figure 1) consists of 16 sensors located throughout the CTF test area. The data from the sensors are gathered by a central computer and transmitted by radio to PC-based displays located throughout the CTF complex. (A detailed description of this operation is addressed in the network section of this report.)

Figure 1. Block diagram of LEW network.

The system is designed to give both a graphic and an audible warning any time that the PG reaches an unsafe level. Sandia uses 1500 V/m as the caution threshold and 2000 V/m as the danger threshold. The data are presented to the user in the form of a graphics map of the test complex with the sensor reading displayed at each sensor location (Figure 2.) When the reading from a sensor is between 1500 and 1999 V/m, that reading is displayed in yellow, and yellow hashmarks are displayed around the sensor site. When the reading from a sensor reaches the danger level of 2000 V/m or greater, the reading and hash marks are displayed in red (Figure 3). An audio alarm is sounded when the PG is 1500 V/m or higher.

By having the data displayed in a map format, users can track the progress and movement of storm across the test complex. For example, if a storm moves in from the southwest, users on the north end of the range can track its movement and have time to close down an operation before the storm reaches a dangerous level at the user's site. Simply stated, the purpose of the LEW system is to provide the operation personnel at the test site **early warning** of an approaching unsafe condition or developing unsafe condition at the work area.

Network Layout

Sensor Locations

The layout of the sensors is described in the following chart and shown in Figure 4. The geographic location of each sensor is indicated in the figure by a black square with a station number next to it.

Sensor Number	Sensor Location
1	Located at the Photovoltaic Test Evaluation Laboratory (PTEL) on the northeast side of Tech Area 1. AC powered. Provides 24-hour coverage for Tech Area I.
2	Located inside Tech Area 2, approximately 200 feet east of Building 807. AC powered. Provides 24-hour coverage for Tech Area 1. In FY 1955, this sensor will be relocated to the new (ECF) complex approximately 500 feet due east of the sensor's current location.
3	Located near Building 6020 in the 6000 explosive storage area. AC powered. Provides 24-hour coverage for the explosive storage area.
4	Located 200 feet west of Building 6741. AC powered. Provides coverage for the 10,000-foot test track area.
5	Located on the southwest side of Tech Area 3. Solar powered. Operational only from 8:00 a.m. to 5 p.m. Provides coverage for the southwest sector of Tech Area 3.

-
6	Located 200 feet south of Building 6650 in Tech Area 3. AC powered. Provides 24-hour coverage for Tech Area 3.
7	Located 100 feet north of Building 6505 in Tech Area 3. AC powered. Provides 24-hour coverage for Tech Area 3.
8	Located at Building 9956 (the starlight gas gun) just east of Tech Area 3. AC powered. Provides coverage for the Building 9956 area.
9	Located at Building 9930, which is southeast of Tech Area 3. AC powered. Provides 24-hour coverage for the Building 9930 area. Also protects the area just north of the solar power tower.
10	Located 100 feet south of Building 9965 on the Thunderwell range. AC powered. Provides 24-hour coverage for Thunderwell range, the south sector of Tech Area 3, and the area west of the solar thermal test tower.
11	Located 400 feet east of the solar power tower control building. AC powered. Provides 24-hour coverage for the solar power test facility. Also provides coverage for the area south of Building 9930.
12	Located 200 feet east of Building 9925. AC powered. Provides 24-hour coverage for Building 9925. Also used by CTF operations to provide early warning of a storm moving in from the west.
13	Located in a remote area of CTF (on top of mount Washington). Solar powered. In operation from 8:00 a.m. to 5 p.m. Used to warn CTF operations of storm activity to the south of the CTF cable site.
14	Located at the east anchor point of the CTF test cable. Solar powered. In operation from 8:00 a.m. to 5:00 p.m. Used to protect the CTF cable test site.
15	Located east of Building 9930 at the burn site. AC powered. Provides 24-hour coverage for the burn site and the CTF test cable area.
16	Located on the far north end of the CTF test range. Solar powered. In operation from 8:00 a.m. to 5:00 p.m. Used to warn CTF test cable area of a storm moving in from the Sandia mountain.
17	Location not shown in Figure 4 or displayed on the network map. However, data from this sensor is displayed at the central station computer. This location is used to test sensors that have been serviced. It is not for general use.

