DISTRIBUTION FOR ATTACHED DOCUMENT

A. Abramovici
W. Althouse
F. Asiri
B. Barish
D. Barker
G. Billingsley
K. Blackburn
R. Bork
J. Camp
M. Coles
D. Coyne
D. Durance
J. Hazel
J. Heefner
S. Kawamura
W. Kells
A. Kuhnert
A. Lazzarini
P. Lindquist
J. Logan
S. Meshkov
F. Raab
G. Sanders
R. Savage
L. Sievers
R. Spero
K. Thorne
D. Tomlinson
R. Vogt
S. Whitcomb
J. Worden
H. Yamamoto
Chronological File
Document Control Center

Ref: LIGO-G960137-00-E

LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Viewgraphs	G960137-00-	E	5/21/96
Document Type	*Doc Number*	*Group-Id*	*Date*

Quarterly Science & Integration Meeting 20, 21 May, MIT

Title

Distributed at CIT by
A. Lazzarini

cc: CIT Science
CIT Engineers
Chronological File
Document Control Center

California Institute of Technology
LIGO Project - MS 51-33
Pasadena CA 91125
Phone (818) 395-2131
Fax (818) 304-9834
E-mail: info@ligo.caltech.edu
WWW: http://www.ligo.caltech.edu

Quarterly Science & Integration Meeting

20, 21 May 1996, MIT

Agenda - Day 1 (Times are EDT)

0900 - 1200

- Report (and discussion) from the working group on Data Analysis Scenarios and Flows -- Vogt/Bork/Blackburn/Zucker/

1200 - 1300

- Lunch

1300 - 1430

- Report (and discussion) on the working group on IFO Diagnostics -- Weiss/Spero/Raab

1430 - 1600

- Report on activities leading to the continuing R&D proposal to the NSF -- Weiss/Vogt

1600 - 1700

- Report on LIGO / VIRGO Data Formats Meeting -- Lazzarini
- Follow-up discussions with Mours -- Blackburn/Bork

Quarterly Science & Integration Meeting

20, 21 May 1996, MIT

Agenda - Day 2 (Times are EDT)

0900 - 0940

- Civil Construction - Coles/Stapfer

0940 - 1040

- Beam Tube System - Jones
- Mini bake status - Althouse
- BT /Baffle alignment tolerancing - Lazzarini

1040 - 1055

- BREAK

1055 - 1140

- Vacuum Equipment System - Worden

1140 - 1230

- Lunch

Quarterly Science & Integration Meeting

20, 21 May 1996, MIT
Agenda - Day 2 (Times are EDT)

1300 - 1320
- Detector Systems Design - Shoemaker

1320 - 1350
- Missions of 40 m research program - Spero

1350 - 1400
- BREAK

1400 - 1420
- Performance of 40 m interferometer, related to LIGO goals -Spero

1420 - 1440
- ISC design - Zucker

1440 - 1515
- PNI status/update - Saha

1515
- MIT Facilities tours

Report (and discussion) from the working group on Data Analysis Scenarios and Flows

Vogt/Bork/Blackburn/Zucker

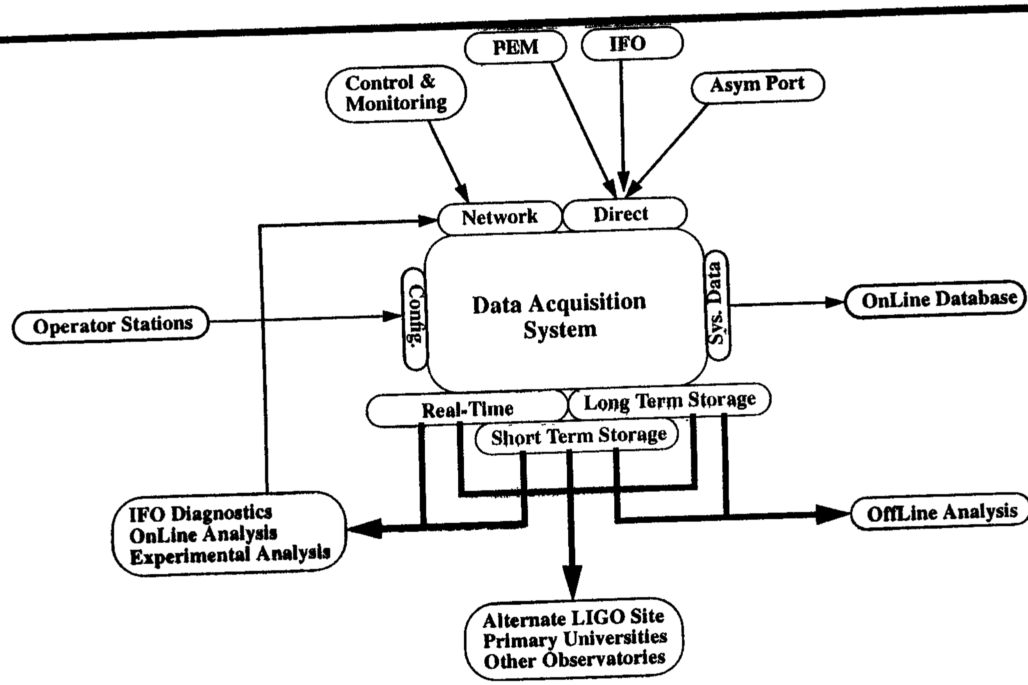
20 May, 1996
0900-1200

Science & Integration Meeting
MIT
May 1996

DATA ANALYSIS SCENARIOS

1. System Overview
2. Data Flow Down
3. Master Tape
4. Data Analysis
5. IBM Univ. Grant Program

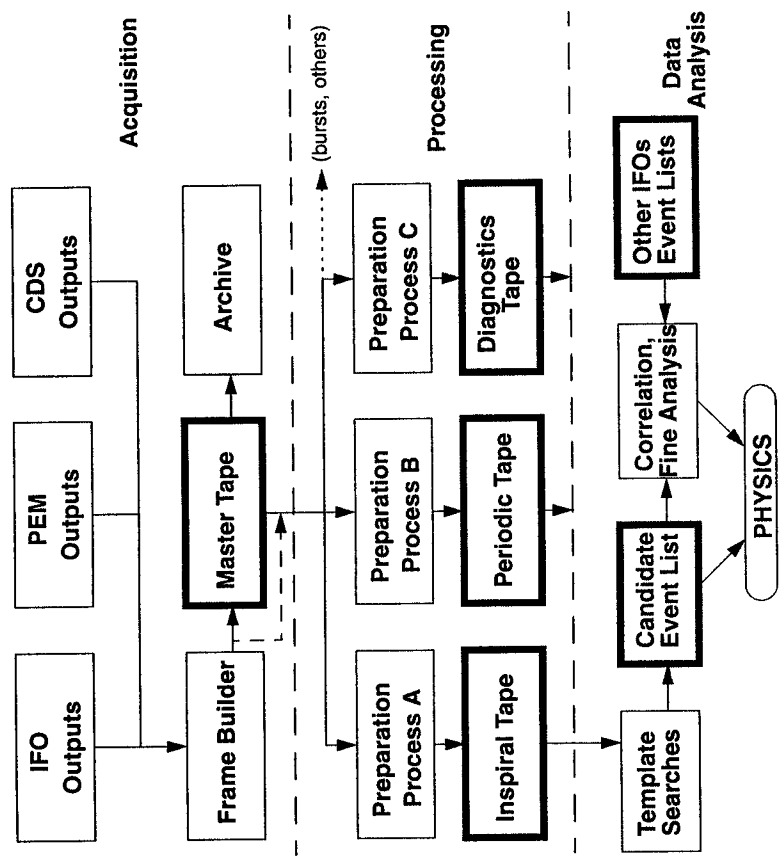
DAQ System Interfaces



LIGO DATA TAPE

Science & Integration Meeting - MIT May 1996

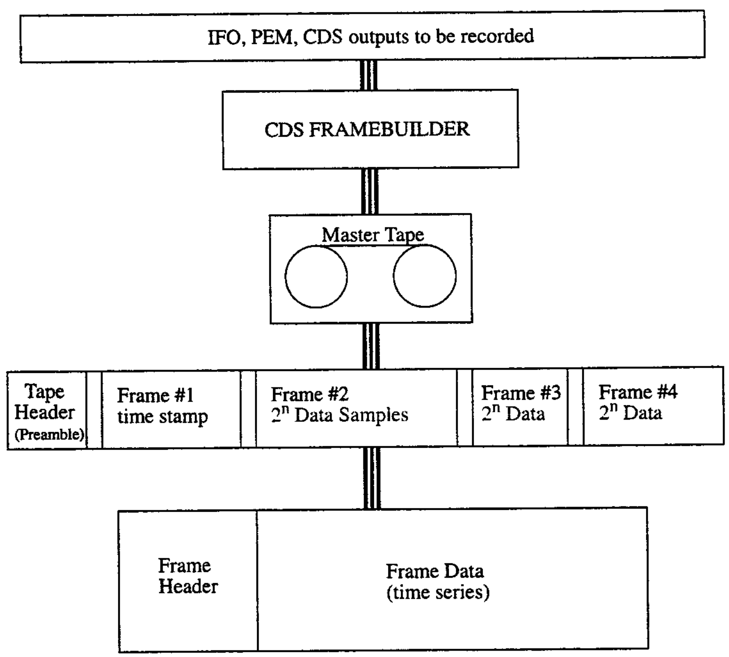
- “Very” Simple Data Flow Concept

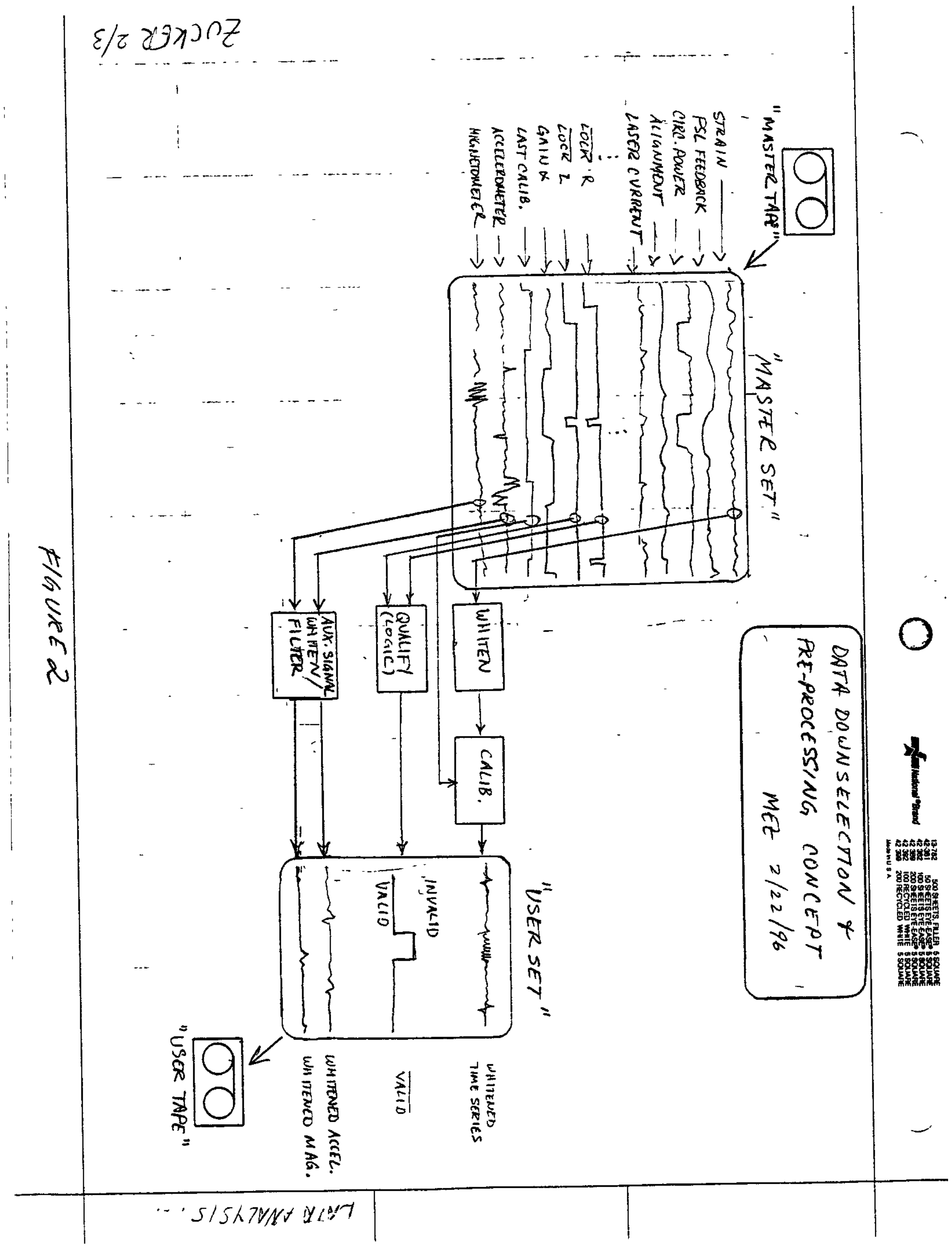


LIGO DATA TAPE

Science & Integration Meeting - MIT May 1996

- “Very” Preliminary Master Tape Concept





LIGO DATA TAPE

Science & Integration Meeting - MIT May 1996

- Recorded Data

The "Master Tape" will contain a complete set of interferometer data necessary to make off-line data analysis and data channel correlations possible.

