Physics Environment Monitoring

Preliminary Design Review

2/5/1997

Agenda

- Updated PEM DRD and PDD (A. Marin, D. Shoemaker)
- PEM DAQ DRD and CDD (J. Heefner)

Updated PEM DRD

Main Changes:

Following the recommended Action Items from PEM DRR

- Requirements & Design
  - must be sufficient to detect influence on Initial IFO
  - clarification of origin of numbers
- Sensors Quantities, Spares, Placements, Availability
  - only one-half of one BT module (1km) in WA to be instrumented
- Dust Monitors now in scope
- Interfaces
  - Electrical: see PEM CDS
  - Mechanical: see updated PEM DRD and PDD
  - needs more definition
- PEM carts
  - First to be built
  - Design of the excitation systems advanced
- Main ***changes*** and/or **additions**: ***italic blue*** or **red**

Seismic Noise

Initial IFO Requirements

- $x\ (100\ Hz) = 2.0 \times 10^{-19}\ m / Hz^{1/2}$
- $x\ (10\ kHz) = 4.0 \times 10^{-18}\ m / Hz^{1/2}$

LIGO Standard Spectrum (SRS)

- $x(f) < 10^{-9}[f]^{-3} m\sqrt{Hz}$ for $0.1 Hz < f < 1 Hz$
- $x(f) < 10^{-9} m\sqrt{Hz}$ for $1 Hz < f < 10 Hz$
- $x(f) < 10^{-7}[f]^{-2} m\sqrt{Hz}$ above 10 Hz

Seismic Noise Low Frequency

Low frequency 3 axis seismometer

- sensitivity: $x(f) < 3\times10^{-10}[f]^{-3} m/\sqrt{Hz}$ for $0.1Hz \le f < 1Hz$. Sufficient to verify the seismic environment as measured before construction at the sites.
- noise level: $a < 10^{-10} g$; dynamic range 100 dB; frequency range 0.1 to 10Hz
- ***availability requirement: all LF seismometers required***
- ***calibration: 10% accuracy; periodic cycling of in-service units to manufacturer, spare to service***

››GURALP CMG-40T Seismometer (NC)

- **model: Transducer CMG-40T + digitizer: CMG-DM16 with RS 232**
- 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 (1/site for initial and periodic adjustments)
- ***interface to CDS Transducer power:12V, 50mA***
- ***Transducer output signal (optional, not used): max ±10 V;***
- ***interface to CDS: Digitizer power 12V, 120mA***
- ***interface to CDS for output signal: RS 232/422 standard interfaces***

•• **Implementation NC (1/bldg: 5+3; no spares)**

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.

Seismic L.F. Noise: Tilts

2 Axis tiltmeter (NC)

- sensitivity: $\theta(f) \le (2 \times 10^{-9} / f^2) rad / \sqrt{Hz}$. Sufficient to observe the expected effect on the IFO **(=sensitivity of available sensors)**. ***Insufficient to detect environmental tilts except possibly at the microseismic peak.*** A sensor with $\theta(f) \le (1 \times 10^{-13} / f^3)$ rad$/\sqrt{\text{Hz}}$, $f < 1$ Hz; & $\theta(f) \le 1 \times 10^{-13}$ rad$/\sqrt{\text{Hz}}$, $1 < f < 10$ Hz, would allow to verify the estimated ambient tilt spectrum.
- dynamic range 100 dB; bandwidth: 10 Hz
- ***availability requirement: 1 in WA, 1 in LA***
- ***calibration: 10% accuracy; manual self-calibrating using built-in micrometer screw***

››Applied Geomechanics 520 Geodetic Tiltmeters (NC)

- resolution: <10nRad; bandwidth: 0-10 Hz; range: $\pm 1400 \mu rad$ for setting 1
- T control monitor (build in): 10mV/deg; -40 to 100^0C range,.0.75^0C acc.
- price for model 520 Platform Tiltmeter with micrometer legs: $8000
- ***interface to CDS for power: 11-15VDC and -11 to -15VDC max 20mA each***
- ***interface to CDS for output signal: up to ± 8VDC single ended (16 diff) at high gain***

•• Implementation (1/bldg: 5+3; no spares)

The tiltmeter will be

- placed directly on the concrete foundation of the building,
- close to one of the test masses, see PEM Interface Control Document.
- 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.

Seismic Noise High Frequency(1)

Seismic Noise: High Frequency *$10 < f < 200$* Hz (NC)

The HF 1 Axis Accelerometer will monitor

1. **motion of the TM tanks** and sample other IFO important points;
2. **beam tube mechanical excitation**, initially on one BT module,
3. **ground motion near seismic support piers** in order to obtain the transfer function from floor to support beams.