Two local (non-network) sensors are located at Sandia: one at Building 9960 and one in Tech Area 3 at Building 6750. Another non-network sensor will be installed in FY95 as a backup at the Explosive Components Facility (ECF) complex.

A portable sensor serves as a local probe in areas not covered by a network sensor. This sensor was designed to operate from an AC power source, internal batteries, or an external 24 Vdc power source.

Figure 2. Graphics map of the test complex with sensor reading displayed at sensor location.

Figure 3. Graphics map of the test complex indicating storm severity. Yellow indicates caution level (1500 to 1999 V/m); red indicates danger level (above 2000 V/m).

Figure 4. Layout of network sensors and display units. Solid squares are sensor locations and blank squares are display unit locations.

PC Display Units

The data collected by the LEW central computer is distributed to PC-based map display units located throughout the base. The geographic location of each display unit is shown in Figure 4 by a blank square.

Central Station

The central station serves as the network controller. It collects data from the sensors and distributes it to the PC display units. A block drawing of the central station is shown in Figure 5.

Block Drawing

The computer used for the central station is an HP RS/20 Vectra 386 tower (Figure 6), equipped with a 103 megabyte hard disk, two floppies, and a VGA display. It is connected to a Mission Instruments RM100 radio modem chassis. A special "Y" cable (Figure 7) is used to allow the parallel printer port on the PC to key the transmitter. The RS 232 data from the RM100 is connected to the COM 1 port on the PC. The DB 9 connector on the RM100 is not wired in accordance with the RS232 standard; i.e., RS232 does not support transmitter control. The "Y" cable makes the required pin-out conversions. Unlike the wiring for the DB 9 connector, the RX and TX data logic levels from the RM100 do meet RS232 specifications.

Software

The software from the central station is tasked with the following functions:

- To wake up the solar sensors during operational hours.
- To page all sensors on the network.

This task is performed via a page cycle. A page cycle is started by turning on the RM100 transmitter via the parallel LPT1 port. The central station software then enters a short delay cycle (about 0.5 second) to allow the repeater to turn on its transmitter and the receiver in the remote probe to decode the PL tone. The central station sends an address packet to the remote probe via the COM1 RS 232 port. (The packet format will be discussed later.) The transmitter is turned off and a timeout timer is started.

The central station computer will now wait for a response from the probe. If the timeout timer expires or a data error is detected in the probe data packet, the probe is repaged. The number of retries allowed for each sensor is set in an array called RETRY(n), where (n) is the sensor address. This setup allows each sensor to have a different retry count. Currently each sensor is allowed five retries.

Figure 5. Block drawing of central station.

Figure 6. HP RS/20 Vectra 386 Tower, the computer used for central station

Figure 7. Drawing of special "Y" input-output cable.

- **To log the data to the disk immediately after the page cycle is completed.** Currently the central station creates seven log files. Five of the seven are now used, and two are for future use. The files are:

LOGPG.PRN	PG readings from each sensor.
LOGDVDT.PRN	Reserved for future DVDT function evaluation.
LOGBTB.PRN	Solar probe battery voltage.
LOGBTI.PRN	Reserved for a possible upgrade (battery current shunt for solar sensors).
LOGTEMP.PRN	Data from the ZWORLD onboard temperature sensor.
LOGLINK.PRN	The number of tries required to page a probe and a data link error report. The following ASCII codes will appear in the data link report. OK—No error encountered; sensor responded to page. PE—A parity error was detected in the data packet. CRC—A CRC error was detected in the data packet. TIME OUT—The probe did not respond, timeout timer expired.

LOGPROBE.PRN Status of the probe. Motor and status alarm bits are logged. (Note: On the solar probes, only the motor status data is available due to the "low current mod." The sensor status word (8 bits) for each sensor is logged in this file in decimal format.

The central station dates and time-stamps each file and puts it in a Lotus ASCII text format. After the data is logged to the disk, the page cycle is complete.

- **To enter the report cycle.** The central station software sends a data packet addressed to the remote PC-based map displays for user viewing.

After the report cycle is completed, the central station enters the wait cycle until time to start the next page cycle.

The central station software also provides troubleshooting functions that are used by the service technicians. The commands for these functions are:

Forced page pages a solar probe that may have shut down because of a low-battery alarm condition. If sufficient battery capacity is left, the probe will respond. When the battery voltage is below the set point of the low-voltage battery alarm, the solar probes turn off the sensor and the support electronics. Only the radio receiver and computer are left powered. The sensor ignores a normal page command. This feature is designed to allow the batteries to recharge by removing the loads.