- One "Master Tape" per interferometer

- Record all IFO *time series* outputs

- Record all PEM *time series* outputs

- Record all CDS *time series* outputs

- Information on the pre-A/D whitening filters used to compress the dynamic range of signals such as the strain, acoustic, accelerometer, etc.

- A quality flag or hierarchical set of flags will be written to the tape using a logical condition which may change as our understanding of the interferometer evolves. This flag will facilitate the qualification of data during analysis

- Transfer functions and IFO state vectors be written to the "Master Tape." This information will appear in the "Master Tape" header and in a specialized frame each time these data vary outside of a TBD "dead-band."

LIGO DATA TAPE

Science & Integration Meeting - MIT May 1996

- Data Structure

The structure of the data stored on the "Master Tape" will at the highest level consist of frames. The "Master Tape" will have a tape header with information pertinent to the entire tape and/or long stretches of the tape. Each frame will consist of a self describing frame header followed by the time series data from all the recorded outputs(channels).

- Frames will contain all data for a fixed intervals of time (frames may vary in byte size)

- Frames time intervals will be an fixed number of seconds and should contain a power of two number of data samples

- Frames will not be so long in time interval as to make data extraction excessively time consuming on standard data analysis computer environments looking at data from multiple interferometers.

- Frame headers with have a time stamp marker corresponding to the start/TBD time of the data contained in the frame.

- Frame headers will contain sufficient self descriptors to identify the type of frame and other TBD characteristics of the frame

- The frame header will be followed by the time series data in a TBD data format for all recorded outputs.

LIGO DATA TAPE

Science & Integration Meeting - MIT May 1996

- Tape Preambles

The "Tape Header" will provide at a minimum a preamble to identify the tape. These are meant to characterize either the whole tape or at least long stretches of the tape.

- Sequential Tape ID (may have encoded within, the Site & IFO number)
- Site
- IFO number
- Date (both local and GMT)
- Time (both local and GMT)
- Detector location (latitude & longitude)
- Detector arm orientation (convention needed)
- Frame Builder version
- IFO mode (recycled, dual-recycled)
- Operation mode (normal observation, research & development)
- Initial IFO state vector (~10's of kilobytes)
- Initial Transfer Functions (~10 kilobytes)
- Pre-A/D whitening filters used to reduce dynamic range
- A FLEXIBLE FORMAT that allows for expansion of this list

LIGO DATA TAPE

Science & Integration Meeting - MIT May 1996

- Tape Summary

The "Tape Header will contain a pre-allocated data space for storing summary and statistical information on various characteristics of the data and the interferometer that are accumulated during the recording period for the tape.

- Data Rates

- ~6 Megabytes per second is the expected data rate / interferometer
- ~2 hours is the expected data collection time per tape (48GB / 6MB/s)

- Frame Types

The tape frame will be sufficiently general to support and completely describe variable frame types. One could propose to use special-purpose frames under the general frame structure for such things as:

- Fast IFO data (e.g. strain, laser power)
- Fast PEM data (e.g. microphone, accelerometer)
- Slow IFO data (e.g. suspension, stack signals)
- Slow PEM data (e.g. temperature, RGA pressure)
- Qualified data time span list (e.g. ignore frame 0000x, 00y00, ...)
- Measured frequency response transfer functions (e.g. strain calibrations)
- Machine state description
- Remote diagnostics & video snapshots

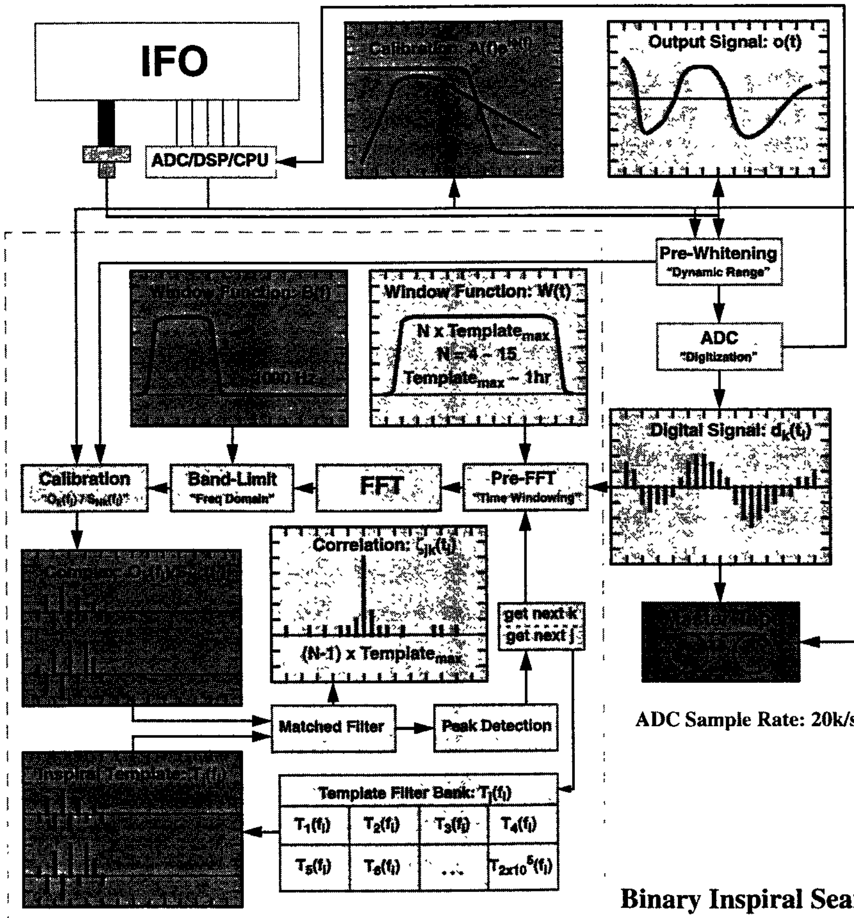
LIGO DATA TAPE

Science & Integration Meeting - MIT May 1996

- Existing Formats
  - HARDWARE: ascii, binary
  - COMPUTER LANGUAGE: Arrays, C-structures, C++ objects
  - PUBLIC DOMAIN: CDF, FITS, GRIB, HDF, netCDF, VICAR, PDS, miscellaneous graphics formats (TIFF, GIF, JPEG, FLI, CGM), SAIF, SDTS, HDS, MedFileS, CXF, JCAMP, CIF, OpenMath, GeoTIFF, DLG-3, DEM ...
  - COMMERCIAL: proprietary database

LIGO DATA ANALYSIS

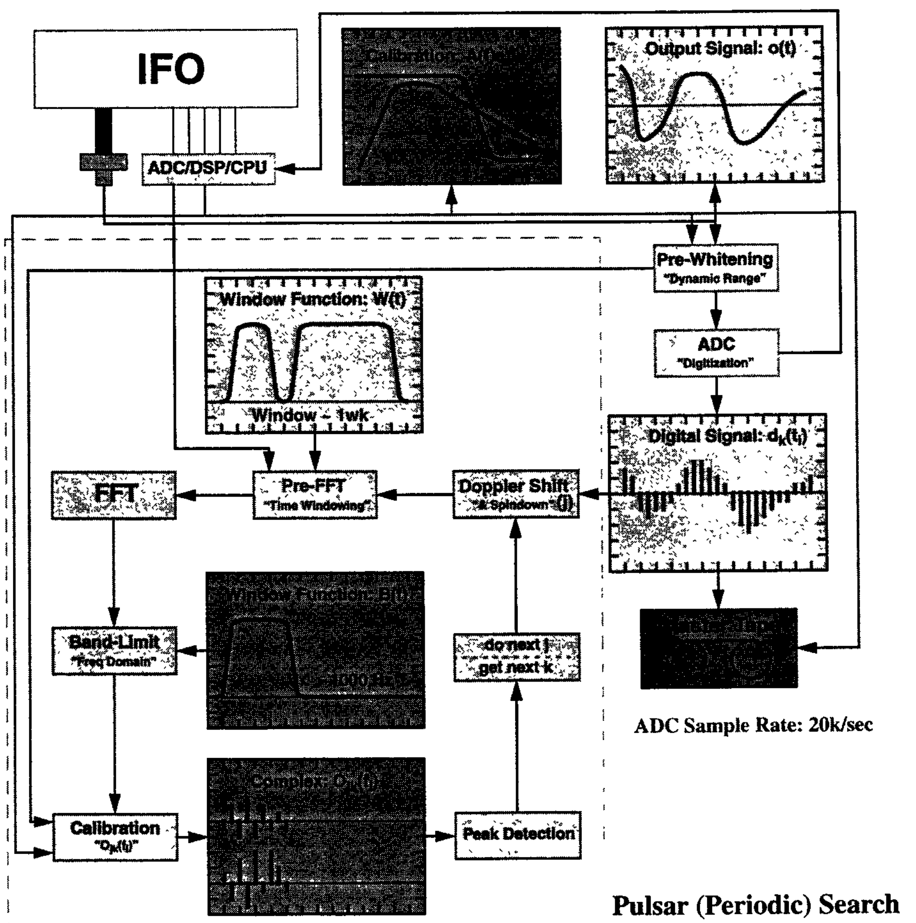
Science & Integration Meeting - MIT May 1996



Binary Inspiral Search

LIGO DATA ANALYSIS

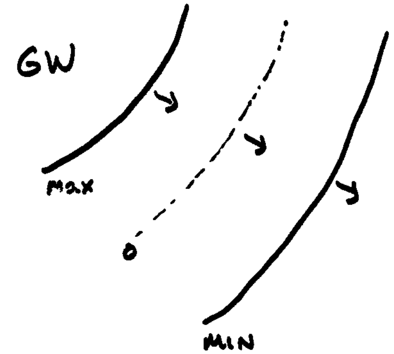
Science & Integration Meeting - MIT May 1996



ADC Sample Rate: 20k/sec

Pulsar (Periodic) Search

STOCHASTIC BACKGROUND DATA ANALYSIS

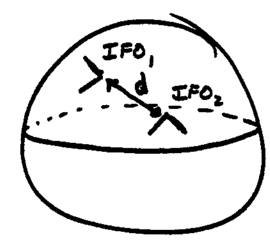


IN PHASE IF:

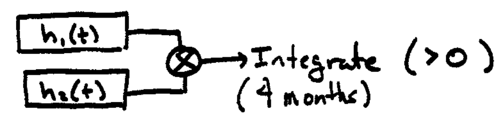
$\frac{\lambda}{2} \gtrsim d$

LIGO: $d = 3000$ km

$\Rightarrow f \lesssim 50$ Hz



Correlate signals from 2 or more detectors



Sensitivity Reduced by factor $\gamma(f)$ (overlap Reduction Function)

