LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Technical Report	**LIGO-T970086-00-**	**D**	24 Jan 97

Physics Environment Monitoring

Preliminary Design Document

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Distribution:

PEM PDR Review Committee

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1 INTRODUCTION

1.1. Purpose

The purpose of this document is to describe the preliminary design for the Physics Environment Monitoring (PEM) subsystem.

1.2. Scope

This document describes the proposed sensing and excitation elements which will make up the PEM. These follow the requirements defined in the PEM DRD document (1.4.1.1).

1.3. Definitions and Acronyms

- BLDG - building: 5 in WA and 3 in LA
- BT - Beam Tube
- BTM - Beam Tube Module (2Km)
- BS - Beam Splitter
- CDS - Control and Data Systems
- ETM - End Test Mass
- ICD - Interface Control Document
- IFO - LIGO interferometer
- ISOLATABLE VOLUMES - in WA: 4/LVEA+(1/VEA*4VEA)=8; in LA: 3+1*2=5
- ITM - Input Test Mass
- LVEA - Laser Vacuum Equipment Area
- PD - PhotoDiode
- PEM - Physics Environment Monitoring
- PSL - PreStabilised Laser
- RH - Relative Humidity
- RGA - Residual Gas Analyzer
- SEI - Seismic Isolation
- SUS - Suspension Control
- T - Temperature
- TM - Test Mass
- TBA/D - To Be Analyzed/Determined
- VEA - Vacuum Equipment Area

1.4. Applicable Documents

1.4.1. LIGO Documents

1.4.1.1 PEM DRD LIGO-T960127-02-D

1.4.1.2 LIGO Science Requirements Document: LIGO-E950018-02-E

1.4.1.3 Detector Subsystems Requirements Document: LIGO-T950112-04D

1.4.1.4 PEM system 1994: LIGO- T960029-00-H

1.4.1.5 ASC documents: Conceptual Design: T960134-00-D; DRD: T952007-03-I; Environmental Input to Alignment Noise: T960103-00-D

1.4.1.6 PEM DRR Report and Action Items LIGO-E960126-A-D

1.4.1.7 Assignment of PEM DRR Action Items: LIGO-L960751-00-D

1.4.1.8 PEM Interface Control Document, LIGO-TBD

2 GENERAL DESCRIPTION

The preliminary design which responds to the performance requirements given in the PEM DRR are given. The interfaces are described in separate documents, the PEM DAQ DRR (for the electrical interfaces, from CDS), and the PEM Interfaces document (to be created).

Many of the elements for the PEM can be purchased commercially, and in these cases the preliminary design consists of citing the relevant item. We give here our present best candidates for the sensors to be used in the PEM, but may wish to search alternatives for the actual implementation (principally to reduce costs or ease interfacing).

A more complete preliminary design is given for those elements which require in-house development.

3 PRELIMINARY DESIGNS

The performance requirements of sensors required can be found in the PEM DRD (see 1.4.1.1). The prices given below are approximate and are given to aid in setting the scale.

3.1. Sensors

3.1.1. Low frequency 3 axis seismometer

3.1.1.1 GURALP CMG-40T Seismometer

- manufacturer/distributor: GURALP/Digital Technology
- model: Transducer CMG-40T
- digitizer: CMG-DM16 with RS 232 interface
- standard velocity output: 800V/m/s
- optional high gain output: 8000V/m/s
- noise level: $a < 10^{-10} g$
- maximum optional frequency range: 0.008 to 50 Hz
- unit price $12,186 with digitizer (no power supply)
- optional CMG-40T hand-held control unit $896 (one unit/site for initial and periodic adjustments)
- Transducer mechanical and electrical interface parameters
- weight: 20 lb
- dimensions (inch): 6.5 x 6.6 diam
- mechanical resonance: > 400 Hz
- temperature sensitivity: < 0.6 V / 10 deg C on low gain channel
- operating range: -10 to 65^0 C
- cable length to electronics: 1m standard
- connector type: KPT06f-16-26S for the transducer
- interface to CDS for power: 12V, 50mA
- interface to CDS for output signal (optional): max ± 10 V;
- Electronics mechanical and electrical interface parameters
- weight: NA
- dimensions (inch): 4 x 6.6 diam
- operating range: -20 to 65^0 C
- interface to CDS: power 12V, 120mA
- interface to CDS for output signal: RS 232/422 standard interfaces
- output cable length (optional): 100/500 ft

3.1.1.2 Implementation

Quantity:

- one per building: 5 in WA and 3 in LA
- spares: one per site

The seismometer will be placed directly on the concrete foundation of the building, close to one of the test masses, as indicated in the PEM Interface Document. A lead-foam insulated aluminum box will be placed over the seismometer for acoustic and thermal insulation. A waist-height rope barrier will be erected around the stay-clear zone (shared with the tiltmeter and other fixed PEM LVEA sensors) to prevent excess excitation or collisions.