Page performs a manual page of a probe and displays all status data.

Sleep commands a probe to go to sleep.

Wakeup commands a probe to wake up.

ICF commands a probe to enter the self-test mode.

Sensor

Note: Design information relating to the field mill and ALB100 alarm box are proprietary to Mission Instruments, (602) 721-9242. Information relating to the internal design will not be discussed in this report.

Type

The Sandia LEW system (pictured in Figure 8) is a network consisting of 16 electric field mill sensors. The field mills used in the Sandia LEW network are the inverted shuttered type manufactured by Mission Instruments in Tucson, Arizona. This

sensor has a dynamic range of ± 20 kV/m. The mill is mounted 1 m above the ground. (For more detailed information refer to the EFS 1000 field mill installation and operating manual and the ALB100 alarm box description supplied by Mission Instruments, in Appendixes A and B, respectively.)

Figure 8. Typical solar-operated sensor

Custom Functions

A microprocessor programmed by Sandia is located inside the ALB100 alarm box. The computer is responsible for the following tasks:

- Network communications—The probe to central station communications protocol is implemented in software onboard the ZWORLD computer.
- Data acquisition.

Analog Data Input

An onboard 8-channel, 10-bit, analog to digital (A/D) converter acquires the following analog data from the electronics: probe PG data and battery voltage (solar units only). An onboard temperature sensor is located on the ZWORLD microcontroller card. Data from this sensor is also acquired by the A/D converter. The least significant bit (LSB) of the PG data is 39.0625 V/bit. This data is converted to the map display LSB of 1 V/bit at the central station. The LSB of the battery voltage monitor is 0.029325513 V/bit. The PG and temperature data conversion are bipolar; the battery monitor conversion is unipolar.

Probe Status Bits

An onboard digital input port acquires the following probe status data from the alarm box:

- State of the alarm box lights (green, amber, red) for ac-powered probes
- Field mill motor status (all probes).

Probe Power

The alarm box electronics and probe can be turned on and off by the onboard computer. Only the computer and radio remain on when the probe is shut down. This allows the probe to receive commands from the central station.

Probe Self-Test

The probe can be commanded to perform a self-test via remote control from the central station or via a control located on the front of the ALB100 alarm box. The calibration sequence of 0,+4KVM,+16KVM,-4KVM,-16KVM is automatically performed when the cal system is triggered.

Microprocessor

The embedded controller used to perform data acquisition and probe control is a ZWORLD Little Giant (LG), pictured in Figure 9. The LG board provides a single-board solution for the I/O requirements of the LEW system. The following features of the LG pertain to the LEW system:

Low power draw from power source (60 MA)

Watchdog timer

Onboard analog I/O (10 bit)

Onboard TTL I/O ports

High-current output ports

Onboard EEROM memory

2 RS232 ports

"C" programming language used to develop software.

A set of configuration jumpers on the LG board require programming to set up the LG for operation in the LEW system. The configuration of jumper settings is shown in Figure 10.

Figure 9. The ZWORLD Little Gaint embedded microcontroller.

NOTES:

J7 RS232 DEV PORT
 J8 RS232 PROBE COM PORT
 J9 RS485 PORT (NOT USED)

GRAY WHITE CABLE
 ORANGE VIOLET CABLE

Figure 10. Settings for configuration jumpers.

Network Communications

VHF Radio Communications.

All communications between the central station probes and PC displays are transmitted via a mountain-top VHF FM repeater. This repeater provides reliable communications to remote locations that do not have a line-of-sight radio path back to Building 6584. The central station and sensors transmit on 164.350 MHz; the repeater rebroadcasts on 173.050 MHz. In case of a repeater failure, a radio modem has been channeled for "reverse," i.e., it receives on 164.350 MHz and transmits on 173.05 MHz. This allows the central station to communicate with probes and PC display stations that have a radio line-of-sight path to Building 6584.

Communications Format (Packet Types)

Four types of communication packets are defined for the LEW network (Figure 11). Three of the four have been implemented; the fourth is reserved for possible future expansion. All data packets are sent at 1200 baud using 8 data bits.

Common frames. All four defined packets have four common frames that are sent. The purpose of each frame is discussed in the following text.