$\Rightarrow$ 1) non parallel arm alignment

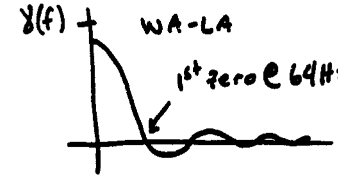
2) signals out of phase

Optimal Filtering (B. Allen)

$$\int_{-\infty}^{\infty} df\, \tilde{h}_1(f)\, \tilde{h}_2(f)\, \tilde{Q}(f)$$

Optimal when

$$\tilde{Q}(f) = \frac{\gamma(f)\,\Omega_{gw}(f)}{f^3 S_1(f) S_2(f)}$$



CONCEPTUAL DATA FLOW PARADIGM V. 2
MEZ 3/7/96

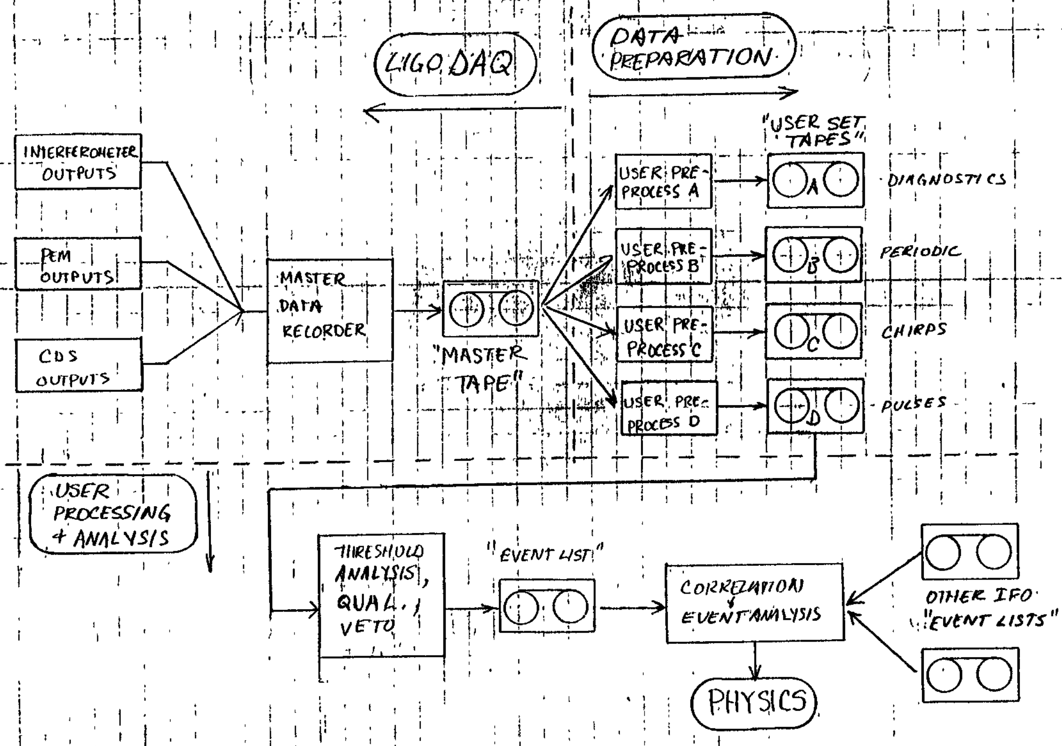
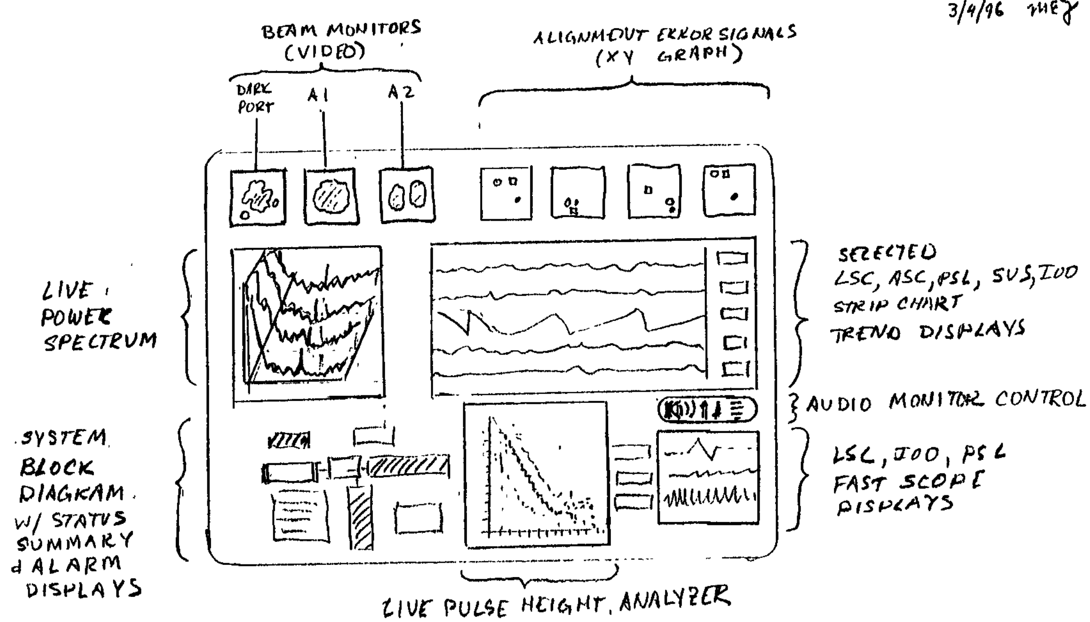


FIGURE 1

WORKING GROUP ON DATA ANALYSIS . . .

ZUCKER 1/3

3/3/96 MEZ
3/4/96 MEZ

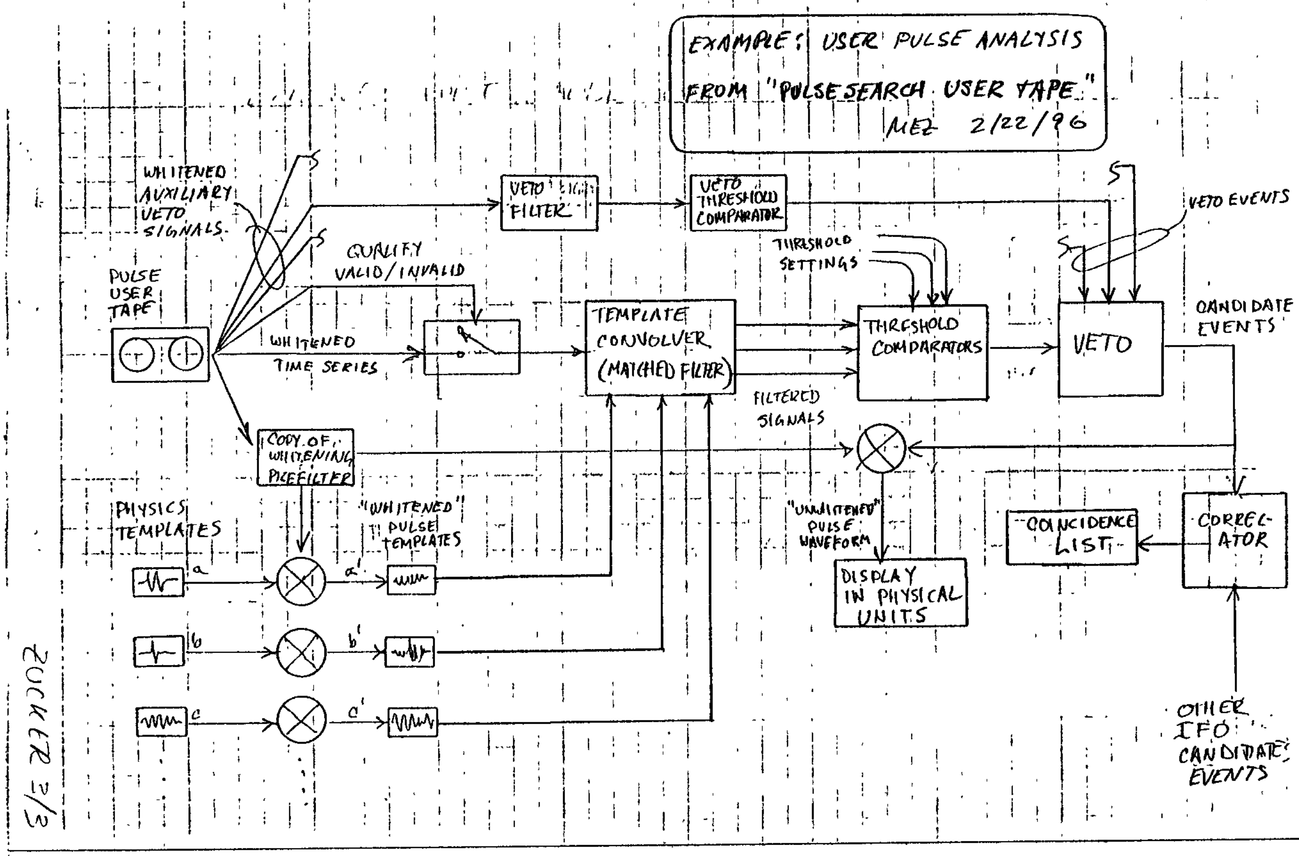


"QUICK LOOK" OPERATOR CONSOLE (CONCEPT)

WKG. GROUP ON IFO DIAGNOSTICS

ZUCKER 1/1

FIGURE 2



EXAMPLE: USER PULSE ANALYSIS
FROM "PULSE SEARCH USER TAPE"
MEZ 2/22/96
WHITENED AUXILIARY VETO SIGNALS
VETO FILTER
VETO THRESHOLD COMPARATOR
THRESHOLD SETTINGS
VETO EVENTS
QUALIFY VALID/INVALID
PULSE USER TAPE
WHITENED TIME SERIES
TEMPLATE CONVOLVER (MATCHED FILTER)
THRESHOLD COMPARATORS
VETO
CANDIDATE EVENTS
FILTERED SIGNALS
COPY OF WHITENING PREFILTER
PHYSICS TEMPLATES
"WHITENED" PULSE TEMPLATES
"UNWHITENED" PULSE WAVEFORM
COINCIDENCE LIST
CORRELATOR
DISPLAY IN PHYSICAL UNITS
OTHER IFO CANDIDATE EVENTS
a
a'
b
b'
c
c'
ZUCKER 2/3

FIGURE 3

Report (and discussion) on the working group on IFO Diagnostics

Weiss/ Spero/ Raab

20 May, 1996
1300-1400

DIAGNOSTIC TESTS
Functions

- Set operating points
  - ›› search for instabilities in servo loops
  - ›› determine minimum noise parameters
  - ›› determine dynamic range of an output
  - ›› determine intermodulation products due to offsets, saturations and non-linearities
- Establish sensitivity to perturbations
  - ›› determine sensitivity at an output by stimulation
  - ›› measure the noise at a sensitive point due to a specific mechanism
- Determine transfer functions and correlations
  - ›› determine transfer function between stimulus and output
  - ›› determine crosscorrelation or cross power spectrum between outputs
- Calibration of the system

DIAGNOSTIC TESTS
Concept to gain sensitivity

- Stimulation by periodic or random excitation
  - ›› Excitation larger than naturally occuring noise
  - ›› Response still linear
- Response to stimulation measured
  - ›› At output Z specifically sensitive to the stimulation
  - ›› Minimally sensitive to other noise sources
  - ›› Transfer function stimulation to Z output
- Transfer function of stimulation to GW output
  - ›› cross-correlation or cross power spectrum Z to GW output
- Noise measurement
  - ›› Stimulation off; cross-correlation of noise at Z with GW output
  - ›› Ultimately extension to full matrix solution not just diagonal terms

DIAGNOSTIC TESTS

- The tests recur :
  - ›› occasionally to set parameters
  - ›› periodically to maintain record of instrument and facility performance
  - ›› continuously as part of the operations data stream
- On line analysis tools
  - ›› plot data with adjustable axes (log and/or linear) and in different colors
  - ›› select data to fit to a linear, exponential or power law
  - ›› make χ^2 minimized fits to non-linear functions; plot: data, fit and residuals
  - ›› take the Fourier transform of selected data
  - ›› display the auto-correlation function of selected data
  - ›› take the cross-correlation function of selected data pairs

DIAGNOSTIC TESTS

›› determine the covariance of selected data pairs

›› calculate the cross amplitude spectrum of selected data pairs

›› calculate primitive statistical parameters of selected data: mean, variance, p-p, skewness and higher moments

