REVISION DATE: 9/05/2023

1 SCOPE

This document establishes the requirements and specifications for an integrated digital accelerograph with solid-state memory and internal triaxial accelerometers that:

1.1 Can function normally in extreme environmental elements of humidity, dust, and temperature.

1.2 Is a standard production model used by leading networks for recording strong motion.

2 APPLICABLE SPECIFICATIONS / STANDARDS / CODES

2.1 Specifications and standards referenced in this document form a part of this specification.

2.2 Upon written request, manufacturer shall submit certification that units and accessories furnished to meet specifications of this document comply with requirements of following standards/codes.

2.2.1 FCC § 15 Class A for industrial/commercial electrical equipment.

2.2.2 Underwriters Laboratories (UL) standard 50 for electrical equipment safety enclosures.

2.2.3 UL standard 508 for Industrial Control Equipment.

2.2.4 UL standard 94-V2 for Flammability of Plastic Materials for internal Parts.

2.2.5 National Fire Protection Association (NFPA) code 70 for electrical conductors, equipment, signaling and communications conductors and raceways.

2.2.6 Ingress Protection (IP) standard 67 for watertight integrity of electrical enclosures.

2.2.7 National Electrical Manufacturers Association (NEMA) Type 6 for electrical enclosures.

2.2.8 NEMA Type 4 for system enclosures.

2.2.9 Latest Electro Static Discharge Association (ESDA) standard S541 for electrical components and enclosures.

3 REQUIREMENTS

3.1 GENERAL OPERATION:

3.1.1 Recorder shall remain in a standby condition and start recording when actuated by strong shaking or manually activated for test purposes. After actuation, it shall stop recording after a set time or after shaking stops, and return to the standby condition, ready to record another earthquake without servicing or attention. Recording shall stop without overwriting previous events when memory becomes full.

3.1.2 Unit shall have 3 or more channels capability.

3.1.3 Unit shall be battery powered with solid-state memory and internal triaxial accelerometers.

3.1.4 Shall be 18-bit or higher AD conversion, with appropriate anti-aliasing filtering.

3.1.5 Shall be able to be installed and field-calibrated with a minimum of adjustment.

3.1.6 Shall include integrated internal triaxial Accelerometers.

3.1.7 Record accurately strong shaking (as high as 4g) without data loss or damage.

3.2   SYSTEM CHARACTERISTICS:

3.2.1   The noise level of the system (including accelerometer, recorder and interconnection) in the absence of shaking shall be a maximum of 0.030 mg (i.e., one count of an 18-bit system with 4g maximum acceleration).

3.2.2   Frequency response of the complete transducer-Recorder system shall be flat to within 1% from 0 to 40 Hz, and full documentation shall be provided to allow for accurate instrument correction of the data recorded. Any effects on the recorded data from signals or noise at frequencies higher than 100 Hz shall be <0.030 mg.

3.2.3   Recorder and Accelerometer shall reject spurious electronic and electromagnetic noise and interference from radio frequencies (RFI) as well as AC & other frequencies.

3.2.4   Recorder, communication equipment and Accelerometer shall also include effective protection against powerand phone line surges and electrostatic discharge (ESD) effects.

3.3   ACCELEROMETERS:

Accelerometers are to *be force-balance ty*pe meeting the following specifications:

3.3.1   **Operating Acceleration Range:** ±4g; full-scale output voltage of Accelerometer shall match the full-scale input of the Recorder.

3.3.2   **Accelerometer Frequency Response (Bandwidth):** Natural frequency of the unit shall be >45 Hz.

3.3.3   **Linearity:** ±1% or 1000µg/g² error from negative to positive full scale.

3.3.4   **Accelerometer Noise:** <0.03 mg from 0 to 100 Hz.

3.3.5   **Cross-axis Sensitivity:** ≤1% g/g.

3.3.6   **Temperature Effects:** <2% over the required operating temperature range of 0 *to 150°F (*-20 to 70°C). Zero point thermal drift shall be <500µg/°C.