Flag frame (2 bytes). This frame allows the receiver to detect the start of a packet.

Address frame (2 bytes). The first byte of this frame contains the 8-bit address of the station that should respond to the packet. The second byte contains the address of the station that sent the packet. The second byte was included to allow for network-monitoring software to be developed in the future.

Byte count (1 byte). This frame defines how many bytes are contained in the information frame (the bytes after the byte count frame up to the CRC frame).

CRC frame (2 bytes). This frame contains the computed CRC code at the sending station. This code is recomputed at the receiving end and is compared with this frame.

Probe page packet. This 8-byte packet is sent by the central station. Its purpose is to address a probe and command the probe to perform a function. It contains the command for the probe to excite.

Probe packet. This 26-byte packet is sent by the probe when it responds to a page. The following bytes are sent in the information frames of this packet.

PG data (2 bytes). Raw A/D counts from the A/D converter representing digitized PG data.

Figure 11. Communications format (packet types)

DVDT (4 bytes). Is set aside for future expansion.

Battery voltage (2 bytes). Raw counts from the A/D converter representing the battery voltage at the solar units.

Temp sensor (2 bytes). Raw A/D counts from the ZWORLD onboard temperature sensor.

Status (1 byte). The current status of the probe (motor and alarm bits)

Note: On solar-powered probes, only motor status is available.

Extra space (8 bytes). This space is set aside for future requirements. All data is set to zero.

PC map display packet. This 55-byte packet is sent by the central station to the remote PC display units during the report cycle. It contains the data and operational status information for each probe on the network. For a detailed description of each byte, see Appendix C.

Text message packet address. A text message packet address was defined for a possible future enhancement to the PC map display program. The purpose of this address is to allow the service technician to send a short text message packet to the user display units from a portable service node PC. This message could be displayed as a scrolling "ticker tape" at the bottom of the map display for 10 minutes from the time it was received and would provide a direct line of communication between the network users and the network managers.

Addressing

The following addressing scheme for the LEW network was defined.

<u>Address</u>	<u>Use</u>
0	Reserved for the central station (network controller)
1 through 128	Set aside for remote probes
129	Reserved for the PG map display
130	Reserved for the PC text message display
131 through 253	Undefined
254	Reserved for a service station node (portable service PC with radio modem)
255	Never to be used to address a device. (This is to prevent confusion with the sync flags.)

Probe Types

Two types of probes are defined in the LEW network software: AC powered (24-hour operation), and solar powered (9-hour operation)

Solar-Powered Probes

Enclosures

The probe support, electronics, charge controller, and batteries are housed in a protective enclosure manufactured by Zomeworks Corporation of Albuquerque (see Figures 8, 12, and 13). The temperature inside the enclosure is regulated by the passive cool-cell system. This enclosure is designed to prevent the battery from freezing during the winter months. For more detailed information, refer to the Zomeworks cool-cell data sheet. A copy of the cool cell data sheet is archived in the LEW development records. The electrical wiring for the solar unit is defined in Figure 14.

Batteries

Two sealed lead-acid batteries are connected in series to provide a 24-V system. Each battery is rated at a capacity of 80 A (Figure 15).

Module Characteristic

The PV modules used are Hoxan 4810 type wt. The modules are rated at 48 W at 25°C and are connected in series to provide the required system voltage (see Figure 8).

Charge Controller

The charge controller used is an SCI ASC-24-8-AF (see Figure 16). The charge controller regulates the charging of the batteries. If the batteries were left directly connected to the solar array, they would be overcharged, and overcharging would shorten their life. The low-voltage disconnect option is not used because probe software provides low-voltage protection. A thermal compensating probe is used to adjust the battery-charging rate for battery temperature.

Low-Voltage Shutdown

A voltage divider is used to scale the battery voltage to the range of the A/D converter on the ZWORLD board. Low-battery shutdown will occur when the battery array drops to 23.5 V. The loads are reactivated when the array voltage rises to 24.5 V. This design feature protects the batteries from damage caused by a low charge condition.

Figure 12. Alarm box (sensor support electronics) and radio modem chassis.

Figure 13. Equipment configuration inside the solar enclosure.

Figure 15. Batteries for solar-powered probes.

Figure 16. Charge controller for the solar unit.