›› display a histogram of the probability distribution of selected data

›› to make a restricted class of wavelet transforms of selected data

- Remote fast diagnostics - functions

›› measurement of peak excursions to uncover saturation

›› measurement of oscillation instabilities in servo loops

›› direct measurement of RF signals before demodulation

›› measurement of servo locking transients

DIAGNOSTIC TESTS

- Fast diagnostic signals - remote oscilloscope

›› common mode cavity output

›› differential mode cavity output

›› common mode Michelson output

›› differential mode Michelson output

›› common mode cavity wavefront sensor output

›› differential mode cavity wavefront sensor output

›› common mode Michelson wavefront sensor output

›› differential mode Michelson wavefront sensor output

›› all test mass position sensor outputs

›› all RF signal inputs to mixers

DIAGNOSTIC TESTS
List of tests

SENSING NOISE TESTS 1

Test 1.1: Frequency noise in the gravitational wave band

Test 1.2: Amplitude noise in the gravitational wave band

Test 1.3: Amplitude noise at the sideband frequency

Test 1.4: Amplitude noise due to unintended interferometers

Test 1.5: Noise due to input beam position and angle fluctuations

Test 1.6: Intermodulation products due to offsets and large amplitude deviations from null

Test 1.7: Phase noise limits due to scattering in the beam tube

OPTIMIZATION OF OPTICAL PHASE SENSITIVITY 2

Test 2.1: Signal to noise optimization of the RF modulation index

Test 2.2: Mode matching into interferometer

Test 2.3: Higher order arm cavity mode scan

Test 2.4: Arm cavity loss measurement

Test 2.5: Recycling cavity loss measurement

Test 2.6: Common mode cavity fringe calibration

Test 2.7: Differential mode cavity fringe calibration

Test 2.8: Common mode Michelson fringe calibration

Test 2.9: Differential mode Michelson fringe calibration

Test 2.10: Common mode arm cavity end mirror rotation calibration

Test 2.11: Differential mode arm cavity end mirror rotation calibration

Test 2.12: Common mode arm cavity input mirror rotation calibration

DIAGNOSTIC TESTS
List of tests

Test 2.13: Differential mode arm cavity input mirror rotation calibration

Test 2.14: Beam splitter rotation calibration

Test 2.15: Recycling mirror rotation calibration

NOISE DUE TO RANDOM FORCES 3

Test 3.1: Suspended optical component seismic noise sensitivity - ambient/driven

Test 3.2: Suspended optical component acoustic noise sensitivity - ambient/driven

Test 3.3: Suspended optical component magnetic field sensitivity - ambient/driven

Test 3.4: Suspended optical component electric field sensitivity - ambient/driven

Test 3.5: Suspended optical component tilt sensitivity - ambient/driven

Test 3.6: Pendulum longitudinal mode Q

Test 3.7: Pendulum wire transverse mode Q

Test 3.8: Pendulum wire longitudinal mode Q

Test 3.9: Pendulum vertical to horizontal cross coupling

OPTIMIZATION TO MINIMIZE NOISE FROM RANDOM FORCES 4

Test 4.1: Search for rotation insensitive beam position on suspended component

Test 4.2: Search for astatic point in suspended component position controller

DIAGNOSTIC TESTS
List of tests

TESTS OF THE FACILITY/DETECTOR INTERFACE 5

Test 5.1: Correlation of residual gas pressure fluctuations with detector output

Test 5.2: Correlation of technical power fluctuations with detector output

Test 5.3: Correlation of facility power fluctuations with detector output

Test 5.4: Correlation of facility monitor flags with detector output

Report on activities leading to the continuing R&D proposal to the NSF

Weiss/ Vogt

20 May, 1996
1430-1600

LIGO RESEARCH PROPOSAL
Schedule

- R&D FUNDING FOR LIGO AT CALTECH/MIT ENDS IN 1/1997
- PROJECT WILL SUBMIT R&D PROPOSAL TO NSF IN OCTOBER 1996 (Vogt, Weiss ,+)
- NSF HAS APPOINTED A "BLUE RIBBON" PANEL TO DETERMINE NEEDS OF THE FIELD
  - First meeting 6/24 - 6/25/96
  - Committee Membership
    - William Frazer Lawrence Berkeley Lab
    - Ned Goldwasser University of Illinois
    - Boyce McDaniel - chair Cornell University
    - Pier Oddone University of California at Berkeley
    - Peter Saulson Syracuse University
    - Sydney Wolff National Optical Astronomy Observatories

LIGO RESEARCH PROPOSAL
Schedule

- PRESENTATIONS BY:
  - ›› LIGO
    - Current state of LIGO construction
    - Planning for operations and data analysis
    - "White paper" on R&D
    - LIGO Visitors Program
  - ›› LIGO Research Community Chair
  - ›› Stanford University Group
  - ›› University of Florida Group
  - ›› University of Colorado Group ?
  - ›› Syracuse University Group ?
- HOPED FOR OUTCOME
  - ›› Scientific prospects and proposal pressure draw in new funds for the field
  - ›› NSF retains part of LIGO construction funding wedge

LIGO RESEARCH PROPOSAL
"White Paper"

- Intent of "White Paper" is to provide pedagogy
- Scientific overview
  - ›› Prospects for Gravitational wave research
    - Consequence for fundamental physics of gravitation
    - Consequences for astrophysics and cosmology
    - Classes of sources
  - ›› The initial LIGO detector
    - Sensitivity
    - Techniques to give confidence of detection
    - Operation as part of a gravitational wave detector network
  - ›› Directions for incremental improvements in the detector

$h(f)$ referenced to Initial and Advanced detector spectra shown in 1992 *Science* article

h_{rms} referenced to 3 events/year NS/NS coalescence at 20, 200, 2000 Mpc

LIGO RESEARCH PROPOSAL
"White Paper"

- Double pendulum suspension
  - Electrostatic controller and elimination of magnets on final suspension stage
  - Mechanical filter for control noise
  - Improved seismic isolation
  - Reduction in sensitivity to thermal noise from final isolation stage
- Reduced internal test mass losses
  - Higher Q test mass: design and materials
- Reduced pendulum losses
  - Alternate mounting techniques
  - New flexure design and materials
- Improved seismic isolation
  - Lower spring constant springs
  - External active isolation (if not incorporated in the initial detector)
- Higher circulating power in arms
  - Higher input laser power
  - Lower loss coatings on test mass mirrors

LIGO RESEARCH PROPOSAL
"White Paper"

›› Directions for qualitatively new detectors

- Dual recycling configurations
  - High frequency narrow band operation
- Completely reflective configurations

›› Fundamental limits

- Gravity gradients
- Naive quantum limit

• LIGO operations

›› Detector installation and qualification

›› Diagnostic procedures and initial noise measurements

›› Observation planning

- data processing
- development of data analysis strategies and algorithms

›› The observations

- data analysis: optimal filtering for different classes of sources
- correlation studies of intra and inter site noise

LIGO RESEARCH PROPOSAL
"White Paper"

- Use of the large baseline facilities for related research
  - Measurement of optical scattering
  - Study of temporal fluctuations in the residual gas
  - Local geophysical measurements

- Strategy for the LIGO R&D
  - ›› Intend to propose collaborative research programs
    - Broadening of expertise to make LIGO more productive
    - Utilization of LIGO infrastructure by collaborators
    - Provide natural entry for collaborations in the use of the LIGO long baseline system

- Rough Cost estimate and level of effort
  - ›› LIGO scientific and engineering staff divided between R&D and operations and data analysis
    - R&D support from new proposal
    - Operations and data analysis support from operations funds

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

- Actions Items from LIGO/VIRGO Meeting, April 1996
  - ››Review the structure of the proposed VIRGO FORMAT
  - ››Investigate the structure of public domain data formats
  - ››Isolate the VIRGO format read/write software into a "library"
  - ››Distribute this new VIRGO format library to LIGO for testing
  - ››Evolve VIRGO format -> LIGO/VIRGO format
  - ››Document format and library
  - ››Meet to finalize technical aspects of format in August
  - ››Finalize LIGO/VIRGO data format in September in Annecy

Report on LIGO/VIRGO Data Formats Meetings

Lazzarini

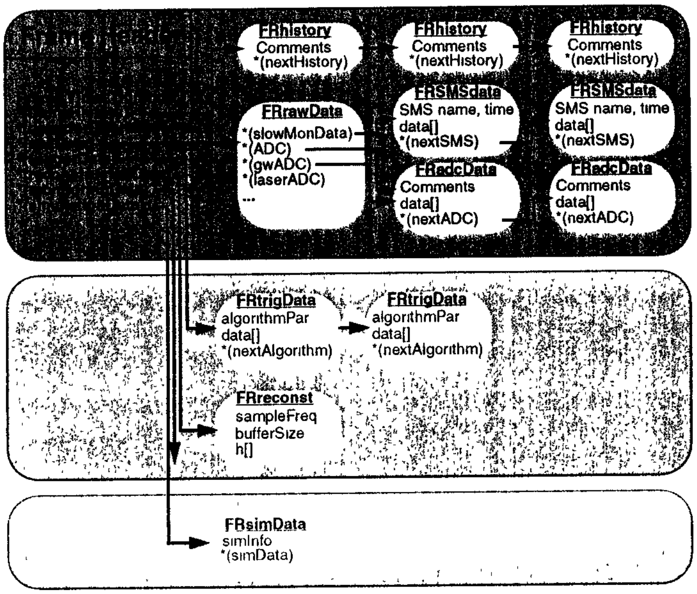
20 May, 1996

1600-1700

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

- PROPOSED VIRGO FORMAT (cont)



C Structures filled by Frame Builder

C Structures filled by On/Off line data processing

C Structures filled by simulations

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

- PROPOSED VIRGO FORMAT

››FRAMES (unit of information containing all information needed to understand the interferometer behavior over a finite time interval)

›› C STRUCTURES (frames are organized as a set of C structures)

››FRAME HEADER (holds pointers to additional structures that contain all information)

››LINK LISTS (used to collect generic data types, PEM, ADC, etc)

››HEADER HOOKS (pointing to frame elements used by online processing or by offline reprocessing)

››2^N DATA POINTS (allowing faster FFT analysis on individual frames)

››DICTIONARY (acts as a catalog of C structures and pointer offsets)

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

• PUBLIC DOMAIN DATA FORMATS (cont)

›› HDF (Hierarchical Data Format)

— Developed at the National Center for Supercomputing Applications (NCSA)

— Reviewed 350 pages of documentation (current version HDF4.01rl patch 1)

— HDF is a multi-object file format for sharing the types of data and metadata common to science in a distributed environment utilizing efficient storage, platform independence, extensibility and compatibility with other standard formats.

— Software library available for C and FORTRAN + utility programs / handles bit issues!

— Supported on Cray, Convex, HP, Vax, Sun, IBM RS/6000, Silicon Graphics, Macintosh, and IBM PC computers (future development towards parallel computers)

— Web browsers to support HDF format being developed

— Supported by commercial software (AVS, Data Explorer/IBM, IDL, IRIS Explorer/SGI, PCI, PV-Wave, Spyglass & public domain software (FREEFORM, GRASS, LinkWinds, ImageMagick, NCSA visualization tools, Collage, HDF-UCD, Mosaic for X w/ Scientific Data Browse-o-rama, Ployview, ...

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

• PUBLIC DOMAIN DATA FORMATS

›› http://fits.cv.nrao.edu/traffic/scidataformats/faq.html: CDF, FITS, GRIB, HDF, netCDF, VICAR, PDS, miscellaneous graphics formats (TIFF, GIF, JPEG, FLI, CGM), SAIF, SDTS, HDS, MedFileS, CXF, JCAMP, CIF, OpenMath, GeoTIFF, DLG-3, DEM ...

›› CDF (Common Data Format)

— Developed at the National Space Science Data Center (NSSDC)

— Reviewed 500+ pages of documentation (current version V2.5.19)

— Self-describing data abstraction for the storage and manipulation of multi-dimensional data in a discipline-independent fashion

— Software library available for C and FORTRAN + utility programs / handles bit issues!