Few accelerometers are ***part of the PEM portable excitation/diagnostic cart.***

- sensitivity: $x(f) \leq (10^{-8} / f^2) m / \sqrt{Hz}$, $10 < f < 200$ Hz. This allows the measured noise level at the sites to be verified.
- dynamic range 100 dB; bandwidth: 200 Hz
- ***number of accelerometers (AI recommendation): 108+45; spares 5+5***

1. WA 4Km IFO: **6**x(4 TM)+**3**x(8 other chambers: BS, 6HAM, PSL) = 48
2. WA 2Km IFO and LA 4km IFO each: (12 chambers) x **3**= 36
3. WA: **3** accelerometers every 500m on one BTM: 15
4. **3 x 3** accelerometers/site for the PEM cart: 9 in WA and 9 in LA

- ***availability requirement: one accelerometer per VE chamber plus PSL***
- ***calibration: 10% accuracy; test/calibrate with PEM shaker (and accelerometer calibrator) if calibration needed; periodic cycling to manufacturer***

››ISOTRON Accelerometer (Endevco 7754-1000) (NC)

- **16 channels signal conditioner&power supply ISOTRON 2793M1**
- range $\pm 5g$; V sensitivity 1V/g; maximum Voltage: $\pm 5V$; BW: 1Hz-10kHz
- residual equiv. g-rms noise for narrow band at 10 Hz: $5 \times 10^{-7} g_{rms} / \sqrt{Hz}$
- Transducer: $745; 16 channels signal conditioner and power supply: $1400
- ***Triaxial accelerometer Mounting Block model ISOTON 2950X: $95***
- ***interface to CDS for power: 117 AC***
- ***interface to CDS for output signal: 10 V pk-pk (3.535 Vrms), >2mA pk-pk***

Seismic Noise High Frequency(2)

•• Accelerometer Implementation (108+45; spares 5+5)

Triaxial Accelerometer **M**ount **B**lock (**TMB**) Assembly will be mounted with screws directly to the indicated location, which will have a corresponding tapped hole.

PSL/IOO: TMB attached to the surface of the optical table carrying the PSL/IOO optics, close to the output optics.

ITM and ETM of the 4kM IFO WA site only: The WA BSC with Test Masses, carries 6 accelerometers (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.

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

Beam Tube (one BTM in WA): The Triaxial Mounting Block will be mounted on the mounting plate glued to the wall of the BT after bakeout. The plate will have a tapped hole pattern matching the TMB Assembly (note that on this mounting plate also mounts the microphone and RH/Temp sensor).

PEM Cart: The PEM cart accelerometers will be mounted together in the TMB. 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.

Acoustic Noise

Required Acoustic Pressure Sensitivity. Microphones

We are proposing to **instrument all VE** chambers (1/VE: in WA: 4 ETM + 4 ITM + 2 BSC + 6 Input HAM + 6 Output HAM = 22; In LA = 11), and 1 per PSL/IOO (2 in WA and 1 in LA), as well as the 2/carts (2 in WA and 2 in LA).

- sensitivity $p(f) \le 10^{-4}(N/m^2/\sqrt{Hz}) = 10^{-9} atm/\sqrt{Hz}$. This allows the ambient noise level requirement in the LVEA to be verified.
- dynamic range 60 dB; bandwidth: 10Hz - 1kHz, TBD
- ***availability requirement: one functioning microphone per 5m radius of intended implementation***
- ***calibration: 50% accuracy; periodic test with PEM loudspeaker***

Product made by many manufacturers. Two possibilities, which span the range:

1. ***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

2. ***manufacturer/distributor: Radio Shack model 33-1067***

   Electret condenser; 'phantom' (remotely supplied, no batteries); bandwidth: 16Hz - 20kHz, ± 10 dB; omnidirectional

- **Implementation (26+14; spares 3+2)**

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.

HAM/BSC:The **seismic support beam** of the chambers 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.

PSL/IOO: Mounted to holes in the **optical table**, using a headless 1/4-20 screw.

Beam Tube: Mounted to the **glued-on bracket** which also carries the T, RH, and triaxial accelerometer

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.