Battery Autonomy

The LEW PV system was specified to provide a 5-day battery autonomy. A paper study discussed in the next paragraph indicates that the system will meet this requirement. However, if the batteries are allowed to discharge (5 to 6 days without any sun and with the sensor operating 12 hours per day), it would take 17 days to fully recover (with the sensor operating 12 hours a day). The actual sensor operating time is 9 hours per day, which should improve recovery time.

Paper Study

A paper study on the LEW PV system was done by Jeff Zirzow, Org. 6219 (Ref. 2); it is archived in the LEW development records. The study concluded that the PV system should meet the requirements of the LEW system. The study also recommended that the PV array angle be adjusted to 35 degrees (up from horizontal) for March through August and to 55 degrees for September through February. This adjustment will maximize the amount of energy available for charging.

PC Display Units

The only major change required to upgrade the existing PC map display units was to install new operating software. The radios and modems used with the old LEW network are compatible with the new network. However, for documenting purposes, the configuration of the PC map display will be described.

Radio

A single-channel GE receiver channeled for 173.050 MHz with an outside antenna is the typical configuration. Audio from the receiver is passed via a coaxial cable to the custom modem card located in one of the PC I/O card slots.

Antenna

Most of the monitor receivers are connected to an outside antenna. This configuration is highly recommended. A radio using an inside antenna will suffer from signal degradation caused by the building from reflections caused by metal objects inside the building (operating frequency is VHF). The new display software can detect transmission errors (CRC encoding used) and will not display any data altered by transmission errors. Good results have been obtained by using 1/4 and 1/2 wave antennas.

Modem

The modem design is based on an EXAR 2211 FSK demodulator chip. The modem card was constructed on a short IBM I/O card and fits inside the PC. The card receives its power from the PC bus. The data output of the modem card is connected

to the PC COM 1 port via a 9-pin D type connector on the modem card. Audio from the receiver is connected to the modem card via a BNC type connector mounted on the modem card. A data carrier detect LED is provided to indicate the presence of the data carrier on the modem card input.

Custom Map Software

The graphic map software is Sandia in-house developed. A map of the base with the reading from each probe displayed at its location is used for data presentation. Refer to Figures 2 and 3 for an example of the map display.

PC Map Display Audio Alarm

A feature was added to the map display program to allow the user to select stations on the network to sound a different frequency tone when they are in an alarm state. The normal alarm tone frequency is 10 beeps of 1200 Hz and 10 beeps of 800 Hz for any station selected for tone shift. By listening to the tone of the warning beep, the operator can tell if an operator-selected sensor is causing the alarm state or if a nonselected sensor is causing the alarm. However, a high condition does exist in the network.

Warning Light Control From the PC

A feature was added to allow warning lights to be controlled via the LPT1 printer port. Figure 17 shows the port pin-out definition. Three lights can be controlled: green for a safe condition, yellow for a warning condition, and red for a danger condition. A trigger bit is also provided that can be used to trigger an external alarm device; when the PG is ≥ 1500 V/m, the trigger line goes high for 1 second. All bits are TTL level and are defined as logic 1 for active. If beep tone shift is selected, the alarm will be reported; i.e., if four selected stations are at 1000, 1300, 1400, and 3000 V/m, respectively, the red alarm light is set. If beep tone shift is not selected, all stations are used to make an alarm-state decision.

Sound Board

A creative labs sound blaster card will be used in a custom LEW display system for the new Sandia ECF complex. This system will be placed in operation in FY95. The sound card will be interfaced to the building public address system, allowing the LEW system to make voice announcements to the building occupants. The software is programmed to make voice announcements any time that the PG is at or above 1500 V/m. A prototype sound system is in operation.

Performance Verification

To ensure that accurate data is provided to all LEW customers, the following tasks are performed by the LEW network managers.

Figure 17. Schematic of port pin-out.

Central Station. The status of the central station is checked twice a day by checking the following items.

- Probes status
- Communication link status
- Antenna VSWR
- Transmitter power
- Current date and time displayed by the central station clock.

After each item is checked, an entry is made in a log book located at the central station. Included in this log book are the date and time of the entry, the status of the central station, and the name of the person performing the check.

Sensors. The sensor sites should be visited every six months and checked for the following conditions.

- Weeds growing under the sensor
- Dirt, insects, or anything else that may have made its way into the sensor
- Any structures that may have been erected near the sensor that may affect its operation.