— Supported on DEC Alpha/OSF1 & OpenVMS, DECstation/ULTIX & VMS, HP 9000 series/ HP-UX, IBM PC/MS-DOS, Windows & Linux, IBM RS600 series/AIX, Macintosh, NeXT/Mach, SGI Iris, Power series and Indigo/IRIX, Sun/SunOS & SOLARIS, VAX/VMS

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

• THE BIT ISSUE

Table 1: Data Types

	2-byte INT	4-byte INT	FLOAT	DOUBLE	CHAR	
XDR	big-endian	big-endian	IEEE 754B	IEEE 754B	ASCII	
SUN	big-endian	big-endian	IEEE 754B	IEEE 754B	ASCII	LIGO
HP	big-endian	big-endian	IEEE 754B	IEEE 754B	ASCII	
NeXT	big-endian	big-endian	IEEE 754B	IEEE 754B	ASCII	
MAC	big-endian	big-endian	IEEE 754B	IEEE 754B	ASCII	
SGI	big-endian	big-endian	IEEE 754B	IEEE 754B	ASCII	
IBMRS	big-endian	big-endian	IEEE 754B	IEEE 754B	ASCII	
DECstation	little-endian	little-endian	IEEE 754L	IEEE 754L	ASCII	
IBM PC	little-endian	little-endian	IEEE 754L	IEEE 754L	ASCII	
AlphaOSF1	little-endian	little-endian	IEEE 754L	IEEE 754L	ASCII	VIRGO
VAX	little-endian	little-endian	F_FLOAT	D(G)_FLOAT	ASCII	
AlphaVMS	little-endian	little-endian	F_FLOAT	D(G)_FLOAT	ASCII	

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

• PUBLIC DOMAIN DATA FORMATS (cont)

›› Both CDF and HDF have evolved to the point that earliest version are no longer supported by current versions.

››HDF used by more groups and projects around the world (very popular!)

››CDF/HDF have abstraction for defining data relationships much like rdb's

››CDF(and now HDF) allows data distribution across multiple files

››HDF compatible with C structures (using the vgroup data object)

››HDF looks like the better of the two formats (3 if including FITS)

››HDF's FUTURE (support for parallel I/O, restructured library to support...)

››Both CDF and HDF could support LIGO/VIRGO data formats

››Both would involve a greater learning curve than C structures

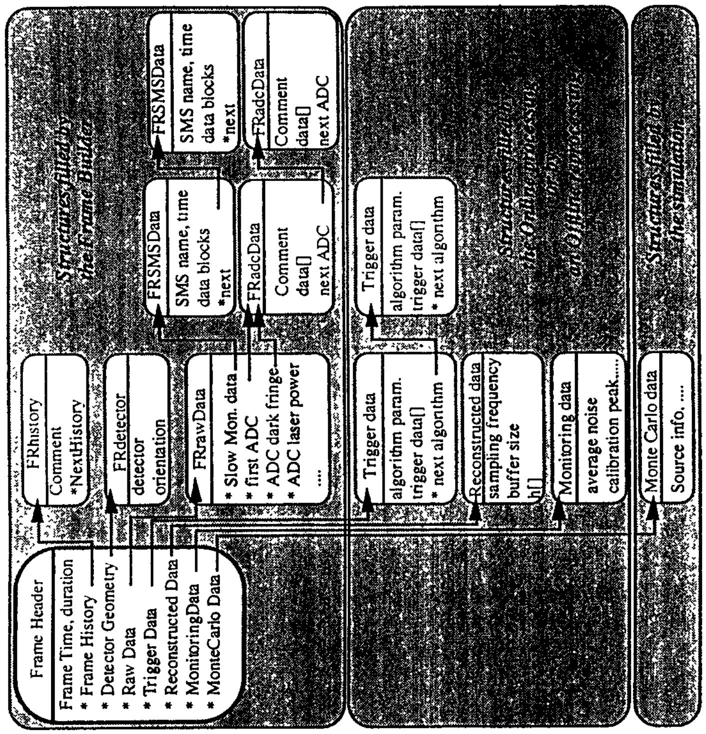


Figure 5400.6 The frame structure

5400.4. The Data Display.

This is a tool to look at the content of Frames (from disk files or from the Data Distribution) and provides tools to plot the data in various way. It could be used online to survey data or offline to play with simulated data or reconstructed data.

5400.5. Online processing

In parallel to the raw data archiving, The online processing has mainly three tasks (see figure 5400.7) described in the following sections. All these tasks are run in CPUs connected in parallel to the Frame builder vertical bus.

-5400.5-

LIGO/VIRGO DATA FORMATS

Science & Integration Meeting - MIT May 1996

- STATUS WITH BENOIT MOURS
  - ›› Initial collection of suggested changes to C structures made to VIRGO
  - ››Review of HDF and CDF nearly complete (Question: Use VIRGO or HDF?)
  - ››Awaiting delivery of VIRGO format I/O library for demonstration (soon)
- ITEMS TO BE COMPLETED
  - ››Make comparison of VIRGO library to HDF library performances
  - ››Make second level of recommendations of changes to VIRGO format
  - ››Document format and library
  - ››Implement VIRGO/LIGO format version control / bug report / enhancement
  - ›› - OR -
  - ››Decide to adopt HDF (internal LIGO followed by VIRGO decision)

```
struct FrameH {               /* Frame header structure                     */
  char *name;                 /* frame name (experiment name)               */
  long run;                   /* run number                                 */
  long frame;                 /* frame number                               */
  long timeSec;               /* frame starting time ( sec since 1/1/70)*/
                              /* (time are given by the C function time)*/
  long timeNanoSec;           /* frame starting time (nsec modulo 1 sec)*/
  double dt;                  /* frame length (nsec)                        */
  long triggerType;           /* trigger type                               */
  struct FrDetector *detectSim; /*detector used for simulation              */
  struct FrDetector *detectRec; /*detector used for reconstruction          */
  struct FrHistory *history; /* pointer to the history bank                 */
  struct FrRawData *rawData; /* pointer to the raw data structure           */
  struct FrRecData *recData; /* pointer to the reconstructed data           */
  struct FrStruct *trigData; /* pointer to the trigger data structure       */
  struct FrStruct *monData;  /* pointer to the monitoring data              */
  struct FrSimData *simData; /* pointer to the simulated data buffers       */
                              /* ------ end_of_SIO parameters ----------*/
  struct FrDetector *curDetector;/*curently used detector                   */
   };

struct FrDetector {
  char   *name;               /* detector name                              */
  struct UJclock *clock;      /* master clock for this detector             */
                              /* ------ end_of_SIO parameters ----------*/
  struct GRound  *ground;     /* pointer to the ground structure            */
  struct MIrrorH *mirrorH;    /* MIrrorLib Header structure                 */
  struct OPticH  *opticH;     /* OptLib Header structure                    */
  struct ELadc   *electH;     /* ElectLib Header structure(first adc)       */
  struct MEtric  *metric;     /* pointer to the metric (M.C. info)          */
 };

struct FrHistory {           /* Describes data history info.               */
  long time;                 /* time of reprocessing( sec since 1/1/70)*/
  char *comment;             /* program name and comment                   */
                             /* ------------- end_of_SIO parameters ---*/
  struct FrHistory *next;    /* pointer to the next history struct         */
 };

struct FrRawData {              /* Hold raw data                            */
  struct FrSmsData *firstSms; /* pointer to the first slow mon. station */
  struct FrAdcData *firstAdc; /*pointer to the first adc structure          */
                              /* ------------- end_of_SIO parameters ---*/
 };
struct FrSmsData {              /* slow monitoring station data             */
  char *name;                   /* slow monitoring station name             */
  long timeSec;                 /* F.B. collection time (sec since 1/1/70)*/
  char *data;                   /* pointer to the data block                */
  struct FrSmsData *moreData; /* additional s.m. data for this station  */
                                /* ------ end of SIO parameters ----------*/
  struct FrSmsData *next;       /* next slow monitoring station             */
   };

struct FrAdcData {      /* hold ADC data                                    */
  char   *name;         /* adc name and comment                             */
  long crate;           /* crate number + site location                     */
  long vmeBase;         /* vme register address                             */
  long dt;              /* sampling time frequency  (unit= nanosecond)  */
  struct UVectB *dataB; /*buffer for the data(if data stored as bytes)*/
  struct UVectS *dataS; /*buffer for the data(if data stored as short)*/
  struct UVectL *dataL; /*buffer for the data(if data stored as long) */
                        /* -------- end_of_SIO parameters ----------*/
  struct FrAdcData *next; /* next adc structure                             */
  };

struct FrRecData {           /* reconstructed data                          */
  char   *name;              /* algorithm name and comment                  */
                             /* algo. param will be written on tape later -*/
  double xDet;               /* detector equatorial position around the sun*/
  double yDet;               /* detector equatorial position around the sun*/
  double zDet;               /* detector equatorial position around the sun*/
  double vxDet;              /* detector equatorial speed around the sun   */
  double vyDet;              /* detector equatorial speed around the sun   */
  double vzDet;              /* detector equatorial speed around the sun   */
  double nu;                 /* sampling frequency                          */
  struct UVectD *h;          /* vector of metric perturbation               */
                             /* ------ end_of_SIO parameters --------------*/
  struct FrRecData *next;    /* next bloc of reconstructed data             */
   };

struct FrSimData {          /* hold SImulated data                          */
  char   *name;             /* name and comment                             */
  long dt;                  /* sampling time frequency  (unit= nanosecond) */
  struct UVectD *dataD;     /*buffer for the data(if data stored as double)*/
  struct UVectF *dataF;     /*buffer for the data(if data stored as float) */
  struct USignal *input;    /* input signal                                 */
                            /* ------ end of SIO parameters --------------*/
  struct FrSimData *next;   /* next structure                               */
   };

struct UVectB {
  char  *name;          /* vector name                  */
  long  nData;          /* number of elements           */
  char  *data;          /* pointer to the data area     */
                        /* --- end_of_SIO parameters -*/
};

struct UVectD {
  char  *name;          /* vector name                  */
  long   nData;         /* number of elements           */
  double *data;         /* pointer to the data area     */
                        /* --- end_of_SIO parameters -*/
};

struct UVectF {
  char  *name;          /* vector name                  */
  long   nData;         /* number of elements           */
  float *data;          /* pointer to the data area     */
                        /* --- end_of_SIO parameters -*/
};

struct UVectL {
  char  *name;          /* vector name                  */
  long  nData;          /* number of elements           */
  long  *data;          /* pointer to the data area     */
                        /* --- end_of_SIO parameters -*/
};

struct UVectS {
  char  *name;          /* vector name                  */
  long  nData;          /* number of elements           */
  short *data;          /* pointer to the data area     */
                        /* --- end_of_SIO parameters -*/
};
```

Introduction to HDF

1.1 Chapter Overview

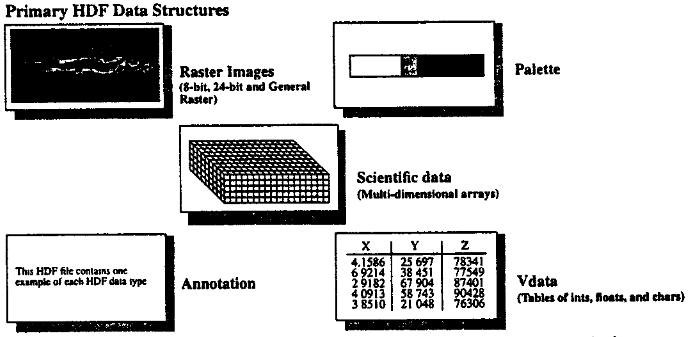
This chapter provides a general description of HDF including its indigenous object structures, application programming interface and accompanying command-line utilities. It also provides a short discussion of HDF's original purpose and philosophy and concludes with a list of the platforms HDF has been ported to.

1.2 What is HDF?

The ***Hierarchical Data Format***, or ***HDF***, is a multi-object file format for sharing scientific data in a distributed environment. HDF was created at the National Center for Supercomputing Applications to serve the needs of diverse groups of scientists working on projects in many fields. HDF was designed to address many requirements for storing scientific data, including:

- Support for the types of data and metadata commonly used by scientists.
- Efficient storage of and access to large data sets.
- Platform independence.
- Extensibility for future enhancements and compatibility with other standard formats.