3.1.2. Low Frequency 2 Axis tiltmeter

3.1.2.1 Applied Geomechanics 500 series Tiltmeters

- manufacturer/distributor: Applied Geomechanics
- model considered: 520 Geodetic Tiltmeter
- resolution: <10nRad
- bandwidth: 0-10 Hz
- range (depends on the setting): $\pm 1400\mu rad$ for setting 1
- temperature control monitor (build in): 10mV/deg.C (Single ended) -40 to 100^0C range,.0.75^0C accuracy
- price for model 520 Platform Tiltmeter with micrometer legs: $8000
- •• Transducer mechanical and electrical interface parameters
- weight: 10 lb
- dimensions (inch): 9.1 x 9.1 x 5.0
- mechanical resonance: NA
- temperature sensitivity: 0.11% per deg.C typical
- operating range: -25 to 70^0C
- cable length to electronics: 3m standard to Switch Box
- connector type: 15-pin quarter turn
- interface to CDS for power: none (through the switch box)
- interface to CDS for output signal: none (through the switch box)
- •• Switch Box mechanical and electrical interface parameters
- weight: 4 lb
- dimensions (inch): 9 x 8 x 5.5
- operating range: -25 to 70^0C
- interface to CDS for power: 11-15VDC and -11 to -15VDC max 20mA each
- interface to CDS for output signal: up to ± 8 VDC single ended (16 diff) at high gain
- output cable: shielded twisted pair to an ADC channel
- terminal strip connection for power and signal
- output impedance: 270 Ohm, short and surge protected

3.1.2.2 Implementation

Quantity: one per building: 5 in WA and 3 in LA; no spares

The tiltmeter will be placed directly on the concrete foundation of the building, close to one of the test masses, as indicated in the PEM Interface Control Document (PEM ICD). A lead-foam insulated aluminum box will be placed over the tiltmeter for acoustic and thermal insulation. A waist-height rope barrier will be erected around the stay-clear zone (shared with the seismometer) to prevent excess excitation or collisions.

3.1.3. High frequency 1 axis PZT accelerometer

3.1.3.1 ISOTRON Accelerometer

- manufacturer/distributor: Endevco Meggitt Aerospace
- model: ISOTRON Accelerometer 7754-1000
- multi-channel signal conditioner power supply ISOTON model 2793M1 (16 channels)
- range $\pm 5g$
- voltage sensitivity 1000mV/g
- maximum Voltage: $\pm 5V$
- bandwidth 1Hz-10kHz
- residual equivalent g-rms noise for narrow band at 10 Hz: $5 \times 10^{-7} g_{rms} / \sqrt{Hz}$
- power requirement: +18-24VDC max 20mA
- unit Transducer price for large quantities: $745
- 16 channels signal conditioner and power supply: $1400
- optional Triaxial accelerometer mounting block model ISOTON 2950X: $95

- Transducer mechanical and electrical interface parameters

- weight: 115 grams
- dimensions (inch): 1.16 x 1 diam.
- mechanical resonance: 9 kHz
- temperature sensitivity: NA
- operating range: -55 to 85^0 C
- cable length to electronics: 3m, model 3061-129 for each accelerometer
- connector type: 10-32 UNF-2B
- interface to CDS for power: none (through the signal conditioner)
- interface to CDS for output signal: none (through the signal conditioner)

- Triaxial Mounting Block

- dimensions (inch): 1.2 x 1.2 x 1.1 without accelerometers
- weight: NA, approx 70 grams mount only
- anodized Al alloy, electrically isolated

- Signal Conditioner mechanical and electrical interface parameters

- 16 channels power supply and signal conditioner
- weight: 4 lb
- dimensions (inch): 19 inch rack mounting 1.73x19x9.45
- operating range: 0 to 50^0 C
- input connectors: BNC
- interface to CDS for power: 117 AC
- interface to CDS for output signal: 10 V pk-pk (3.535 Vrms), 2mA pk-pk or greater
- output connectors: BNC and 25-pin D connector
- output cable: shielded twisted pair to an ADC channel
- output impedance: 10 ohm

3.1.3.2 Implementation

Quantity: number of accelerometers at different locations:

1. WA 4Km IFO: 6x(4 TM)+3x(8 other chambers: BS, HAM, PSL) = 48
2. WA 2Km IFO: (12 chambers) x 3= 36
3. LA 4Km IFO: (12 chambers) x 3 = 36
4. WA: 3 accelerometers every 500m on one BTM: 15

TOTAL installed accelerometers at WA site: 9(cart)+48(4Km IFO)+36(2Km IFO)+15(BTM)=108

TOTAL installed accelerometers at LA site: 9(cart)+36(IFO)=45

Spares: 5 at WA, 5 at LA in addition to the above

For the positions requiring three axis accelerometer mounting, the Triaxial Mounting Block will be used. The accelerometers will be mounted on the Mounting Block (hardware provided). The Triaxial Accelerometer Mount Assembly will be mounted with screws directly to the indicated location, which will have a corresponding tapped hole.

The accelerometers are used in several applications:

3.1.3.2.1 PSL/IOO

The triaxial accelerometer assembly will be attached to the surface of the optical table carrying the PSL/IOO optics, close to the output optics.

3.1.3.2.2 ITM and ETM of the 4kM IFO WA site only

The BSC with Test Masses (ITM and ETM), carries 6 accelerometers, and the objective is to sense all six degrees of freedom This signals will not bear a simple relation to the actual stack excitation for frequencies higher than the resonances of the frame (the first resonance is expected to be at ~46 Hz), but will cover, with reasonable assurance, all excitation paths. A modal analysis will be performed to determine the best use of the 6 accelerometers and the interpretation of their signals.

The triaxial accelerometer assembly will be attached to the underside of the 4 ends of the seismic stack support beams (using tapped holes (i) in the stack support beam, close to the bellows interface, as shown in the PEM ICD. The triaxial blocks will be populated as needed.