Magnetic Field (1)

3 Axis Magnetometer

- sensitivity $B(f) \le 2 \times 10^{-11} (T / \sqrt{Hz})$. Sufficient to determine if the environment will influence the test masses, with reasonable assumptions for B field sources external to the VE. $B(f) \le 1 \times 10^{-12} T / \sqrt{Hz}$ = our ***best estimate*** for the B at the TM which would = thermal noise in the initial IFO.
- dynamic range 100 dB, with 60,120 Hz filters; bandwidth: 1kHz
- ***availability requirement: remote magnetometer required.***
- ***calibration:10%; periodic cycling of units to the manufacturer for calibration, and informal calibration with the PEM magnetic field source***
- ***initial installation: total 8 in WA and 2 in LA as follows***

1. 1 per cart: 1 in WA and 1 in LA
2. 1 for each chamber with a core optics (RM, BS, 4xTM): 6 in WA only
3. 1 remote magnetometer per site, **outside** the LVEA, to be placed such that the 60Hz and multiples are minimized: 1 in WA and 1 in LA.

- ***CDS extensibility to allow one/chamber with core optics in LA: +4 in LA***

››Magnetometer Bartington/GMW

- **MAG-03MCES100-L7 Environmentally sealed with low noise option**
- **power and conditioner module, 6 chan MAG-03DAM, 16/24 bits res.**
- range: $\pm 70 \mu T$; $\pm 10 V$ full scale at the DAQ module input); BW: 0 to 4.5 kHz;
- internal noise: better than $7 pT_{rms} / \sqrt{Hz}$
- price cylindrical probe: $2930.; power supply: $4390 for 6 ch; $300 cables
- 60 Hz and multiple notch filters (built in-house)
- ***interface to CDS for power: 9-24 VDC via mains adaptor, 120 mA (10h battery included)***
- ***interface to CDS for output signal: BNC, $\pm 10 V$ analog output (RS 232 port available)***

Magnetic Field (2)

•• Implementation (8+2; no spares)

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.

– 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.

– 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).

– 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.

High Sensitivity Custom Made Coil (not for initial IFO)

- sensitivity $B(f) \le 2 \times 10^{-12} T / \sqrt{Hz}$ at 1kHz. This possible increase in sensitivity will allow a measurement of the field at the same level which would affect the test masses.
- built-in bucking coil for $n \cdot 60$ Hz compensating field

Magnetic Field (3)

Thunderstorm monitor

- information on lightning activity is proposed.
- add value beyond the local magnetic field sensors

›› subscribe to the services of the ‘National Lightning Detection Network’, a private network of lightning sensors.

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.
- One estimate is that this is 25% of the total lightning activity, and thus may not be complete enough for our needs.

›› delivers the following specifications for cloud-to-ground strikes.

- timing accuracy to ~10 microsec
- position of cloud-to-ground strike to <1 km, continental US
- intensity of strike, ~30% accuracy
- real-time data delivered via satellite link
- availability requirement: TBD
- calibration: by others
- spares: none

•• **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.

RF Interference(1)

Multi-channel Antenna/Receiver

- sensitivity $E \leq 10(\mu V/m)$. No model to indicate coupling RFI to GW output; this sensitivity will allow the natural RF environment to be detected.
- dynamic range 120 dB; bandwidth: 1.3GHz; peak detection in 6 bands with msec timing; data rate per receiver: 6x16 bit, 2048 Hz sample rate
- ***availability requirement: both RFI receivers must be operational***
- ***calibration:10% in field strength; periodic cycling of units to manufacturer for calibration, with rented substitute***

››HP 8902A Multichannel Receiver and Antenna (NC)

- **Hewlett Packard, model: Signal Analyzer HP 8902A, 6 channels receiver**

- 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 $45000 (HP 11722 module, 2 filters, antenna HP 11966xx included)

RF Antenna/Receiver interface parameters

- mounting tripod and positioning devices available; preamplifiers available
- ***RF Antenna interface to CDS for power: TBD***
- ***interface to CDS for power: 117 VAC***
- ***interface to CDS for output signal: GPIB interface and TBD***

•• Implementation (1+1; no spares)

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

RF Interference(2)

Narrowband RF receivers

- one per RF modulation frequency
- sensitivity $E \leq 10(\mu V/m)$. We do not have a model to indicate coupling from RFI at the modulation frequencies to the GW output; this sensitivity level will allow the probable natural RF environment to be detected.
- antenna placed in close proximity to the antisymmetric photodiode
- data collected on TBD 1 db change in level
- ***2 in WA and 1 in LA***
- ***availability requirement: all Narrowband RF receivers must be operational***
- ***calibration: using PEM source; relative response only***
- ***spares: none***

››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.