FIGURE 1a **Primary HDF Data Structures**



Five of the primary data objects supported by HDF are illustrated in Figure 1a. A sixth, the vgroup object, does not contain data and is designed for the purpose of grouping the other five primary data objects within an HDF file.

HDF Fundamentals

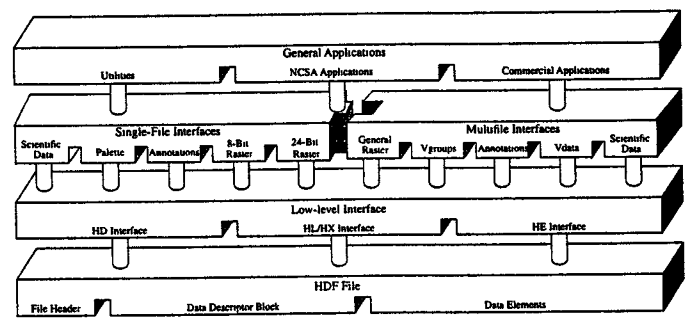
2.1 Chapter Overview

In this chapter, our description of HDF in Chapter 1, titled *Introduction to HDF*, is expanded to include a description of the hierarchical structure of HDF interaction with HDF file objects, the physical format of HDF files, the low-level HDF interfaces, and programming language issues pertaining to the use of Fortran-77, ANSI C and K&R C in HDF programming.

2.2 The Hierarchy of HDF Interaction

To review the description of HDF provided in Chapter 1, HDF is a physical file format at its lowest level and a collection of utilities and applications at its highest. Between these two levels, HDF is a library that itself provides two levels of programming interfaces. HDF can be thought of conceptually as three interface layers built upon a physical file format.

FIGURE 2a **The Three Levels of Interaction with the HDF File Format**



Refer to Figure 2a. Of the three types of top-level general applications, only the command-line utilities will be extensively covered in this manual. See Chapter 13, titled *HDF Command-Line Utilities*, for descriptions of this aspect of HDF. These general applications directly call the single-file and multifile interfaces.

The two interactive levels immediately below this level, the ***low-level interface*** and the HDF data file itself, are only briefly described as the single-file and multifile interfaces provide a safer and more standardized means of accessing these levels. The single-file and multifile interfaces - the second highest level of interaction within HDF - are routinely updated as aspects of these lower-level interfaces are changed, in a manner as transparent to the HDF user as possible. With the exception of the few instances where lower-level interface functionality has not yet been incorporated into the higher-level interface functions, the HDF user need not directly concern themselves with these levels.

2.3 Data Objects

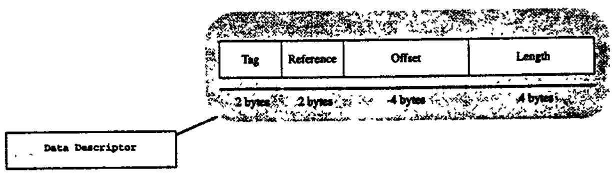
The term ***data object*** is used to describe the fundamental conglomerate structure use to encapsulate data.

Data objects contain a ***data descriptor*** and a ***data element***. Data descriptors consist of information about the type, location, and size of a data element. Data elements contain the primary data itself.

2.3.1 Data Descriptors

All data descriptors are twelve bytes long and contain four fields. (See Figure 2b.)

FIGURE 2b **The Contents of a Data Descriptor**



Tags

Tags identify the type of data stored in its data element. For example, a raster image descriptor is identified by a DFTAG_RI tag and a palette descriptor a DFTAG_LUT tag. There are currently over 200 tags defined for general use. A complete list of tags and their descriptions can be found in Appendix A of this manual

Tag values ranging between 1 and 32,767 are reserved for commonly-used data types. These tags are assigned by the HDF development group. Tag values ranging between 32,768 and 64,999 are not regulated by NCSA and are available for private application. These tags are not documented by NCSA and may therefore conflict with tags assigned by someone else. Therefore, it is best to limit applications to the use of the commonly-used tags.

Reference Numbers

Reference numbers distinguish between different data elements with the same tag. For example, all raster image descriptors will have the same raster data tag. The pairing of a tag and a reference number provides a unique identifier for any HDF object within a file.

Although HDF assigns reference numbers in increasing order, it is the write operations that are counted, not the number or type of data objects added to the file. For example, writing a raster image set followed by a scientific data set uses a minimum of six data objects but only two write operations. Consequently, HDF will assign 1 as the reference number for the first raster image set and all its members and 2 as the reference number for the scientific data set and all its members.

While application programmers may find it convenient to impart some additional meaning to reference numbers, it should be noted that HDF will not internally recognize any such meaning.

Offsets and Lengths

The offset field points to the location of the data element in the file by storing the number of bytes from the beginning of the file to the beginning of the data element. The length field contains the total size of the data element in bytes.

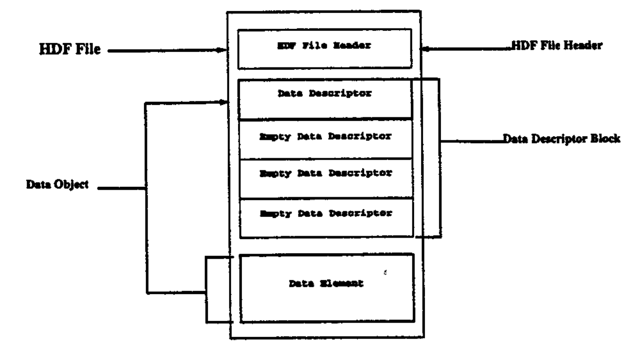
Data Elements

The type of the data stored in a data element is identified by its tag, however, other interpretive information may be required before it can be processed properly.

2.4 File Format

HDF files contain a ***file header*** and at least one ***data descriptor block***, as depicted in Figure 2c. The HDF file header occupies the first four bytes of every HDF file with a signature field containing the 32-bit hexadecimal value 0e031301. This number is considered a "magic cookie" as it identifies the file as an HDF file. Initially the data descriptor block consists of a group of empty data descriptors. As data objects are written to the file, the HDF library fills the data descriptor block by pairing one data descriptor for each data element. Refer to the following figure.

FIGURE 2c **The Physical Layout of an HDF File Containing One Data Object**



2.4.1 Grouping Data Objects in an HDF File

HDF files that contain more than one data element are generally easier to work with when the data objects containing related data are grouped together. These groups of data objects are called ***data sets***. The HDF user uses the application interface to define, manipulate and dispose of data sets in a file.

As an example, an 8-bit raster image data set requires three objects: a group object identifying the members of the set, an image object containing the image data and a dimension object indicating the size of the image. It is sometimes possible to add additional data objects to the minimum set - for example, an 8-bit raster image set may include a palette.

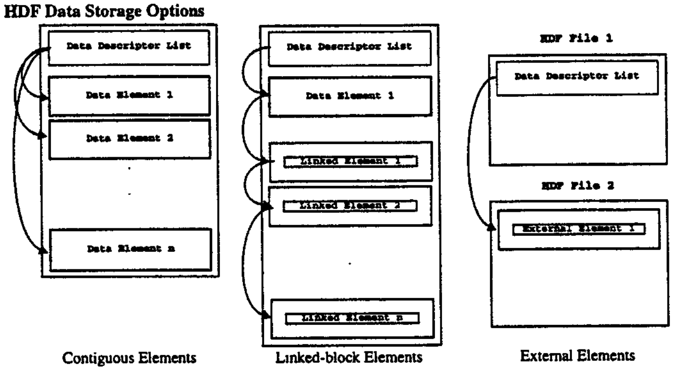
Data objects are individually accessible even if they are included in a set, therefore data objects can belong to more than one set and sets can be included in larger groups. For example, a palette object included in one raster image set may also be a part of another raster image set if its tag and reference number are included in a data descriptor within that second set.

Several data sets may be further grouped into ***group objects***. The contents of the group object depends on the HDF data set it supports.

2.4.2 Storing Data Objects

Data objects can be stored in HDF data files as a ***contiguous element***, as ***linked-block elements*** or as ***external elements***. These data storage options are illustrated below in Figure 2d.

FIGURE 2d **HDF Data Storage Options**



2.4.2.1 Contiguous Data Elements

This is the default method of data storage in HDF. In this case, all data objects exist in one HDF file and are stored in the manner illustrated in Figure 2c. Each data element in the file is one complete unit of raw data, and as only one unique data descriptor points to it there are no references or relationships to the other data elements in the file. As additional data elements are created and written they are appended to the end of the HDF file.

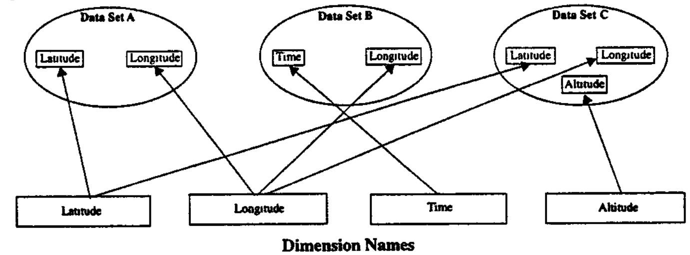
2.4.2.2 Linked-block Data Elements

Linked-block elements are a series of data elements existing in one HDF file which serve as a means of adding data to a pre-existing data element. These elements are linked to each other and to the original data element by a linked-list structure similar to the data descriptor list. They are of a uniform size with the exception of the first block after the original data element, which is the only block that can be resized.

2.4.2.3 External Data Elements

External data elements are those that exist in a file apart from the one the data descriptor list resides in. These additional HDF data files are referred to as ***external data files***. The HDF library

FIGURE 3c **Dimension Records and Attributes Shared Between Related Data Sets**



3.9 User-defined Attributes

User-defined attributes are attributes defined by the calling program that contains auxiliary information about a file, SDS array or dimension. This auxiliary information is sometimes called ***metadata***, because it is data about data. There are two ways to store metadata, as a user-defined attribute or predefined attribute.

They take the form `label=value`, where `label` is a character string containing `MAX_NC_NAME` or fewer characters and `value` contains one or more entries of the same data type as defined at the time the attribute is created. Attributes can be attached to three types of objects: files, data sets and dimensions. These are referred to, respectively, as ***file attributes*** , ***array attributes*** and ***dimension attributes***:

- ***File attributes*** are attributes that describe an entire file. They generally contain information pertinent to all data objects in the file and are sometimes referred to as ***global attributes***.
- ***Data set attributes*** are attributes that describe individual SDS arrays. Because their scope is limited to an individual SDS, data set attributes are sometimes referred to as ***local attributes***.
- ***Dimension attributes*** provide information applicable to an individual SDS dimension. It is possible to assign a unit to one dimension in a data set without assigning a unit to the remaining dimensions.

For each object, a separate ***attribute count*** is maintained that identifies the number of attributes associated with the object. The attribute count begins at zero and is increased by one for every new attribute assigned to an object. Each attribute associated with an object has a unique ***attribute index***, a value between 1 and the total number of attributes. The attribute index is used to retrieve an attribute's value or information about an attribute.

The data types permitted for attributes are the same as those allowed for SDS arrays. SDS arrays with general attributes of the same name can have different data types. For example, the attribute `valid_range` specifying the valid range of data value for an array of 16-bit integers might be of type 16-bit integer, whereas the attribute `valid_range` for a variable of 32-bit floats could be of type 32-bit floating-point integer.