3.1.3.2.3 HAM, BSC, ETM (2Km WA, and LA), ITM (2Km WA, and LA)

The triaxial accelerometer assembly will be attached to one of the seismic stack support beams (using a tapped hole in the stack support beam), close to the bellows interface, as shown in the PEM ICD.

3.1.3.2.4 Beam Tube (one BTM in WA)

The accelerometers monitoring the beam tube will be mounted together as a $x - y - z$ triplet in the Triaxial Mounting Block. A mounting plate will be glued to the wall of the Beam Tube after bake-out, which will have a tapped hole pattern matching the Triaxial Mounting Block Assembly (note that on this mounting plate also mounts the microphone and RH/Temp sensor; see 3.1.4.2.3).

3.1.3.2.5 PEM Cart

The accelerometers associated with the PEM cart will be mounted together as a $x-y-z$ triplet in the Triaxial Mounting Block. A supply of mounting plates will be available which can be glued to the surface of interest; it will have a tapped hole pattern matching the Triaxial Accelerometer Mounting Block.

3.1.4. Acoustic Microphones

3.1.4.1 Microphones

This is a product made by many manufacturers, and one with a more convenient interface may be found. Two possibilities, which span the range (i.e., are extreme limits) are

- manufacturer/distributor: Bruel&Kjaer Falcon 4189
    - prepolarized free-field 1/2 inch
    - sensitivity: 50mV/Pa
    - Frequency range: 6.3Hz to 20 kHz
    - dynamic range: 15.2dBA to 146dBA with preamplifier 2639/69
- manufacturer/distributor: Radio Shack model 33-1067
    - type: electret condenser
    - power: ‘phantom’ (remotely supplied, no batteries)
    - bandwidth: 16Hz - 20kHz, ±10 dB
    - output level: TBD, low impedance
    - omnidirectional
    - unit price: TBD

3.1.4.2 Implementation

Quantity:

- one per VE chamber, two near PSL/external IOO, two per cart per site: 22+2+2=26 in WA and 11+1+2=14 in LA
- spares: 5

The microphone will be purchased with a stand and microphone clip and an adaptor which converts the pipe-thread clip to a 1/4-20 tapped hole. The microphone will be glued in its clip.

3.1.4.2.1 HAM/BSC

The seismic support beam of the chamber in question will have a 1/4-20 tapped hole near the bellows, for top mounting of the microphone in its clip with a headless 1/4-20 screw.

3.1.4.2.2 PSL/IOO

The microphones will be mounted to holes in the optical table, using a headless 1/4-20 screw.

3.1.4.2.3 Beam Tube

The microphone will be mounted to the glued-on bracket which also carries the temperature, humidity and triaxial accelerometer assembly (see 3.1.3.2.4).

3.1.4.2.4 Cart

The microphone will be mounted in its clip as above. A microphone stand with boom and 2-foot gooseneck will be acquired to support the microphone.

3.1.5. 3 Axis Magnetometer

3.1.5.1 Magnetometer

- manufacturer/distributor: Bartington/GMW
- transducer model: MAG-03MCES100-L7 Environmentally sealed with low noise option
- DAQ module (power and conditioner module, 6 channels): model MAG-03DAM, 16/24 bits resolution,
- range: $\pm 70 \mu T$);$\pm 10 V$ full scale at the DAQ module input)
- bandwidth: 0 to 4.5 kHz
- noise at full bandwidth: less than 2nT
- internal noise: better than $7 pT_{rms} / \sqrt{Hz}$
- unit price with cylindrical probe: $2930.
- power supply: $4390 for 6 channels
- cables $260 and up (depend on the length and type of probe)
- 60 Hz and multiple notch filters (built in-house)
- • Transducer mechanical and electrical interface parameters
- weight: 100 grams
- dimensions (mm): 202 x 25 diam.
- mounting bracket available (specification NA)
- mechanical resonance: NA
- temperature sensitivity: NA
- operating range: -40 to 85^0 C
- cable length to electronics: 3, model MAG-03MCES 5-600 m, 10 pin connector/cable
- connector type: Amphenol GB 62GB51T10-7P, see cable model
- interface to CDS for power: none (through the DAQ module)
- interface to CDS for output signal: none (through the DAQ module)
- • DAQ module mechanical and electrical interface parameters
- 6 channel power supply and signal
- weight: 2.8 kg
- dimensions (mm): 265 x 255 x 55
- operating range: NA room temperature
- input connectors: 2*RM15TRD10P plug (see cable assembly from transducer)
- interface to CDS for power: 9-24 VDC via mains adaptor, 120 mA (10 h battery included)
- interface to CDS for output signal: $\pm 10 V$ analog output (RS 232 port available)
- analog output connectors: BNC, 9 way D socket
- output cable: shielded twisted pair to ADC channels
- output impedance: NA

3.1.5.2 Implementation

Quantity:

- one per cart: 1 in WA and 1 in LA
- one for each chamber with a core optics (RM, BS, 2xITM and 2xETM): 6 in WA
- one remote magnetometer per site, outside the LVEA: 1 in WA and 1 in LA.
- Spares: none

The sensors are 202mm in length, 25mm diameter; 100 gr in weight; and a bracket 55x55x36 mm is available. The cable length can be as great as 600m.

3.1.5.2.1 BSC/HAM

The magnetometer sensor will be mounted on an aluminum pedestal at the height of the test mass, and within 50cm of the wall of the Vacuum Chamber in question.