•• Implementation (2+1; no spares)

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

Cosmic Muons

Position: corner building near the an TM tank. Sensitive to short bursts of muons. At the present time, we are proposing to install *only one detector at the WA site*.

Scintillator Muon Detector

- The sensitivity in terms of the flux of minimum ionizing muons of at least 100 MeV kinetic energy $F(E > 100 MeV) \leq 10^{-4} \mu / s / m^2$.
- 1msec timing resolution or better, dynamic range: 60dB
- estimated data rate per detector: 1x16 bit 2048 Hz sample rate

  – To be built in-house from standard components. (about $10000)

- 25 x 50 x 2.5cm Scintillator (Bicron BC 412): min 50 PE/cm for MIP
- 2 x 2 inch Hamamatsu PMT model R3234-01, with base and shield
- 2 x custom made clear UVT lucite light guide from Scintilator to PMTs
- mounted in a wooden box of dimensions 1x0.5x0.5 cubic meters
- range: 1-10000 particles/Scintillator: two sets of PMTs at different gains (HV) to extend the dynamic range. Low HV PMTs serve as trigger.
- resolution: better than 0.01ms
- custom made or commercial charge/shaping amps, gain 1-100 (EG&G 4890 or equivalent separate charge preamp+shaping amp, or custom made CDS)
- analog signal after a charge preamp/shaping amp: max 10V for CDS ADCs
- NIM modules: **LeCroy** 821 discriminator, Fan-in/Fan-out 429A, quad maj. logic unit coinc. 365AL, **EG&G** Const. Fract. Discr., Counter 770, NIM bin 4001A, (equivalent modules might be used as well).
- 1 x HV power supply 3kV, EG&G 556 (NIM) or 556H or equivalent

•• **Implementation (1 in WA only)**

The Scintillator and PMTs will be mounted in the same stay-clear as the low-frequency seismometers and tiltmeters.

Power Line Fluctuations

FMCS Current monitors

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

- ***availability requirement: Entire Building signal required***
- ***calibration: 10%; no variation anticipated***

•• Initial installation: 1 for entire building, 1 for the chiller plant, and 1 for utility buses (TBD) No spares

Power Line Monitor

Measure power quality and perform cross-correlation analysis with the IFO during commissioning to determine the factors and levels to which IFO is sensitive. Establish requirements for a complete power monitoring system for later installation. No model to indicate coupling from power line fluctuations to the GW output; the sensitivity level (fractional fluctuations in voltage) is conventional for power line monitors.

- maximum data rate per power line monitor: 4x16 bit, 2048 Hz sample rate, at threshold crossing, 20Hz sample rate for continuous monitoring.
- ***availability requirement: All power line monitors must be operational***
- ***calibration: periodic (~yearly) cycling to manufacturer, one unit at a time***

››BMI Power Line Monitor *model: 8800 Power Scope (NC)*

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

- 4 channels (three phases+neutral); price: $13495 + probes $355-545 each
- ***Electrical interface to CDS: via RS 232/GPIB***

•• Implementation (2+1; no spares)

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

•• CDS extensibility to allow 1/bldg: additional 3 in WA and 2 in LA.

Weather monitor(1)

We require a sensitivity and precision sufficient to **correlate weather conditions with interferometer behavior**, and to give warning of exceptional meteorological conditions.

1. Variations of the **T, RH and P** may affect the alignment of LIGO components, may induce additional **spurious noises** due to expansion or contraction of the BT.
2. **Wind and Precipitation** are sources of local **seismic noise**.
3. **P, T, RH and wind** variations might indicate an **approaching thunderstorm.**

- estimated data rate/channel: 1x16 bit sample rate 2Hz

Thermometers

- precision 1^oC, resolution: 0.01^oC. No direct path known from T to GW output. Resolution and precision sufficient to track dimensional changes w/ T.
- range: inside 0-50 deg. C; outside -20 to 70 deg. C
- ***availability requirement: one thermometer per building operational***
- ***calibration: accurate to 1^oC; periodic(~yearly) with hand-held probe.***

•• **initial implementation: 30 in WA and 15 in LA(5+5 spares):**

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

•• **CDS extensibility** ***to allow: one/500m on BT: 11 in WA and 16 in LA***

Precipitation (1 in WA and 1 in LA)

- precision 10%. Rainfall can increase the ambient seismic and acoustic noise (Lazzarini, TBP). No known direct path (barring leaky ceilings) for precipitation to appear in the GW output; precision/resolution standard for sensors.
- ***availability requirement: Not required for operation.***
- ***calibration:10%; periodic check with a watering can***