3.3.7   **Function Testing:** Accelerometers shall produce calibration voltages during static tilt tests on all channels to allow verification of sensitivity constants. Accelerometer operation shall be verifiable via signal offset in response to signal command issued from the Recorder.

3.3.8   **Accelerometer Zero Output (Zero Adjust):** Adjustable to 0, ±10mg after field installation of accelerograph to a horizontal surface. Accelerometer zero value shall be stable over time, without steps or other changes during recording. Accelerometer zero adjustment mechanism, if present, shall lock securely so that the Accelerometer output resumes the pre-event zero level after earthquake shaking. If auto-zeroing of DC level is possible, it shall have the ability to be deactivated.

3.4   RECORDER:

The recorder shall have unity gain or selectable gain in fixed steps, and meet the following specifications.

3.4.1   **Sampling:** Recorded data sampling rate shall be selectable from 100, 200 or 500 samples per second per channel.Anti-alias filtering of the analog signal from the Accelerometers or extraneous sources.

shall meet the System Characteristics noise specification (see 3.2). Channel-to-channel sampling to be synchronized to within 0.2 msec.

3.4.2 **Recorder Noise:** During normal operation, and when the Recorder transitions from the standby state to recording operation, the noise level shall not exceed the System Characteristics noise specification (see 3.2).

3.4.3 **Temperature Effects:** <2% over the required operating temperature range of 0 to 150°F (-20 to 70°C).

3.4.4 **GPS Timing:** Recorder shall record sample time information from the internal or external GPS receiver in the event header and in each file data block. Accelerograph shall also include an internal clock that is accurate to within 1 minute per month in the absence of GPS. Duty cycling of the GPS receiver shall be settable from 0% to 100%. Time and amount of last GPS update, GPS status information, and time-averaged location information (latitude, longitude and elevation) shall be available from the event header and via a status command. GPS receiver shall update internal clock when drift is greater that 0.5 msec. GPS antenna and receiver shall be locatable up to 1000 feet (300 m) from the Recorder without performance problems. Units shall be delivered with 75 feet of antenna cable.

3.4.5 **Event Run Time:** Pre-event run time shall be adjustable from 1 to 60 seconds. Post-event hold-on time shall be adjustable from 10 to 60 seconds.

3.4.6 **Triggering:** Declaration of a triggered condition to depend on the acceleration (within the 0.1 - 12 Hz frequency band) and channel trigger voting. When the acceleration on a specified channel exceeds the trigger threshold level specified for that channel, that channel's specified number of votes is added to the total votes for trigger. When the total number of votes reaches the minimum specified for triggering, a trigger condition is declared, and recording is to begin at the start of the next second. Once a triggered condition is declared, recording shall continue until after the detrigger condition is met, dependent on the continuing motion and the channel detrigger voting. When the acceleration on a channel no longer exceeds the detrigger threshold level specified for that channel, continuously for the number of seconds specified by the post-event run time, that channel's specified number of votes is added to the total votes for detrigger, for as long as that condition continues. When the total number of votes reaches the specified minimum for detrigger, a detrigger condition is declared, and recording shall stop at the start of the next second. For all channel signals, trigger and detrigger threshold levels shall be independently adjustable from 0.1 mg to full-scale. The number of votes for each channel shall be settable from 0 through 5 for both trigger and detrigger. The total number of votes required to trigger or detrigger the Recorder shall be independently settable from 0 through 9. Recorder shall be configurable to do timed trigger recording at minimum 5 settable times of a day with duration of 1 to 600 seconds. The recorder shall also set external trigger line active for the same duration.

3.4.7   **Function Tests:** Under user control, Recorder shall generate test signal commands to the Accelerometers to allow verifying Accelerometer operation from the recorded data. Recorder shall manually trigger to accommodate and record tilt tests on all 3 axes to allow calibration of the sensitivity constants of the Accelerometers.

3.4.8   **Diagnostics/State of Health Monitoring:** Upon power up, and under user control at other times, Recorder shall perform internal self-checks and diagnostics to verify proper operation. Under user control, Recorder shall also provide, without generating an event, amount of available memory, firmware version number, timing, battery voltages, recording parameters and Accelerometer output levels (ambient and with offset signal applied). All Recorder configuration and operating parameters shall be written into a retrievable text file with a single command.