In addition, from the central station, the sensors should be commanded to perform a self-test at least once a month.

Archival of information. The central station data should be archived to tape at the beginning of each month. After the data is archived, the battery data from the solar systems should be examined to verify operation and condition of the charging system. If any storms occurred during the month, the PG data should also be examined. Data from the central station is archived for one year.

Calibration. Every six months the sensors are calibrated with the CF100 calibration fixture. This will verify the calibration of the sensor and its internal self-calibration generator against a traceable standard.

Calibration

Calibration and maintenance of the Sandia LEW system is performed by Department 2761, Energetic and Environmental Testing. Department 2761 calibrates the sensors every six months and maintains the calibration records for the LEW equipment. "As found" and "as left" calibration data for the sensors are logged in the records. Information identifying the traceable standards used to perform the calibration is placed in the record. Samples of the calibration forms used are included in Appendix D.

DOE regulations require that radio transmitters be certified on one-year intervals; therefore, radio modems used for each sensor are calibrated on a one-year recall. The procedures for performing and documenting calibrations are given in *Engineering Procedure, Calibration Program, EP401560, Department 2732 Calibration Op Issue A*, and Mission Instruments documentation.

References

1. R. T. Hasbrouck, *Lightning—Understanding It and Protecting Systems from Its Effects*, Lawrence Livermore National Laboratory, Livermore, CA, 1989.
2. J. A. Zirzow, "A Paper Analysis of the Lightning Early Warning System's (LEW's) PV Power System," Unpublished document archived in the Lightning Early Warning System development records. Sandia National Laboratories, Organization 6219, Photovoltaic Technology Evaluation Department, March 1993.

APPENDIX A
EFS 1000 Field Mill Brochure

SPECIFICATIONS

MODEL: Mission Instruments EFS 1000, 1001
DYNAMIC RANGE: 0-±20kV/m in stand,
other ranges possible.

RESPONSE TIME: 0.1 second

ACCURACY:

100 < E < 500 V/m; ±2%

500 < E < 20 kV/m; ±1%

ANALOG OUTPUT: ±10 Volts

POLARITY: Potential Gradient or
Electric Field available

OUTPUT FUNCTION: $E = V_{cm} \times 2000V/m$

DIGITAL INTERFACE:

TYPE: Serial

SPECIFICATION: RS-232, 485

RESOLUTION: 15 Bits

SAMPLE RATE: 8 per Second

MOTOR:

TYPE: 3-Phase, DC operated elec-
tronic control, overload protected.

BEARINGS: Replaceable ball bear-
ings, oversized, special lubricant.

SPEED: 1650 RPM

INSTRUMENT POWER:

VOLTAGE (AC): 100, 115, 200, 230, 50-60Hz

VOLTAGE (DC): 20 to 30 (single supply)

POWER: 10W, typical; 40W, max startup

PROTECTION: All interfaces transient-protected

MECHANICAL:

SENSOR WITH STAND:

HEIGHT: 57 in. (145 cm)

WIDTH: 22.5 in. (57 cm)

CONSTRUCTION: Aluminum with
white powder-coat finish.

ENVIRONMENTAL:

OPERATING TEMPERATURE:

-20° to +140°F

-30° to +60°C

ABOUT MISSION INSTRUMENTS

Mission Instruments Company was founded in 1988 to design and build premium quality instrumentation to meet the specialized needs of industrial, government, and military users.

Encouraged by dissatisfied users of existing equipment, Mission produced the EFS 1000 field mill in 1989. We strove to build the better mousetrap, and succeeded! The EFS 1000 has proven itself ever since with highly-acclaimed performance and reliability in the field.

EFS 1000 users report unusually quiet, precise outputs, with reliable, continuous operation through all weather conditions.

Now Mission marches on with the ALB 100 monitor — and more products in the future!

Specify Mission Instruments—we're proud of our products!

MISSION INSTRUMENTS CO.
5937 East Pima Street
Tucson, Arizona 85712-4353
(602) 721-9242 Phone/FAX

MISSION

instruments co

presents
the

EFS 1000 Field Mill

Consistently Reliable
Electric Field Measurements
for
Lightning Warning
or Research Uses

CONSTRUCTION FEATURES

MOTOR— Brushless with ball bearings, stainless steel shaft, electronically-controlled, burnout-proof, field serviceable.