Weather monitor(2)

Humidity Detectors

- precision 10% RH, resolution 1% RH. Not known path for RH variations to appear in the GW output; this precision/resolution is standard for sensors.
- ***availability requirement: one hygrometer per building operational***
- ***calibration:10%, RH; periodic(~yearly) check with hand-held probe.***
- **•• initial implementation: 11 in WA and 4 in LA (3+3 spares):**

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

- **•• CDS extensibility: one/500m (TBD) on BT: 11 in WA and 16 in LA**

Barometers (1 in WA and 1 in LA, no spares)

- pressure precision/resolution: 1mm Hg. Barometric changes influence the flatness of the foundation slab; this sensitivity is sufficient to resolve insignificant changes. No known path for P variations to appear in GW output.
- range: 650-850 mm Hg with max/min feature
- ***availability requirement: not required for operation.***
- ***calibration: 1 mm Hg; comparison with local weather reports***

Wind monitors (5 in WA and 3 in LA; spares 1+1)

- wind speed precision: 1mph. Wind can increase the ambient seismic and acoustic noise (see Parsons calculations). No known direct path for wind to GW output; this precision/resolution is standard for sensors.
- wind direction precision: 5deg
- ***availability requirement: one anemometer per site must be operational.***
- ***calibration:10%; periodic (~yearly) rotation of outside unit with spare.***

Weather monitor(3)

Proposed Weather Sensor Configuration

- A possible weather sensor configuration is presented in Table 1. Note that C-P ** stands

Model	***Location***	***Total WA+LA***	***T Out***	***T In***	***RH Out***	***RH In***	***Wind***	***Press***	***Rain***
C-P 20	Corner Bldg	1+1	1+1	1+1	1+1	1+1	1+1	1+1	1+1
C-P 10	Mid, End Bldg	4+2	4+2	4+2			4+2		
HX-93	WA BT	5+0		5+0		5+0			
HX-92	Mid, End Bldg	4+2				4+2			
TX-92	3/Bldg	15+9	15+9						
Total	Channels	:	20+12	10+3	1+1	10+3	5+3	1+1	1+1

for Cole Parmer GL 99800-**, while the HX and TX are OMEGA sensors.

Weather monitor(4)

- Individual T and RH sensors

  ›› RH and Temperature transmitter (OMEGA HX-93)

  - range and accuracy: RH: 3-95%; ±2%;   T: -20 to 75^0C; ±0.6^0C
  - RH temperature compensation; price: $210; calibration kit: $65 (1/site)
  - ***Interface to CDS: 24VDC; Output 0-1VDC or 4-20 mA for each channel***

  ›› RH Detector (OMEGA HX-92)

  - RH range and accuracy: 3-95%; ±2%; temperature compensation; $180
  - ***Interface to CDS: 24VDC; Output 0-1VDC or 4-20 mA***

  ›› T Sensor and Transmitter (OMEGA TX 90 series)

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

- Weather Stations Sensors

A 'weather station' may be used to convert monitor data to a convenient form. Sensors fulfill or exceed requirements.

›› T, RH **(Parts of the Weather Station C-P Model 99800-20 & 10)**

›› Anemometer **range/acc.: direction 0 -** 360^0/±5^0**; speed 0-150mph/**±2 **%**

›› Barometer **(C-P 20) range: 660 - 810 mm Hg; accuracy** ±1.3 **mm Hg**

›› Precipitation sensor **(C-P-20 w/rain collector 99800-50(inch) & 51(mm)**

range: daily up to 999.8mm, accumulated up to 9999mm; accuracy: ±2%

Weather monitor(5)

- **Low Cost Weather Station (Cole Parmer 20) for corner buildings**
  - C-P GL-99800-20; $570 (w/rain collector, outdoor T/RH sensor and cables)
  - Monitor: ***Temperature*** (in and out), ***Relative Humidity*** (in and out), ***Wind*** (speed and direction), ***Air Pressure***, ***Rain fall***, also **Dew point** and **wind chill**.
  - ***Interface to CDS: RS 232 interface***
- **Low Cost Weather Station (C-P 10) for mid and end buildings**
  - same as C-P 20, but for ***Temperature and Wind monitoring only;*** cost: $195
- **Implementation**

– Inside Buildings

1. 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.
2. The **barometer:** part of the weather station C-P 20, does not require mounting.