3.4.9   **Data Storage**: A minimum of 60 minutes of data per channel shall be recorded, stored on standard memory cards (e.g., PC CARD, USB Flash Drive) readable by laptop PCs (MS® Operating System). Files on memory cards shall be individually deletable as well as globally deletable.

3.4.10   **Batteries:** Entire system shall be powered by sealed internal and/or external 12-volt rechargeable DC batteries. Lithium batteries (if any) shall have a sealed stainless-steel case. All batteries shall have the capability to be replaced without soldering.

3.4.11   **Battery Charging:** Recorder shall include AC charging circuitry for maintaining the charge of the internal and/or external main batteries. Charger must be able to charge a completely discharged battery, and charging voltage and current shall be held within battery manufacturer guidelines.

3.4.12   **Recovery after Loss of Power:** In the event of main battery failure, Recorder shall automatically return to normal operation (i.e., able to trigger and record data) once power is restored, without affecting retrievability of previously recorded data. In the event of long-term power loss, recorded data shall be preserved in memory.

3.4.13   **Power Consumption:** Total power consumption at standby, to facilitate solar-powered deployment, shall be less than 65 watt-hrs/day (at 12 VDC nominal), including the power for the sensors, the power for the GPS timing receiver with 5% duty cycling, and the power for the communication components (see 3.5.2) in the absence of calls. Internal charger shall be capable of charging sufficient external batteries for 4 days autonomous operations.

3.4.14   **Accelerograph Housing:** Compact (1 foot^3 or less), total weight less than 40lbs (18Kg) when fully equipped with internal sensors and batteries.
Housing shall be suitable for outdoor deployment, made of engineering plastic, galvanized or stainless steel, crushresistant (able to withstand 30lb weight drop from 3 feet), resistant to EMI/RFI, NEMA6/IP67 rated and include a rigid mounting base. Accelerometers shall be securely mounted orthogonally in the accelerograph housing, perpendicular and parallel to thecase sides, within 1 degree.

3.4.15   **Deployment:** Accelerograph shall be easily secured to a horizontal surface; mounting base shall have three

protruding points of contact to facilitate leveling and mounting on irregular surfaces without deformation of mounting base.

3.4.16 **Electrical Connectors:** All external electrical connectors shall be of the sealed "MS" type. Accelerograph shall allow input (with an optional connector) from three external sensors up to 2000 ft away, in lieu of the internal sensors. Any externally accessible switches shall require a key to operate.

3.4.17 **Interconnection of Recorders:** Triaxial recorders to be installed at various locations on a structure shall be interconnectable with up to 5 other units, located up to 4500 ft (1400m)apart, using standard cabling or optional repeater. Each recording unit shall provide a trigger signal for triggering other units, which goes high on declaration of trigger by the Recorder and is held high until detrigger conditions are met on the Recorder (trigger and de-trigger declarations occurring as specified in 3.4.6).

3.5 **COMMUNICATION WITH RECORDER:**

3.5.1 **Remote Communication:** Remote interrogation of the system state-of-health shall be available via TCP/IP and if equipped via analog modem without retrieving or altering the data in memory. The state-of-health information shall include battery voltages, battery charging status, GPS system status, amount of memory used, event count, and accelerogram parameters (including peak values, event length, time of trigger and channels causing trigger). The remote access shall allow performing all functions that the local on-site connection can perform (includingdata retrieval, upgrading the firmware, and functional and diagnostic tests) and shall include protection against unauthorized access. All interrogation and control shall be by means of ASCII-character commands from a PC in command line interface.

3.5.2 **Communication Power Control: Communication** (internal or external) shall normally not be powered, or in the absence of calls, use <3 watt-hrs/day at 12vDC. Communication equipment, when active, shall use <225mA at 12VDC nominal.
The Recorder shall, upon triggering, power the communication equipment and initiate call-out within 5 seconds. communication control shall include ≥ 5 specifiable windows of time during which the communication equipment and optional external cellular phone are powered. Communication equipment shall remain powered for the duration of the call.