MATERIALS— Front end components and all hardware of stainless steel for high durability and best corrosion resistance. Exterior housing and stand of aluminum with epoxy powder coating.

INSULATORS— These critical parts are custom-molded then precision-machined from premium virgin TFE.

MAINTENANCE— Mission understands the problems of field maintenance. Each component is designed for easy servicing. Thoughtful design allows full disassembly and reassembly without disturbing calibration.

TESTING— Each machine tested over the entire temperature range to ensure reliable field operation.

QUALITY— All components chosen to ensure reliable, long-term, drift-free operation for many years. Mil-spec components used in critical locations.

OPERATING FEATURES

SELF-TEST— Built-in self-test circuit can be activated at any time. Provides a 30-second demonstration of current calibration status.

MOUNTING— Inverted mounting keeps instrument clean and greatly reduces precipitation noise. Units can be interchanged in moments in any weather.

STABILITY— Highly stable circuitry and close-tolerance mechanical construction yields long-term stability and precisely repeatable measurements.

PROTECTION— All interfaces are protected against lightning surges.

POWER— Operates on worldwide AC or 24V DC.

OPTIONS

PORTABLE STAND— Optional removable plate allows temporary mounting.

COMPUTER INTERFACE— Standard serial port is available for interfacing with most any digital system.

CUSTOM MODIFICATIONS— Custom measuring ranges, built-in microcontrollers for remote or network usage, mechanical changes, and special communications features are some of the modifications Mission can perform for its customers.

ALARM/MONITOR OPTION

Mission offers the ALB 100 option, a flexible unit which allows easy monitoring of the electric field.

- Direct display of electric field.
- Two user-adjustable threshold alarms.
- 3-light system—green, amber and red—indicates alarm status.
- Generous outputs for remote signals.
- Selectable Zero-Crossing and Activity Detectors help provide early warnings.
- Bright graphic display shows electric field level clearly, even across a room.
- Flexible audible signal announces status changes.
- System monitor display indicates that system is up and running.
- Front panel switch activates self-test.

APPENDIX B
ALB 100 Field Monitor

**Mission Instruments Company
5937 East Pima Street
Tucson, Arizona 85712-4353
TELEPHONE (602) 721-9242 FAX (602) 721-9242**

ALB 100- THE FLEXIBLE AND EASY-TO-USE ELECTRIC FIELD MONITOR

Mission Instruments' ALB 100 is the perfect companion to the EFS 1000 electric field mill. It monitors the atmospheric electric field to provide a warning of lightning hazards due to developing thunderstorms. Many government and military installations require monitoring of the electric field in order to predict the presence of a lightning hazard to local operations. The ALB 100 provides not only a numerical readout of the field for manual observations, but also contains two alarms which may be set by the user to conform to alarm threshold requirements of the particular installation.

The ALB 100 is provided as an accessory to the Mission EFS 1000 electric field mill, and when selected, is provided in place of the receiver box normally supplied. The EFS 1000 is normally mounted in its stand outdoors on level ground, (although other mounting configurations are possible), and is connected to the ALB 100 via a multiconductor cable. The ALB 100 is normally provided in a standard 19" rack-mount chassis, but is also available in a table-top chassis.

- * Front-panel digital display of the electric field in Volts per meter
- * Color bar graph display showing intensity and polarity of electric field
- * System status lights indicate functional status of various system components
- * Self-Test system (ICS) in field mill can be activated anytime by front-panel switch on the ALB. Test progress is displayed by digital LCD and color bar displays
- * All Clear (green) indicator means that system is in operating condition and that none of the alarm criteria have been met recently
- * Warning (amber) alarm displayed on front panel when user-selectable threshold is exceeded, or other lightning-like electric field activity is detected. This alarm alerts the operator that the atmospheric electric fields are rising

- * Danger (red) alarm displayed on front panel when user-selectable "danger" threshold is exceeded. This threshold can be set to a level locally identified as a "shut-down" level
- * Switchable audible signal indicates changes in status
- * Optional automatic battery backup system can keep field mill and alarm box fully functional (except AC receptacles) for up to 2 hours in the event of external power failure
- * System may be operated by external DC source of 20 to 30 VDC
- * "Dry" relay contacts available on rear panel connector for Green, Amber, and Red alarms plus audible signal, to simplify interfacing with the facility
- * Switched AC outlets provided for alarms plus audible signal to simplify connection of external signal lights, etc.
- * Various digital interface options are available allowing interrogation and control by computing devices such as personal computers. Contact the factory for available configurations