Attribute names follow the same rules as dimension names. Providing meaningful names for attributes is important, however using standardized conventional names may be necessary if generic applications and utility programs are to be used. For example, every variable assigned a unit should have an attribute name of "units" defined. Furthermore, if an HDF file is to be used

Follow-up discussions with Mours

Blackburn/Bork

20 May, 1996
1600-1700

Civil Construction

Coles/Stapfer

21 May, 1996
0900-0940

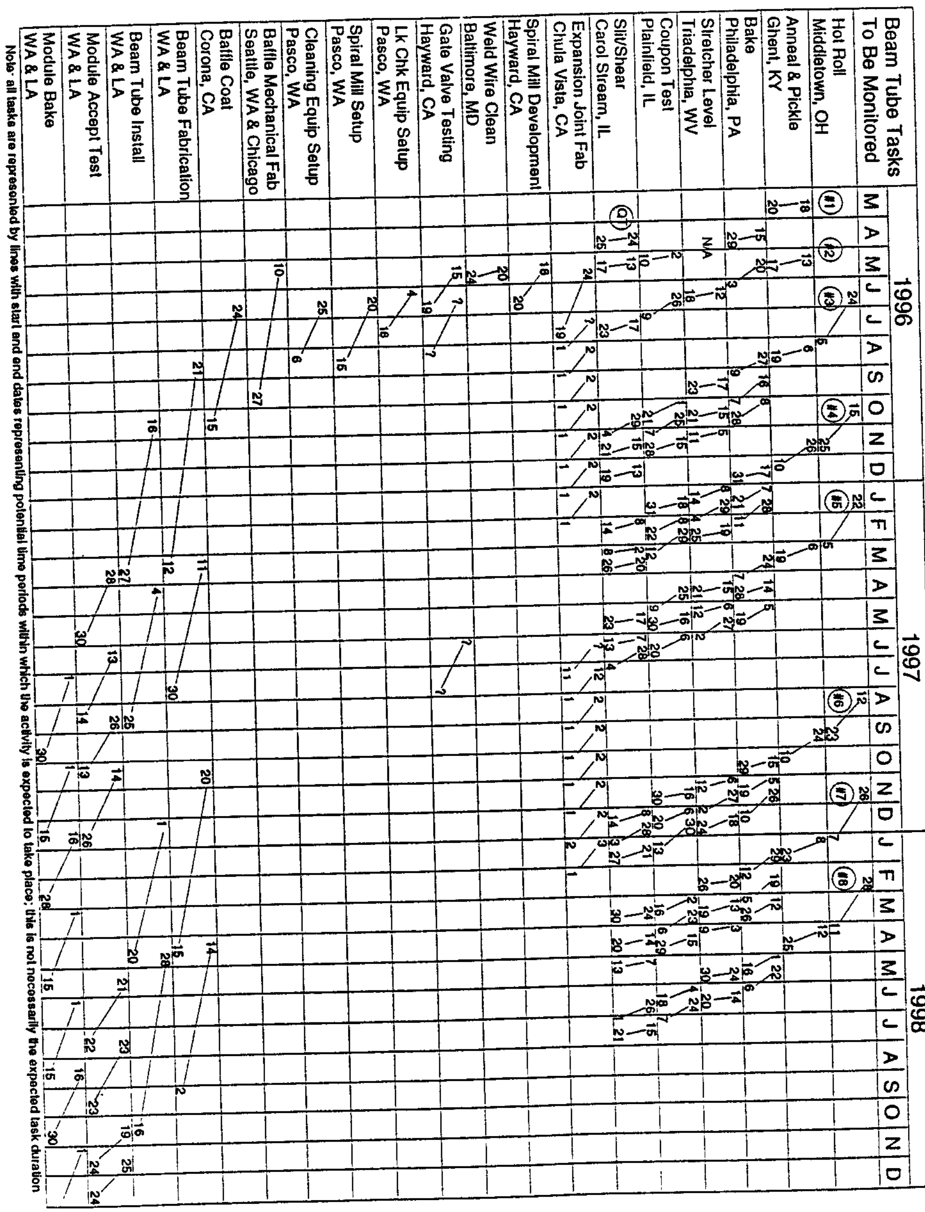
(Times are EDT)

Beam Tube System

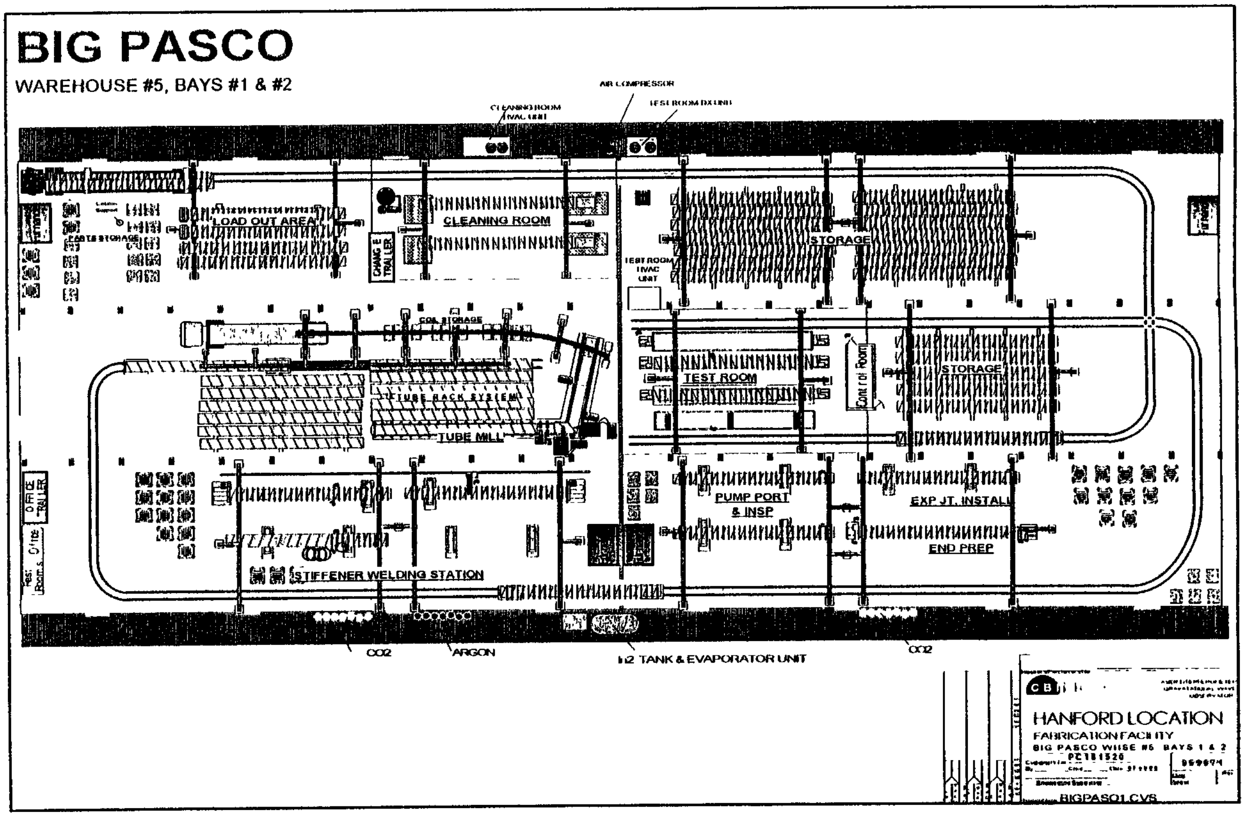
Jones

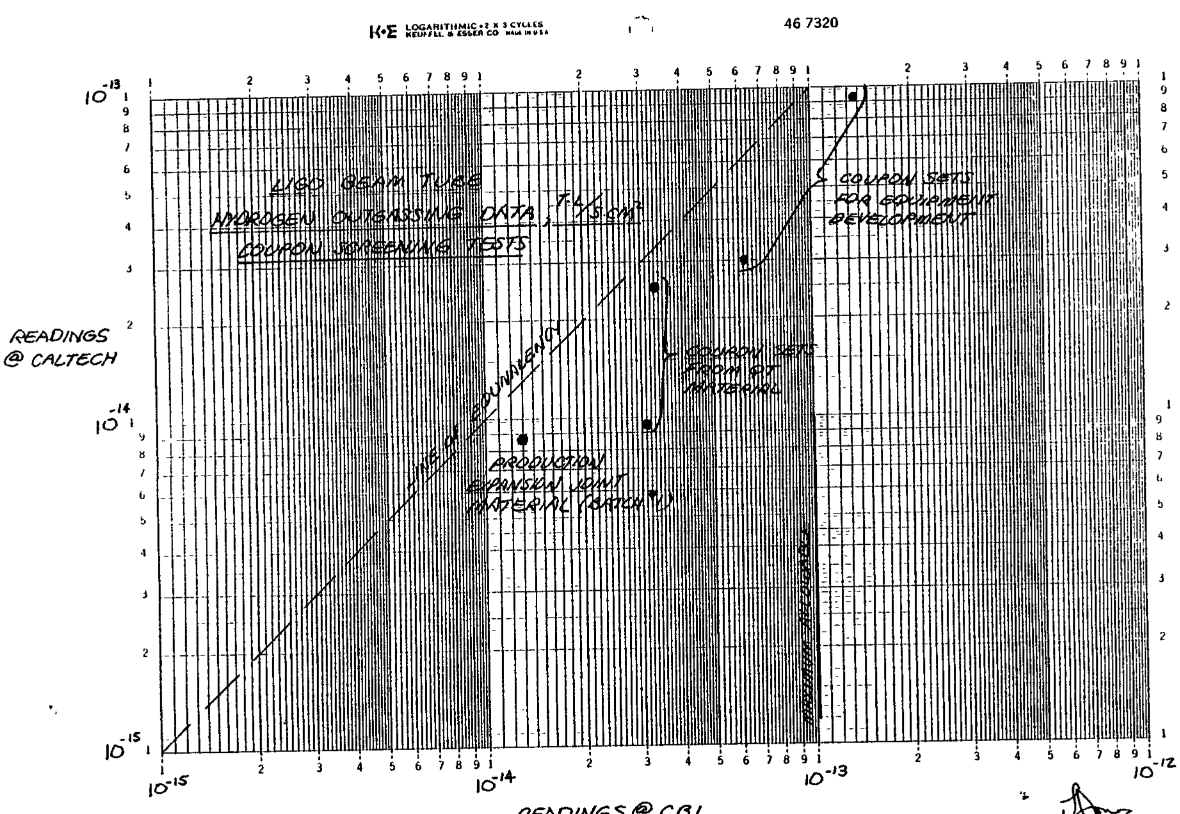
21 May, 1996
0940-1040

(Times are EDT)



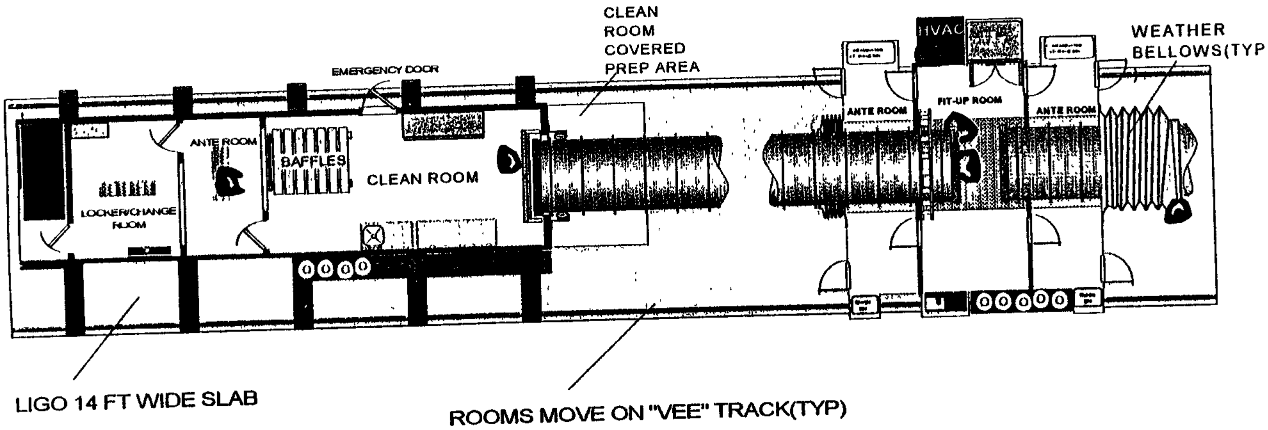
L. Jones viewgraphs


BIG PASCO
WAREHOUSE #5, BAYS #1 & #2
AIR COMPRESSOR
CLEANING ROOM HVAC UNIT
TEST ROOM DX UNIT
LOAD OUT AREA
CLEANING ROOM
STORAGE
TEST ROOM HVAC UNIT
COIL STORAGE
TEST ROOM
Control Room
TUBE RACK SYSTEM
TUBE MILL
OFFICE TRAILER
PUMP PORT & INSP
EXP JT. INSTALL
END PREP
STIFFENER WELDING STATION
CO2
ARGON
H2 TANK & EVAPORATOR UNIT
HANFORD LOCATION
FABRICATION FACILITY
BIG PASCO WHSE #5 BAYS 1 & 2
BIGPASO1.CVS