3.1.5.2.2 Remote

The magnetometer will be mounted in a cinderblock shed on an aluminum pedestal at the corner station, at the limit of the LIGO property, far from evident sources of sources of 60 Hz and multiples. One approach is to survey the completed building site and to choose the placement of the shed accordingly. The sensor (MAG-03MC) can tolerate temperatures of -40 deg C to +85 deg C; thus, it is expected that the shed can be left without environmental control. The electronics will be placed within the nearest appropriate building (within 500m).

3.1.5.2.3 Cart

The magnetometer sensor will be mounted on an aluminum pedestal of adjustable height and position. It will occupy a floor space of 20cm x 20cm.

3.1.6. Thunderstorm Monitor

3.1.6.1 Commercial data source

The ‘National Lightning Detection Network’ is one source of real-time data on ground-cloud lightning strikes. Data can be retrieved as an ASCII stream with time, place, intensity, and multiplicity of lightning strikes, effectively in real-time.

The costs are being determined; either order of 17k$/year, or 12k$plus 5k$/year, not yet clear.

3.1.6.2 Implementation

Quantity: One for the two sites; data shared using internet or equivalent.

A satellite receiving dish is required (roof mounted) with cabling to a dedicated PC.

3.1.7. Radio Frequency Multi-channel Antenna/Receiver

3.1.7.1 HP 8902A Multichannel Receiver and Antenna

- manufacturer/distributor: Hewlett Packard
- model: Signal Analyzer HP 8902A.

- RF power (with 11722 sensor module)
  - range 30dBm(1W) to -20dBm(10microW)
  - bandwidth: 0.1MHZ to 2.6GHz
- Tuned RF Level
  - range: 0 to -127dBm
  - bandwidth: 2.5MHz to 1.3GHz
- Optional Selective Power Measurements: Filter Bandwidth availability
- RF Frequency
  - resolution 1Hz
  - range 150kHz to 1.3MHz
- Amplitude and Frequency Modulation Measurement
- Phase Modulation, Audio, frequency and Distortion Capabilities
- Prices: total around $40000
  - receiver only HP 8902A: $31500
  - HP 11722 module: $2570
  - Various frequency filters (including cellular) in sets of two: $2965
  - manuals: $533 (not necessarily for all units)
  - matched antenna HP 11966x: $2500-5000 TBD
  - •• RF Antenna mechanical and electrical interface parameters
  - specifications TBD
  - mounting tripod and positioning devices available
  - preamplifiers available
  - interface to CDS for power: TBD
  - interface to CDS for output signal: none
  - •• RF mechanical and electrical interface parameters
  - 6 channels receiver
  - weight: NA
  - dimensions (mm): NA
  - operating range: NA room temperature
  - input connectors: TBD (see antenna)
  - interface to CDS for power: 117 VAC
  - interface to CDS for output signal: GPIB interface and TBD
  - analog output connectors: TBD
  - output cable: TBD
  - output impedance: NA

3.1.7.2 Implementation

Quantity: one per site: 1 in WA and 1 in LA (moveable units)

Spares: none

The antenna and receiver form a portable unit and will be purchased with a stand for the antenna.

3.1.8. Narrowband RF Receivers

3.1.8.1 Narrowband RF Receiver and Antenna

To be built in-house. See CDS PEM DRD for details. The data are transferred to the CDS ADC via shielded twisted pair cable.

3.1.8.2 Implementation

Quantity: 2 in WA and 1 in

Spares: none

The antenna for the narrowband receiver will be attached to the optics table carrying the antisymmetric diode using standard optics mounts.

3.1.9. Charged Particle Detector

3.1.9.1 Scintillator Detector and PMT

To be built in-house from standard components.

- Scintillator (Bicron BC 412 or equivalent) sensitivity: min 50 Photoelectrons/cm for Minimum Ionizing Particles
- 25 x 50 x 2.5cm scintillator
- 2 x 2 inch Hamamatsu PMT model R3234-01 or equivalent, with base and magnetic shield
- 2 x custom made clear UVT lucite light guide from scintillator to PMTs
- the scintillator, light guides and PMTs are mounted in a wooden box of dimensions 1x0.5x0.5 cubic meters
- range: 1-10000 particles/slab of Scintillator: propose two sets of PMTs driven at different gains (HV) in order to extend the dynamic range. The low gain PMTs can serve for the trigger generator.
- resolution: better than 0.01ms
- custom made or commercial charge/shaping amplifier, gain 1-100 (EG&G 4890 or equivalent separate charge preamp+shaping amp, or custom made CDS TBD)
- analog signal after a charge preamp/shaping amplifier: max 10V compatible with the CDS ADCs
- NIM modules: LeCroy 821 discriminator, LeCroy Fan-in/Fan-out 429A, EG&G constant fraction discriminator, counter EG&G 770, NIM bin EG&G 4001A, LeCroy quad majority logic unit coincidence 365AL (Note: equivalent modules might be used as well).
- 1 x HV power supply max 3kV, example EG&G 556 (NIM) or 556H or equivalent
- estimated costs per detector: $10000

3.1.9.2 Implementation

Quantity: one in WA only

Spares: none

The Scintilator and PMTs will be mounted in the same stay-clear as the low-frequency seismometers and tiltmeters (see 3.1.3.2.4).

3.1.10. Power Line Fluctuations (see 2.4.8)

3.1.10.1 FMCS Current monitors

The CC-installed current monitors will be integrated into the PEM system.