3.5.3 **Triggered Communication:** Upon being triggered, Recorder shall establish communication with a remote computer within <5 seconds. Recorder shall identify, and save in a log file, the name of the event file causing it to communicate. If the communication is unsuccessful, the unit shall re- attempt to communicate after successive time intervals doubling in length, starting at 15 second increasing to 3 days, and maintain a retrievable log of the communication attempts. Recorder shall declare communication success in a retrievable log file.

3.5.4 **Alarm Communication:** Recorder shall call a remote computer (see 3.5.3) upon detecting selectable equipment malfunctions (including at least low battery level and loss of AC) and indicate the reason for the call. Recorder shall also call out at a specifiable time or when user specifiable channels exceed specifiable "alarm" threshold levels.

3.5.5   **Triggered Data Retrieval:** Recorded data shall be retrievable locally or remotely via TCP/IP, using a desktop or laptop PC and communication software using terminal mode and standard file transfer protocols, allowing data from theRecorder to be transferred rapidly to standard PC media. During data retrieval and interrogation, the system shall remain operational and record any events that occur. Peakacceleration values shall be updated during the event and be available for retrieval while the event is still being recorded. Data retrieval from memory shall yield an exact copy of the file, and not cause stored data to be erased. Vendor shall provide specification, operating system, and interface software for the MS® Operating System Recovery computer.

3.5.6   **Data Transfer:**   Rate Data transfer rate (per three channels) shall be such that 1 minute of three-channel data is transferred in <1 minute (that is, on a per-channel basis, a transfer time of <20 seconds/channel for 60 seconds of data). Compression algorithm (if any) shall have a data-reconstruction error of <1 LSB from 0Hz to the Nyquist frequency.

3.5.7   **Data Handling Software:** Data review and retrieval software shall be provided which operates on a MS® Operating System PC and provides for field review of data as well as output in an event file with well-documented format. Software shall include a stand-alone program to display and print the event header information in a summary form. Full documentation of the header and data layout in the raw event file shall be provided. File conversion software shall be provided (with documented source code) to convert the event file from native format to COSMOS Volume 0 Strong Motion Data Format, v 1.20 (http://www.strongmotion.org).

3.5.8   **Continuous Data Transmission:** Simultaneously with other operations, instrument shall be capable of low latency, as defined by the California Integrated Seismic Network (CISN), continuous transmission of a digital data stream for full duplex real-time communication. Unit shall use a fully documented protocol compatible with modern TCP/IP communications for input into a digital seismic monitoring system (e.g., Earthworm, etc.). The digital data stream output shall be SeedLink or other formats used for California earthquake early warning by CISN.

<u>Appendix A</u>

The following units have met the CGS/SSC Triaxial Accelerograph System Requirements and are currently in use by the California Strong Motion Instrumentation Program (CSMIP), California Geological Survey.

Model and Manufacturer:

   ETNA2 and Obsidian Strong Motion Accelerograph

   Kinemetrics, Incorporated

   322 Vista Avenue

   Pasadena, California 91107

   (626)795-2220

   www.kinemetrics.com

Model and Manufacturer

   SMHR2 Strong Motion Accelerograph

   REF TEK Systems, Inc.