– Outside Buildings

1. The **thermometers** which monitor the outside will be contained in protective enclosures to reduce the influence of sun and precipitation. They will be placed to take a representative sample of T on the given bldg. (LVEA/VEA) ext. wall.
2. The **hygrometer** will be placed with one of the external thermometers.
3. 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).

– 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.

Dust Particle Detectors

Dust particle counters are required to monitor the air quality of the **C**lean **R**ooms (**CR**). PEM will provide fixed and portable dust particle counters for the spaces listed bellow.

1. 1 per OSB optics lab (fixed cleanroom corner station) (1WA and 1 in LA)
2. 1 per OSB Vacuum Equip. Prep. room (fixed, corner station) (1WA + 1LA)
3. 2 per LVEA at corner station(2 in WA and 2 in LA)
4. 1 per VEA mid and end stations (4 in WA and 2 in LA)
5. 1 per Mid & End-Station optics lab (4 in WA and 2 in LA)
6. 1 per portable cleanroom (3 corner+2 mid+2 end=7 in WA, 3+1=4 in LA)
7. 1 per PSL/IOO (2WA + 1LA)

- ***availability requirement: The monitors on the PSL/IOO must be operational.***
- ***calibration: intercomparison between units.***
- ***spares: none (units can be used interchangeably)***

››Dust Particle Detectors for Fixed Clean Rooms

- Met One Model 4800 or 227B (same, but 227 includes a vacuum pump)
- Particle size>0.3 μm; storage capability; sample/hold time: 1sec to 24 h
- ***Interface to CDS: RS 232/485 interface***

•• **Implementation: (21 in WA and 13 in LA, *no spares)***

Dust particle monitors will be portable. Mounted with Velcro or equivalent.

– Clean Rooms (CR)

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

– 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.

Seismic Excitation System (1)

• Specifications

PEM will provide SEI with design details for attaching *mechanical 'shakers'* to the stack support beams; the 'shakers' will be moved from chamber to chamber as needed. If the Detector includes an active SEI system, PEM will use those means as well to excite the support point. 'Shaker' specifications:

1. possibility of **excitation along all axis**; no requirement of uniform or mono-directional excitation
2. **amplitude** of motion 10x LIGO measured spectrum from 0.3 Hz to 100 Hz (integral about 1 micron rms, or pk-pk 2.5 microns).
3. **uniformity** of response ± 10 dB; the response need not be very uniform in frequency, as we will monitor the net motion with accelerometers.
4. **harmonic distortion** at maximum level: -30 dB

In addition, PEM will acquire standard *electromagnetic 'shakers'* (such as standard small B&K specifications) for multipurpose use, to be associated with the Cart.

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.

• Multipurpose Signal Generator (2 WA, 2 LA)

- model SRS DS 335:
- multiple wave shapes
- maximum frequency: 3.1 MHz for sine and square pulses
- ***Interface to CDS: GPIB and RS 232 interfaces***
- ***Interface to CDS: power 115VAC***
- Output amplitude: 0.05 - 10V into 50 Ohms
- Note: used for the all shakers and acoustic noise

Seismic Excitation System (2)

• Seismic Excitation System Components:

››PZT Excitation System (15WA and 15 LA, no spares)

1. The PZT 'shaker' will be built in-house.
2. Basic principle: multi-layer PZT stack 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.
3. Electromagnetic shakers must be avoided for use near the TMs due to the test mass magnetic field sensitivity.
4. signal source will be either a general purpose oscillator (see above) or the CDS DAQ/Diagnostics system. A high-voltage amplifier will be specified and supplied to interface to the PZT shaker.

››Portable PZT Accelerometer Calibrator ***(Endevco 28959E)***

A portable calibrator for the PZT is proposed to be part of the standard equipment at each site (cart) (1 in WA and 1 in LA).

- range: up to 10 g; BW: 3 Hz to 10 kHz; freq. readout acc,: 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
- ***interface to CDS for power: charger for batteries 115 VAC***
- ***interface to CDS for output signal: RS 232 with a DB-9 female connector***

Seismic Excitation System (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

- **Implementation: 3 WA, 3 LA**
- **Seismic Excitation Systems Mechanical Interfaces**

– ***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.***

Acoustic Noise Generator

- Specifications
  - dynamic range $10^{-5} \geq p(f) \geq 10^{-9} atm / \sqrt{Hz}$ bandwidth: 10Hz - 1kHz, TBD
  - harmonic distortion at maximum level: -30 dB
  - two per site for the PEM carts
  - calibration: none
  - spares: none

››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)

•• Implementation

- 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.