Quantity: one for entire building, one for the chiller plant, one for utility buses

3.1.10.2 BMI Power Line Monitor

The sensor described here may be well in excess of our needs in some aspects (sophisticated internal data thresholding and recording).

- manufacturer/distributor: BMI
- model: 8800 Power Scope
- 4 channels (three phases+neutral) monitoring
- RMS Voltage and RMS Current monitoring: 2% long period resolution
- frequency measurement
- Spikes: less than 5% fractional voltage fluctuations in less than 0.1ms
- high frequency noise
- total harmonic distortion
- spectrum analysis
- price: $13495 + probes($355-545 each, in function of total current and bandwidth)
- Electrical interface to CDS: via RS 232/GPIB

3.1.10.3 Implementation

Quantity: 2 technical power monitors at WA and 1 at LA

Spares: none

- The power line monitor is a portable self-contained unit, with IEE488 or RS232 interface to the Data Acquisition system.

3.1.11. Residual Gas Monitor (RGA)

3.1.11.1 BALZERS RGA

- manufacturer/distributor: Balzers
- requirements: meets PEM DRD
- model: BKM 18111 QMG421-3 without RGA head: $23000
- Head only QMA 430: $13000
- ion counter preamp CP 400 and board IC 421: $5000
- network server BN882086: $2600
- total RGA: $43600

3.1.11.2 Implementation

Quantity:

- RGA *heads* installation: 9 in WA and 5 in LA (ports and power required) as follows:

1. 7 isolatable volumes (4/LVEA in WA and 3/LVEA in LA) + 1 isolatable volume per VEA x 6 VEAs (4+2) = 13 total RGA heads (8 in WA and 5 in LA)
2. one RGA head in the midpoint of one BTM at WA site

- initial RGA *controller* installation: one/cart and one /building: 6 in WA and 4 in LA

Spares: one head and one controller per site

The RGA consists of a sensor head and readout electronics. The readout electronics are self-contained rack mounted and will be mounted in roll-around carts for use with multiple heads in different places. The heads are mounted on existing ports of the Vacuum Equipment and the Beam Tube as described in the PEM ICD. Each isolatable volume (given in the PEM DRD) will carry an RGA. The RGA should in general be mounted as close as possible to contamination-sensitive optics, although not in direct line-of-sight. RGAs to be installed on existing ports on the Vacuum Equipment and Beam Tube; the Vacuum Equipment ports are to be identified by PSI nomenclature. Leaks and RGAs to be installed with metal valves allowing calibration without corruption of the Vacuum Equipment or Beam Tube by dead volumes or trace gases.

3.1.12. Vacuum Contamination Monitor

The requirements are listed in 3.2.1.9 and APPENDIX 1 of PEM DRD (1.4.1.1). The Contamination Monitor Preliminary Design will be finalized at a later date, based on all information available at the time; a study of contamination is underway at the time of the Preliminary Design Review. The fallback plan, in the event that no new information becomes available in the timely way, is described below.

3.1.12.1 Fallback Contamination Monitor Design

A monitor of deposited material, a ‘crystal deposition monitor’, will be placed with an RGA head on a port of each chamber carrying a core optic. The two instruments will be in an isolatable volume. The deposition monitor will be periodically polled to track any contamination. After some perceptible deposit is accumulated on the crystal monitor surface, the volume will be isolated and the deposition monitor will be heated to cause the contaminants to be outgassed. The RGA will analyze the outgassed material to determine its composition.

The following estimated costs are from the initial Cost Book PEM estimates (1.4.1.4) in 1994 dollars.

- manufacturer: Leybold model IC/4 PLUS or equivalent:
- specifications: TBD
- crystal head assembly $3794
- electronics for crystal head: $9243
- RS 232 interface
- resolution 0.0058 Angstrom/Sec/Measurement
- maximum frequency 1.5MHZ

3.1.12.2 Implementation

Quantity:

- one ***head*** per isolatable vacuum volume (excluding the beam tube), or 8 in WA and 5 in LA; the heads should be close to the RGA heads.
- one set of ***control electronics and PC*** per building, or 5 in WA and 3 in LA; intermittent data/ control transfer to/from PC

Spares: none

The crystal head sensors are mounted on existing Vacuum Equipment ports, nearby RGA sensor heads (see 3.1.11.2), as per the PEM ICD document; their placement should be as close as possible to contamination-sensitive optics. The readout electronics are self-contained rack mounted and will be mounted in roll-around carts for use with multiple heads in different places.

3.1.13. Weather monitor

The thermometers and hygrometers are stand-alone sensors; the other weather sensors may be purchased with and with data converted by ‘weather stations’.