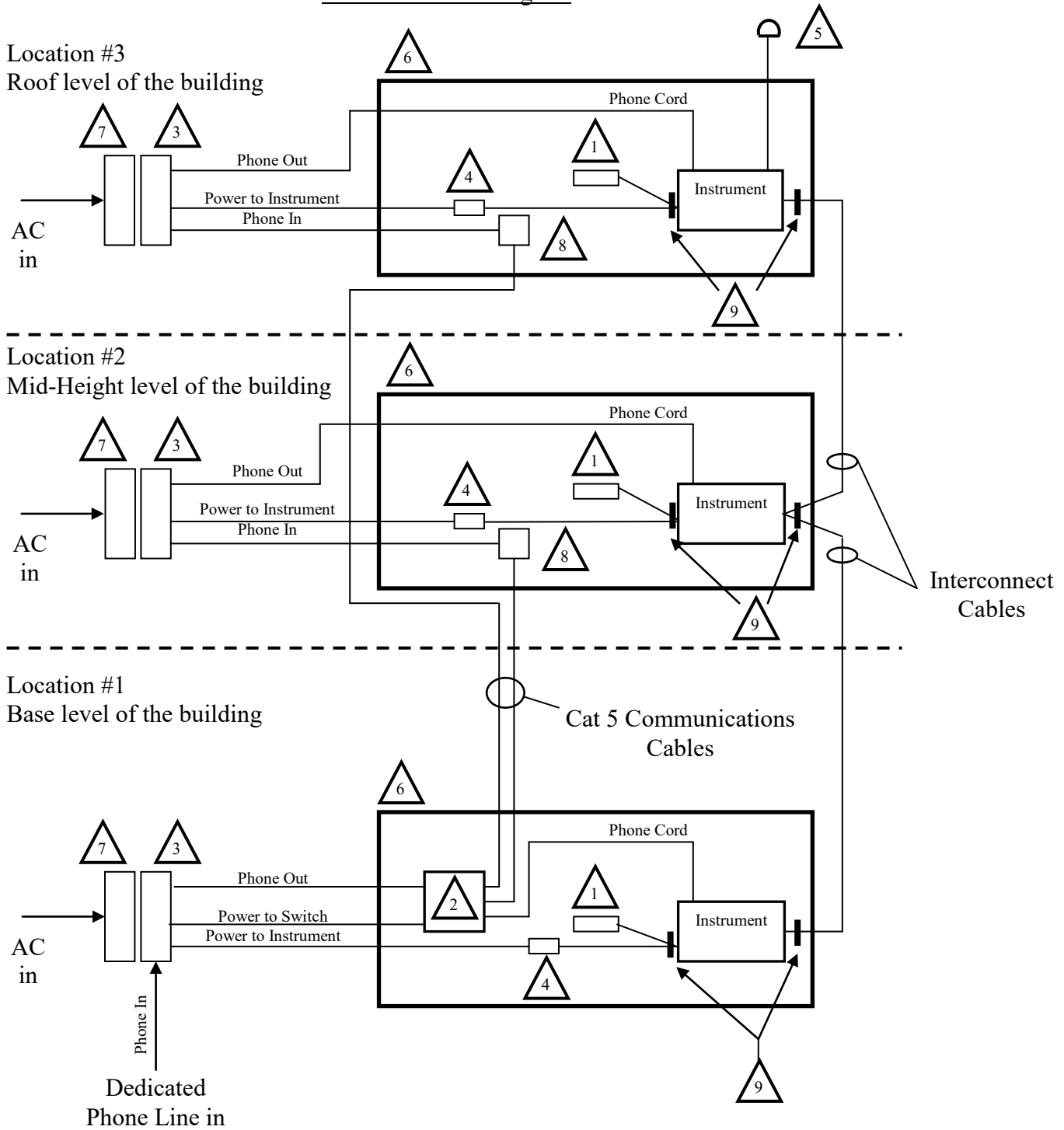   1475 Richardson Drive, Suite 200

   Richardson, Texas 75080

   (902)444-0539

   www.reftek.com

Code-Building Triaxial Accelerograph
Interconnection Diagram

Location #3
Roof level of the building

Phone Cord

Phone Out

Power to Instrument

Phone In

AC in

Instrument

Location #2
Mid-Height level of the building

Phone Cord

Phone Out

Power to Instrument

Phone In

AC in

Instrument

Interconnect Cables

Location #1
Base level of the building

Phone Cord

Phone Out

Power to Switch

Power to Instrument

AC in

Phone In

Instrument

Dedicated Phone Line in

Cat 5 Communications Cables

Notes:

1	18 AH battery	4	Instrument power brick	7	AC Duplex Outlet
2	ComSwitch 7500	5	Optional GPS time antenna	8	Splice for Cat 5 Communications cable
3	Surge suppressor	6	Protective Metal Enclosure	9	Ferrite Shield