APPENDIX C

PG Map Display Communications Format

APPENDIX D

Samples of Calibration Forms

LIGHTNING EARLY WARNING SYSTEM MAINTENANCE RECORD

ALARM BOX AND PROBE

EQUIPMENT LOCATION: _____

EQUIPMENT SERIAL NUMBER: _____

DESCRIPTION OF PROBLEM: _____

DESCRIPTION OF WORK _____

CALIBRATION DATE: _____ CALIBRATION DUE DATE: _____

STANDARDS USED _____

AS FOUND DATA

CAL POINT V/M	POWER SUPPLY	TP READING	LOWER READING LIMIT	CENTER READING	UPPER READING LIMIT
+ 1500 V/M	+ 585 V		+.735	+.750 V	+.765 V
+ 2000 V/M	+ 780 V		+.980	+1.0 V	+1.02 V
-1500 V/M	-585 V		-.735	-.750 V	-.765 V
- 2000 V/M	-780 V		-.980	-1.0 V	-1.02 V

NOTES: _____

AS LEFT DATA

CAL POINT V/M	POWER SUPPLY	TP READING	LOWER READING LIMIT	CENTER READING	UPPER READING LIMIT
+ 1500 V/M	+ 585 V		+.735	+.750 V	+.765 V
+ 2000 V/M	+ 780 V		+.980	+1.0 V	+1.02 V
-1500 V/M	-585 V		-.735	-.750 V	-.765 V
- 2000 V/M	-780 V		-.980	-1.0 V	-1.02 V

NOTES: _____

TECH: _____	CASE# _____	TIME CHARGED _____	DATE CHARGED _____
TECH: _____	CASE# _____	TIME CHARGED _____	DATE CHARGED _____
TECH: _____	CASE# _____	TIME CHARGED _____	DATE CHARGED _____
TECH: _____	CASE# _____	TIME CHARGED _____	DATE CHARGED _____
TECH: _____	CASE# _____	TIME CHARGED _____	DATE CHARGED _____

JOB CLOSE OUT DATE: _____

LIGHTNING EARLY WARNING SYSTEM MAINTENANCE RECORD RADIO MODEM

EQUIPMENT LOCATION: _____

EQUIPMENT SERIAL NUMBER: _____

DESCRIPTION OF PROBLEM: _____

DESCRIPTION OF WORK _____

CALIBRATION DATE: _____ CALIBRATION DUE DATE: _____
STANDARDS USED _____

AS FOUND DATA

FREQUENCY	READING	LOWER READING LIMIT	CENTER READING	UPPER READING LIMIT
MHz		-200 HZ	164.350 MHz	+ 200 HZ

MODULATION	READING	LOWER READING LIMIT	CENTER READING	UPPER READING LIMIT
KHz DEV		+/- 3.6 KHz	+/- 3.9 KHz	+/-4.2 KHz

OUTPUT POWER	READING	LOWER READING LIMIT	CENTER READING	UPPER READING LIMIT
WATTS		3 WATTS	5.0 WATTS	10.0 WATTS

NOTES: _____

AS LEFT DATA

FREQUENCY	READING	LOWER READING LIMIT	CENTER READING	UPPER READING LIMIT
MHz		-200 HZ	164.350 MHz	+ 200 HZ

MODULATION	READING	LOWER READING LIMIT	CENTER READING	UPPER READING LIMIT
KHz DEV		+/- 3.6 KHz	+/- 3.9 KHz	+/-4.2 KHz

OUTPUT POWER	READING	LOWER READING LIMIT	CENTER READING	UPPER READING LIMIT
WATTS		3 WATTS	5.0 WATTS	10.0 WATTS

NOTES: _____

TECH FCC LICENSE NUMBER _____

TECH: _____ CASE# _____ TIME CHARGED _____ DATE CHARGED _____
TECH: _____ CASE# _____ TIME CHARGED _____ DATE CHARGED _____

JOB CLOSE OUT DATE: _____

DISTRIBUTION:

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10	0503	Gerald M. Boyd, 2335
1	0555	Edward Rankin, 2707
1	0555	David B. Davis, 2707
1	0557	Gary L. West, 2701
1	1135	Mark S. Garret, 2761
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