3.1.13.1 RH and Temperature Detectors

3.1.13.1.1 RH and Temperature transmitter (HX-93)

- manufacturer/distributor: Omega
- model: HX 93
- RH range and accuracy: 3-95%; ±2 %
- Temperature range and accuracy: -20 to 75^0 C; ±0.6^0 C
- Output 0-1VDC or 4-20 mA for each channel
- RH temperature compensation
- power requirements: unregulated 24 VDC
- price: $210; calibration kit: $65 (not required for each transmitter)
- optional power supply: $40

3.1.13.1.2 RH Detector (HX-92)

- manufacturer/distributor: Omega
- model: HX 92
- RH range and accuracy: 3-95%; ±2 %
- Output 0-1VDC or 4-20 mA
- RH temperature compensation
- power requirements: unregulated 24 VDC
- price: $180

3.1.13.1.3 Temperature Sensor and Transmitter (TX 90 series)

- manufacturer/distributor: Omega
- thermocouple model: WTE-14-S-12 bolt-on model $8
- transmitter model: TX 91A-E2 (with optional cast iron protection) $150
- T range and accuracy: $-40^o to 60^o C$; ±2 %
- Output 0-1VDC or 4-20 mA
- power requirements: unregulated 24 VDC

3.1.13.2 Implementation

Quantity:

Thermometers:

- one every 500m on one 2Km BTM: total 5 in WA.
- inside buildings temperature: 5 in WA and 3 in LA
- outside temperature on four building sides: 20 in WA and 12 in LA
- spares: 5 per site

Hygrometers:

- one every 500m on one 2Km BTM: total 5 in WA.
- inside building humidity: 5 in WA and 3 in LA
- outside humidity: 1 in WA and 1 in LA
- spares: 3 per site

Anemometers:

- one per building: 5 in WA and 3 in LA
- spares: 1 per site

Precipitation sensors:

- one per site: 1 in WA and 1 in LA
- spares: none

Barometers:

- one per site: 1 in WA and 1 in LA
- spares: none

3.1.13.2.1 Inside Buildings

The temperature and humidity sensors in the buildings are to be placed in the LVEA or VEA in places corresponding to the Facilities HVAC system zones, as indicated in the PEM ICD. They will be mounted to the walls of the facility on a bracket giving a suitable sample of air.

3.1.13.2.2 Outside Buildings

The thermometers which monitor the outside environment will be contained in protective enclosures to reduce the influence of sun and precipitation on the sensing element. They will be placed such that they take a representative sample of the temperature on the given building (LVEA/VEA) exterior wall. The hygrometer will be placed with one of the external thermometers.

3.1.13.2.3 Beam tube

The combined hygrometer-thermometer will be attached to the bracket attached to the beam tube used for the triaxial accelerometer assembly and microphone (see 3.1.3.2).

3.1.13.3 Anemometer

- Part of the Weather Station Cole Parmer Model 99800-20 (10)
- range: direction 0 - 360^0 ; speed 0 - 150 mph (or in kmh)
- accuracy: direction $\pm 5^0$; speed better than ± 2 %

3.1.13.4 Barometer

- Part of the Weather Station Cole Parmer Model 99800-20
- range: 660 - 810 mm Hg
- accuracy ±1.3 mm Hg

3.1.13.5 Precipitation sensor

- Part of the Weather Station Cole Parmer Model 99800-20 with rain collector 99800-50(inch) or 51(mm)
- range: daily up to 999.8mm, accumulated up to 9999mm
- accuracy: ±2 %

3.1.13.6 Implementation

The anemometer and precipitation sensors will be mounted on top of the LVEA, at a point which will be representative of the free wind velocity on the surface of the building (the observation deck may be appropriate).

3.1.13.7 Weather Stations

A ‘weather station’ may be used to convert the anemometer and precipitation monitor data to a convenient form. The model below is one possibility.

3.1.13.7.1 Low Cost Weather Station (C-P 20) for corner buildings

- manufacturer/distributor: Cole Parmer
- model: GL-99800-20 indoor/outdoor monitoring system
- Monitor: Temperature (in and out), Relative Humidity (in and out), Wind (speed and direction), Air Pressure, Rain fall, also Dew point and wind chill.
- fulfill requirements
- RS 232 interface
- cost: $570 (base unit with rain collector, outdoor T/RH sensor and cables)
- optional PC software: $165

3.1.13.7.2 Low Cost Weather Station (C-P 10) for mid and end buildings

- same as C-P 20 (see 3.1.13.7.1), but for Temperature and Wind monitoring only
- cost: $195

3.1.14. Dust Monitoring (TBD)

3.1.14.1 Dust Particle Detectors for Fixed Clean Rooms

- Met One Model 4800 or 227B (same characteristics, but 227 includes a vacuum pump)
- Particle size min 0.3 microns
- storage capability
- sample/hold time: 1sec to 24 hours
- RS 232/485 interface

3.1.14.2 Implementation

Quantity:

- 1 per OSB optics lab (fixed cleanroom corner station) (1WA and 1 in LA)
- 1 per OSB Vacuum Equip. Preparation room (fixed, corner station) (1WA + 1LA)
- 2 per LVEA at corner station(2 in WA and 2 in LA)
- 1 per VEA mid and end stations (4 in WA and 2 in LA)
- 1 per Mid & End-Station optics lab (4 in WA and 2 in LA)
- 1 per portable cleanroom (3 corner+2 mid+2 end=7 in WA, 3+1=4 in LA)
- 1 per PSL/IOO (2WA + 1LA)
- spares: none (units can be used interchangeably)

All dust particle monitors will be potentially portable. All will be mounted with Velcro or equivalent and use flexible cabling.

3.1.14.2.1 Clean Rooms

The sensors associated with the temporary clean rooms will be attached to the interior of the clean room frame when the clean rooms are implemented; they will be attached to nearby Vacuum Equipment external chamber walls when the clean rooms are not installed. In the permanent clean rooms, there will be a standard placement on a wall using Velcro; a flexible cable will allow implementation elsewhere in the room.

3.1.14.2.2 PSL

The sensor associated with the PSL will be mounted close to the output optics, inside and on the structure forming the walls of the dust/beam cover for the optical table.