Magnetic Field Generator (1)

• Specifications and Design Philosophy

The magnetic field generator should be able to produce fields and gradients in all directions near the location of the test masses and have sufficient strength to induce motions seen above the noise in the suspensions.

- Dynamic range: $10^{-13} \le B \le 10^{-5} T$
- frequency range, sinusoidal output: (± 10 dB): 1 Hz - 1kHz
- Bursts duration: 10-300μs
- One per building or one per cart (TBD: possible need for one coil per tank if needed to obtain a specific field configuration of interest)
- calibration: PEM magnetometers
- spares: none

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.

Magnetic Field Generator (2)

››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 $10^{-3} < \mathrm{I} < 10$ A

››Current Supply:

- range: 1mA to 12 A DC custom made precision transformer/rectifier, or LAMBDA custom design current supply.
- ***Interface to CDS: power 115VAC***

•• Implementation

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.

RF generator

- Specifications
  - dynamic range 120 dB, minimum level 1μV/m at 1 m
  - bandwidth: 1.3GHz
  - AM: DC - 1 kHz, 100% modulation depth
  - ***two per site***: portable unit or part of the PEM cart (TBD)
  - calibration: periodic cycling to manufacturer
  - spares: none

  ›› 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) TBD
  - ***Interface to CDS: power 115VAC***

  •• **Implementation**

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

Residual Gas (vacuum) (1)

Residual Gas monitor (RGA)

Requirements for **pressure measurement** in instrumentation chambers, associated tube and beam tube modules:

- sensitivity: measurement the pressure of the residual gas in the 4Km beam tubes: the sensitivity should be of the order of $10^{-14} torr$, 1-100 amu.

This sensitivity of the system is intended be able to determine the contribution of gas bursts and other coherent residual gas fluctuations, leaks, etc.; to measure the composition of the residual gas.

- timing resolution on a single mass number $\Delta t_{res} \leq 10 ms$. This is sufficient to stamp the time dependence of the pressure and bursts measurements.
- dynamic range: 10^9
- estimated data rate per RGA: 1x16 bit, 2048 sample rate on threshold crossing, 20Hz sample rate for continuous monitoring below threshold.
- availability requirement: one RGA head and controller per building required to be operational and in recent calibration.
- calibration: calibrated leaks to be installed with each RGA head
- ***spares: one head and one controller per site***

Residual Gas (vacuum) (2)

››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

1. total RGA: $43600

•• Implementation: RGA *heads* installation: 9 in WA and 5 in LA

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

•• CDS extensibility to allow one RGA head/Km of BT: additional 7 in WA and 8 in LA.

- 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.

Vacuum Contamination Monitor(1)

Initial step: research one approach for monitoring

1. procure a crystal deposition monitor
2. study and establish if the crystal monitor is adequate
3. study how many crystal monitors are necessary after the experience during the commissioning of the IFO.

- availability requirement: Not required for operation.
- calibration: TBD
- spares: none

•• initial installation (estimate, if method is successful):

1. 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.
2. one set of ***control electronics and PC*** per building, or 5 in WA and 3 in LA; intermittent data/control transfer to/from PC

•• Requirements (point of departure) for contamination monitors in instrumentation chambers and associated tubes

- Capability to measure deposition of 1 monolayer/month on ambient temperature surface.
- Capability to perform qualitative desorption analysis to separate water from other adsorbed molecules
- The analytic capability is provided by:
  1. evaporation of absorbed layer vs. crystal oscillator sample collector temperature
  2. measurement of the evaporated layer by an RGA

Vacuum Contamination Monitor(2)

•• The following estimated costs are from the initial Cost Book PEM estimates 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

•• Implementation

1. one ***head*** per isolatable vacuum volume (excluding the BT), 8 in WA and 5 in LA No spares
2. one set of ***control electronics and PC*** per building, or 5 in WA and 3 in LA; intermittent data/control transfer to/from PC. No spares.

- The crystal head sensors are mounted on existing Vacuum Equipment ports, nearby RGA sensor heads, 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.

Interface Definitions

- Interfaces to other LIGO detector subsystems
  - The PEM system is designed as an independent system
  - There are no signal or optical interfaces with the interferometer subsystems, to avoid corruption of either.
  - PEM accepts and provides monitor and control inputs, used in acquisition, and eventually in control or on-line veto of the acquisition data taking.
  - For the initial stage of the LIGO detector, there are no hardware vetoes.