3.2. PEM Excitation System

NOTE: All the excitation systems are part of the PEM moveable cart and not permanently installed.

3.2.1. Seismic Excitation System

Ideally, the PEM seismic excitation system would create a motion at the 4 corners of the support beams which exceeds the ground noise by a factor of 10 for a sine wave excitation at all frequencies where seismic noise could appear in the interferometer spectrum or where significant resonances are expected. Again ideally, this would be in 3 axes at each corner, to allow driving the load in various ways. This ideal case is designed to help visualize the goal.

An important point is that the test masses are very sensitive to magnetic fields, and so electromagnetic solutions to actuator problem might be not attractive.

3.2.1.1 PZT Excitation System

The PZT ‘shaker’ will be built in-house. The basic principle is to use a multi-layer PZT stack which is firmly attached to the object to be shaken at one end (e.g., the seismic support beam) and to a reaction (proof) mass on the other end (of 1 kg order of magnitude). A second ‘shaker’ using a mechanical impedance transformer in the form of an arm on a hinge, driven close to the fulcrum and with a mass some distance from the fulcrum, may be needed to obtain sufficient force at low frequencies. The size of the shaker will be order of 10x10x10 cm. Electromagnetic shakers must be avoided for use near the TMs due to the test mass magnetic field sensitivity.

Quantity:

- 15 WA, 15 LA ‘shakers’
- 2 Signal Generators per site
- spares: none

The signal source will be either a general purpose oscillator (see below) or the CDS DAQ/Diagnostics system. A high-voltage amplifier will be specified and supplied to interface to the PZT shaker.

- SRS Signal Generator, model SRS DS 335:
  - multiple wave shapes
  - maximum frequency: 3.1 MHz for sine and square pulses
  - GPIB and RS 232 interfaces
  - Output amplitude: 0.05 - 10V into 50 Ohms
  - *This generator will be used for the acoustic noise generator as well*

3.2.1.2 Portable PZT Accelerometer Calibrator

A portable calibrator for the PZT is proposed to be part of the standard equipment at each site (cart).

- manufacturer/distributor: Endevco/Meggitt Aerospace
- model number 28959E
- range: up to 10 g
- bandwidth: 3 Hz to 10 kHz
- frequency readout accuracy: 0.001%±1 count
- acceleration uncertainty: better than 1 dB frequency dependent
- amplitude range 10g pk max, frequency and mass dependent
- internal memory: 128Kbyte, store up to 1600 individual test results
- unit price: $8610
- Mechanical and electrical interface parameters
- weight: 10 kg, portable unit
- dimensions (inch): 11 x 10 x 6
- operating temperature: NA
- interface to CDS for power: charger for batteries 115 VAC
- interface to CDS for output signal: RS 232 with a DB-9 female connector

3.2.1.3 Electromagnetic Excitation System

One possibility is given below; a reaction mass shaker is preferred and will be substituted

- Electromagnetic shakers Bruel&Kjaer, 3/cart
- Impact Hammer type 8202 with build-in force transducer 8200
- transducer sensitivity: 1pC/N
- Force range: 1000N tensile to 5000N compressive

- impulse duration: 0.23ms to 5 ms
- weight 280 gr
- plastic, rubber and steel tip
- signal generator shared with other excitation systems (3.2.1.1)

3.2.1.4 Implementation

Quantity: 3 WA, 3 LA

The shaker will be housed in a box with through holes, to be attached as needed to the seismic support beam (via tapped holes, as per the PEM ICD) or other object to be shaken.

The PZT calibrator does not require special provisions. It is a portable system with rechargeable batteries and it has an RS 232 serial interface.

The electromagnetic shaker will be attached to the object to be shaken using through and/or tapped holes in the shaker body and jigs as needed.

3.2.2. Acoustic Noise Generator

3.2.2.1 Acoustic Noise generator (one system/cart)

- One conventional wide-bandwidth loudspeaker
- one or several portable localized sources of sound, like ‘tweeters’ and sound guns
- one pulse generator (shared with the mechanical excitation system 3.2.1.2)

3.2.2.2 Implementation

Quantity:

- two per site for the PEM carts
- spares: none

The loudspeakers will be purchased with a stand which will allow placement at heights up to 1.5m and placed close to sensitive elements. Small sealed speakers (<20x20x20 cm) will be used. The localized sources of sound will be built in-house, and will consist of electromagnetic or piezoelectric tweeters and squawkers built into hermetic boxes with a well defined point for sound to be emitted.

3.2.2.3 Magnetic Field Generator

- • Design Philosophy

Preliminary design parameters for a coil mounted near the TM VE chambers, having the coil axis pointed to the TM, can be derived from the following formula:

$$B = \frac{\mu_0 \mu}{2\pi (R^2 + x^2)^{3/2}} \quad \text{where}$$

B is the magnetic field at the test mass location

$\mu_0 = 4\pi \times 10^{-7}$ is the permeability of the free space in units of Tesla Meters/Amps
$\mu = NIA = NI\pi R^2$ = dipole moment of the coil equivalent magnetic dipole
I= current in the coil
N= turns in the coil
R= Coil Radius
x = distance between the coil center and the test mass (x is perpendicular to the coil plane)

If $x \gg R$, then $$B \approx \frac{\mu_0 \mu}{2\pi x^3}$$

So, a simple coil can create magnetic field with an intensity inverse proportional with the cube of the axial distance from the coil center to the test mass. As for example, we will list bellow the magnetic excitation system design parameters for a two coil configuration to be mounted at about 2 meters from the test mass position:

- Small Coil Parameters
  - R = 0.1 m
  - x = 2.0 m
  - N = 5 turns of insulated Cu $1mm^2$
  - mounted coil dimensions: ring diam IO=0.17m, OD=0.25m, length=0.10m
  - B range: $10^{-12} < B < 10^{-9}$ T for a current $10^{-3} < I < 1$ A
- Large Coil Parameters
  - R = 0.5 m
  - x = 2.0 m
  - N = 51 turns urns of insulated Cu $1mm^2$
  - mounted coil dimensions: ring diam IO=0.9m, OD=1.1m, length=0.30m
  - B range: $10^{-9} < B < 10^{-5}$ T for a current $10^{-3} < I < 10$ A
- Current Supply:
  - range: 1mA to 12 A DC custom made precision transformer/rectifier, or LAMBDA custom design current supply.

3.2.2.4 Implementation

Quantity:

- One per building or one per cart (TBD: possible need for one coil per VE chamber if needed to obtain a specific field configuration of interest)
- spares: none

The radiating coil will be supported by an aluminum stand of adjustable height, allowing placement at the height of a sensitive component (e.g., test mass) and close to the Vacuum Equipment chamber in question.

3.2.3. RF generator

3.2.3.1 HP RF generator

- model HP 8643A with option 002: $25000 with options
- satisfies performance requirements for source
- amplitude and frequency modulation
- low power broadband amplifier 0-50GHz, gain=20dB, HP 83006A $4105
- matched antenna HP 11966x: $2500-5000 (shared with the Broadband RF signal analyzer, see 3.1.7) TBD

3.2.3.2 Implementation

Quantity:

- two per site: portable unit or part of the PEM cart (TBD)
- spares: none

The antenna will be purchased with a stand which allows convenient placement. The RF generator and amplifier are rack-mounted in the PEM Cart.

APPENDIX 1 SUMMARY TABLES

Table 1: Initial PEM System characteristics and estimated costs. (For carts see table 2)

	Detector	*Sensitivity*	*Range*	*Nr* *WA LA*	*Cost* *Unit Total* *k$*
Seismic Noise	3 axis seismometer	10^{-10} m @1Hz	1 - 10Hz	1/bldg 5 + 3	14 112
	2 axis tiltmeter	10^{-9} rad @1Hz	1 - 10Hz	1/bldg 5 + 3	10 80
	1 axis accelerometer	10^{-11} m @100Hz	10Hz-200 Hz (new)	6/tank 12/BT 113+50	1.1 179
Acoustic Noise	Electret Micro-phones	2×10^{-9} atm @100Hz	~1kHz	1/tank 26+14+5	0.2 9
Magnetic Field	3 axis magnetometer	10^{-11} T @100Hz	DC - 1kHz	1/tank 8 + 2	3.5 35
Thunderstorm Monitor	Thunderstorm satelite service			1+1	TBD
RF Interference	BroadbandMul-tichannel Receiver	0.01mV/m 6 channels	up to 1.3GHz	1/bldg 1 + 1	36 72
RF Interference	Narrowband Receiver	0.01mV/m	TBD 25-35MHz	2 + 1	TBD
Cosmic Muons	Scintillator Detector	$\frac{10^{-6}\cdot\mu}{s\cdot m^2}$	100Mev 1ms res.	1 WA	10 10
Power Line	Line Monitor	see 2.4.8.1	up to 2kHz	2 + 1	13 39
Residual Gas Head Controller	RGA	$P \le 10^{-14}$ torr	1-100 amu	9 + 5 6+4	42 70 400
Contamination	Crystal Head controller	monolayer/ week		8+5	12 156
Weather Moni-tor	T,RH,Prec, wind,P	see text		35 + 30 units (see text)	11
TOTAL	**COST**	**for full**	**PEM**	**no carts**	**TBD**
TOTAL	**COST**	**for full**	**PEM**	**w/carts**	**TBD**

- Table 2 present the PEM cart components, characteristics and estimated cost. The cart estimated cost does not include the mechanical structure, optional batteries and the DAQ cart system.

Table 2: The PEM Carts instrumentation (one per site).

	Equipment	*Sensitivity*	*Range*	*Chan*	*Unit Total k$*
	Sensing	equipment	for	carts	
Seismic Noise	3x3 axis accelerometer	$10^{-11} m$ @100Hz	10Hz-200 Hz	6	1.1 7
Acoustic Noise	Electret Microphones	$2 \cdot 10^{-9} atm$ @100Hz	~1kHz	2	0.2 0.4
Magnetic Field	3 axis magnetometer	$10^{-11} T$ @100Hz	DC - 1kHz	1	3.5
RF Interference	Multichannel Receiver	0.01mV/m 6 channels	up to 1.3GHz	6	36
Contam +RGA	Contr.head control RGA	$P \leq 10^{-14}$ torr	1-100 amu	1	51
	Excitation	equipment	for	carts	
general purpose Generator	DS 335		wide range	1	TBD
Seismic Noise	PZT and e-m Shaker		above 10Hz	15	TBD
Acoustic Noise	Loudspeaker Generator		20-1000Hz	2	2
Magnetic Field	Custom design coils		DC-1kHz	1	1 TBD
RF noise	RF Generator		up to 1.3GHz	1	25 TBD
TOTAL	**COST**	**per**	**CART**		**TBD**