Documentation of interfaces

›› A separate document (PEM ICD) to be assembled

›› to contain drawings of footprints, details of attachment, specific VE ports to be occupied

›› Will then be integrated into the unified Detector IICD

Testing

››First articles of each sensor/actuator element of the PEM will be tested to their specifications. If 100% testing is indicated by these spot checks, it will be carried out.

››In addition, each in-house built sensor and actuator will be tested to its specifications before delivery to the sites.

››The PEM Carts will be assembled and given a system check before delivery to the sites.

Diagnostics and Calibration

››Diagnostics Philosophy

- The redundancy of the PEM system supplies a cross-check for most sensors to determine if they are functioning correctly.
- For example, if one accelerometer on a TM chamber ceases to function correctly, its signal will be markedly different from the other 5 mounted on that TM.

››Exceptions:

- Thunderstorm monitor (if a commercial service is retained, it will come with its own calibration and diagnostic information)
- Power Line monitor (propose sending to manufacturer for calibration during planned service times)
- RGAs (an off-line test manifold is proposed with Vacuum Equipment; TBD)
- Contamination monitor (periodic replacement of the sensor head is proposed)
- hygrometers, barometers, anemometers, precipitation sensors, and wind-speed sensors (Local weather forecasting will give an adequate measure of the go/no-go performance of these sensors).

Installation and Commissioning

››PEM Cart

- The PEM cart will be the first element of the PEM to be delivered and used at the sites.
- It is self-contained by design, and will be used even in advance of the completion of the buildings.
- The **target date for completion is mid-97 for two carts** (to be delivered to WA and LA). It will have undergone a system test at MIT/CIT, so will have effectively been commissioned before arrival at the site. Initial tests to determine performance will be undertaken, and then it will be used on an as-needed basis by staff at the sites.

››Other PEM elements

- The installation and commissioning plan is in a rudimentary state
- The philosophy of the installation plan is to have the PEM sensors (and actuators via the Cart) in place early enough to aid in the installation and commissioning of the parts of the interferometer (and site in general) for which those measurements/excitation would be helpful.
- For example, the seismic excitation and accelerometers will be in place to allow testing of the seismic isolation stacks as they are constructed, giving an early characterization of as-installed frequency and Q of the stack solid-body resonances.

Cost

Total cost of equipment (non-CDS) for initial PEM installation: ~1.3M

- Original cost book estimate ~3M
- Principal difference is in numbers of sensors
- BTs not completely instrumented
- Will determine final cost AFTER initial PEM measurements

Schedule

Final Design Review: June 98

- ›› in-house designs completed, with rough prototypes
- ›› last choices for commercial instruments made
- ›› interfaces detailed
- ›› parts for carts ordered, drawings finished, construction started

Fabrication

- ›› To be timely for on-site needs

Installation/commissioning

- ›› To be timely for on-site needs

Cost

	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	see text 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 satellite service			1+1	~20
RF Interference	Broadband Multi-channel 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	2 6
Cosmic Muons	Scintilator Detec-tor	$\frac{10^{-6}\cdot\mu}{s\cdot m^2}$	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 heads 6+4 controllers	13 32 500
Contamination	Crystal Head controller	monolayer/ week		8+5 heads 5+3 controllers	156
Weather Monitor	T,RH,Prec, wind,P	see text		35 + 30 units (see text)	11
TOTAL	COST	for full	PEM	no carts	~1.3 M

Cart equipment and costs

	Equipment	*Sensitivity*	*Range*	*Chan*	*Unit Total k$*
	Sensing	equipment	for	carts	
Seismic Noise	3x3 axis accel-erometer	$10^{-11} m$ @100Hz	10Hz-200 Hz	9	1.1 10
Acoustic Noise	Electret Micro-phones	$2 \cdot 10^{-9} atm$ @100Hz	~1kHz	2	0.2 0.4
Magnetic Field	3 axis magne-tometer	$10^{-11} T$ @100Hz	DC - 1kHz	1	3.5
RF Interference	Multichannel Receiver	0.01mV/m 6 channels	up to 1.3GHz	6	36
Contamination +RGA	Contr.head control RGA	$P \leq 10^{-14}$ torr	1-100 amu	1	55
	Excitation	equipment	for	carts	
general purpose Generator	DS 335		wide range	1	2
Seismic Noise	PZT and e-m Shaker		above 10Hz	15	~ 2 30
Acoustic Noise	Loudspeaker Generator		20-1000Hz	2	~ 2 4
Magnetic Field	Custom design coils		DC-1kHz	1	~2 2
RF noise	RF Generator		up to 1.3GHz	1	~12 12
TOTAL	EQ COST	per	CART		~155