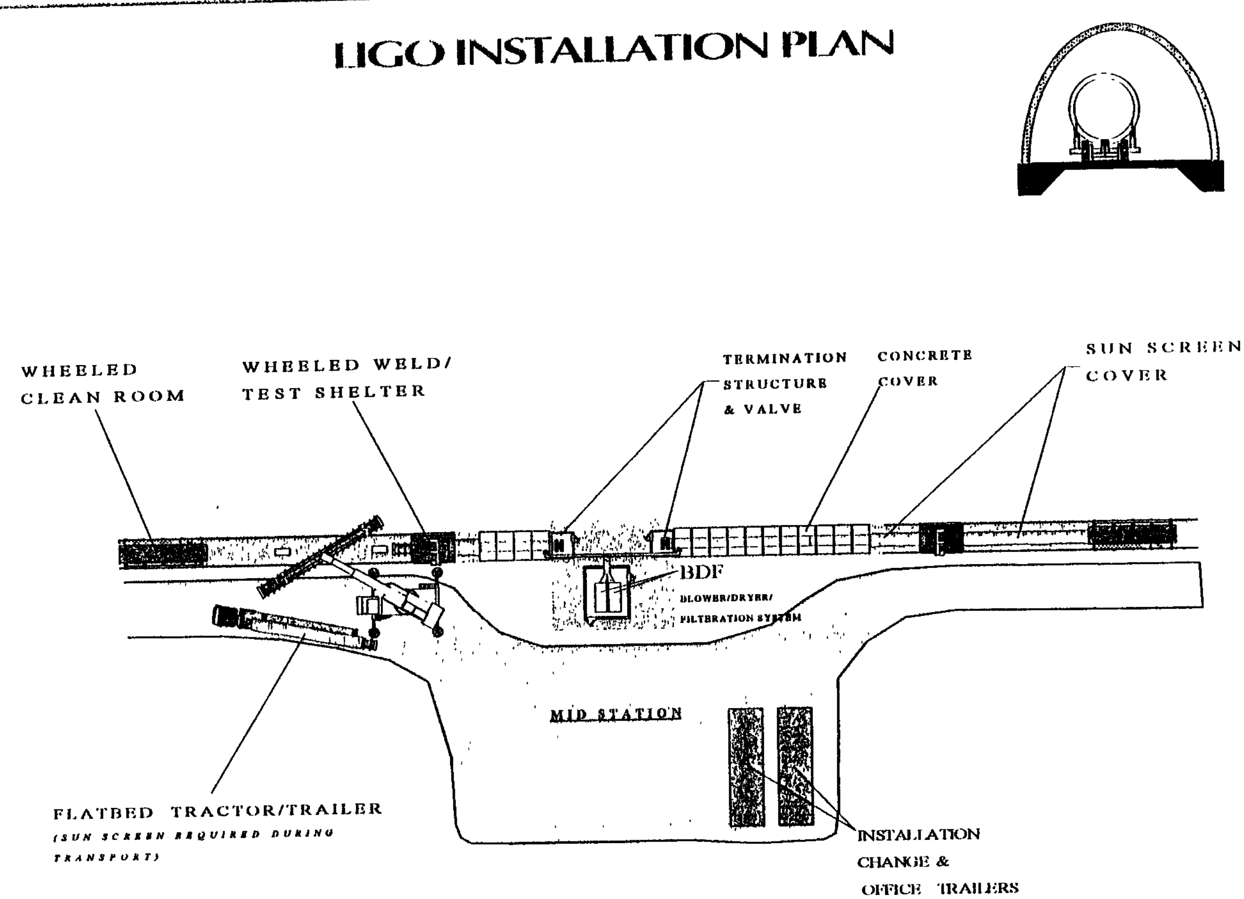

K+E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO.
46 7320
LIGO BEAM TUBE
HYDROGEN OUTGASSING DATA, T-L/5 cm²
COUPON SCREENING TESTS
COUPON SETS FOR EQUIPMENT DEVELOPMENT
COUPON SETS FROM ST MATERIAL
PRODUCTION EXPANSION JOINT MATERIAL (BATCH 1)
LINE OF EQUIVALENCY
MINIMUM RECORDABLE
READINGS @ CALTECH
READINGS @ CBI
10^{-13}
10^{-14}
10^{-15}
10^{-12}

5-17-96

INSTALLATION PLAN



LIGO INSTALLATION PLAN



"Minibake" discussion - 5/14/96
LIGO Technical Board

- Objective: assess need/means for conducting a vacuum performance test of the current beam tube fabrication/installation processes
- Advisory to PI/PM; no decision
- Baseline schedule assumed:
  - ›› Fab begins 8/96, install begins 10/96
  - ›› Fab/install proceeds on two modules in parallel
  - ›› Fab/install proceeds immediately to next arm
  - ›› Module bakeouts proceed immediately after acceptance test

Mini bake Status

Althouse

21 May, 1996
0940-1040
(Times are EDT)

What did the Qualification Test (QT) do?

- Demo'd vacuum performance (comparison with LIGO sensitivities)
- Demo'd air signature leak detection procedure
- Demo'd coupon H_2 outgassing test apparatus
- Demo'd basic mechanical design, fit
- Demo'd baffle installation procedure (design since changed)
- Demo'd girth weld procedure, equipment
- Revealed a problem with spiral weld procedure/equipment
- Demo'd thermal performance of expansion joint, bakeout insulation/ heating
- Many lessons learned

Beam Tube Performance Requirements

- Clear aperture

  ›› CBI is responsible for delivering 1.19 m clear aperture at supports; we estimate 1.05m clear aperture w/baffles
- Leak-free

  ›› CBI is responsible for all detectable leaks before bake: >10^{-5} t-L/s guaranteed by CBI; >2×10^{-8} t-L/s (our estimate)
- Vacuum performance level

  ›› CBI is responsible for following approved low H_2 steel, cleaning and handling procedures

What has changed since the QT?

- Spiral weld: tube mill, skelp width, welding equipment, weld procedures, personnel (now CBI)
- Cleaning procedure
- Baffle design, coating
- Baffle installation procedure

What was *NOT* tested by the QT?

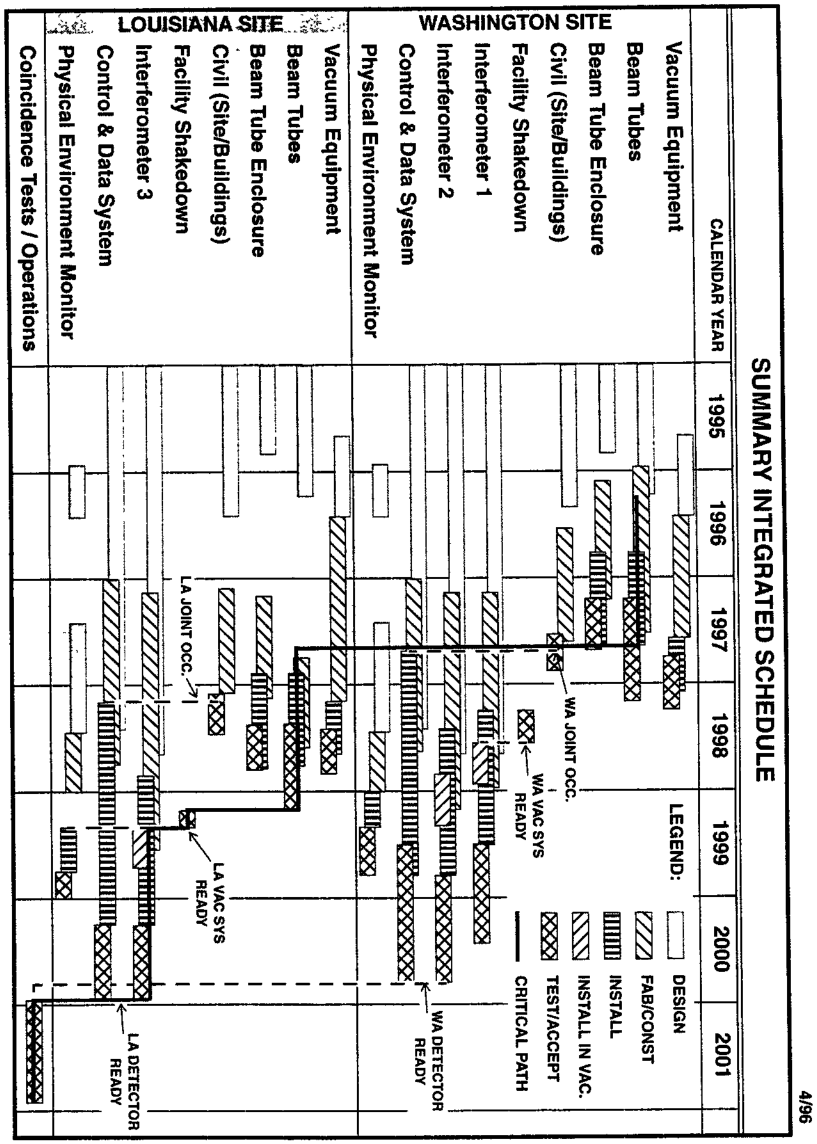
- Field installation equipment
  - ››Portable clean rooms: seals against environmental intrusion
  - ››Portable clean rooms: confined working space
- Outdoor conditions
- Beam tube structural supports, termination anchors
- Outgassing of gate valves
- Leak localization techniques
- Pump port hardware
- Section leak test coffins
- Expanded tube section ends

Discriminants between "Minibake" scenarios

- Impact on CBI's plans
- Impact on LIGO staff
- Number of "real" variables tested
- Timing of availability of results
- $ costs

"Minibake" scenarios (vacuum performance tests of baked vessels)

- Ship first 65' section to CBI or Caltech or MIT, cap, bake/test
- Join two capped sections on-site, cover with BTE, bake/test
- Install isolation valve 250m downstream in first production module, insulate and bake/test in-situ
- [violates schedule assumption] Bake/test first module (of 2 initial) *before* proceeding with other 6
- [baseline plan] Bake/test first module in parallel with fab/install of remainder (results to late too affect Hanford installation)



Sequence of Activities:

Initial field makeup (6 days):

- Use portable clean rooms and field installation methods developed by CBI to build first two BT ~~modules~~ sections plus one expansion bellows (baseline plan)
- weld on either end while still mounted in portable clean room.
- seal pump out ports
- bridge expansion joint
- use spreader bar to lift assembly off slab and move it to opposite arm near corner station

Benefits

- re-establish performance baseline for fabrication process
- validation of effectiveness of field installation procedures and installation eqpt
- develop staff experience for 2 km module bakeout (which may be more cost effective to lead as in-house effort).
- develop procedures for 2 km bake (potentially better cost estimate even if we don't do it ourselves)
  - due to experience working in field environment, weather, etc.

Drawbacks

›› impact on CBI

- some schedule impact (approx 1 week planning time plus several days of execution time)
- some cost impact (< $100K)
- little personnel impact during setup or test

›› re-direction of key LIGO staff during initial fabrication/ installation of beam tube:

- likely staff headcount demand is approx 5 months FTE
  - 2 months for "chief baker" (under contract to LIGO as field bake project leader)
- 3 months combined from:
  - Franklin, Worden, Sibley, Jones, Riesen, Coles, Stapfer
  - Rai Weiss
- 3-4 weeks of additional planning and coordination time (primarily Larry Jones)

Risks and downside considerations

If we do find something that needs to be altered before the 2 km bake, does it cost any less to fix because of the test?

Test representative of systematic effects only, not a good statistical indicator.

Some systematic effects of 2 km bake are not represented:

- Single point control of distributed power supplies (fail safe req't)
- Leak finding technique in 2 km system
- Operational difficulties in 2 km module (material and personnel access into BTE, etc.)

Likely that any specific technical problem we anticipate can be more cheaply identified by specific narrowly defined tests (cleaning, etc.)

Positive Considerations

Test as a training ground to develop effective full bake looks promising

- potential to "earn back" savings in 2 km bake

Cheap insurance (<1% of total cost) to increase likelihood that beam tube will satisfy operational criteria following bake.

BT/Baffle alignment toleranc-ing

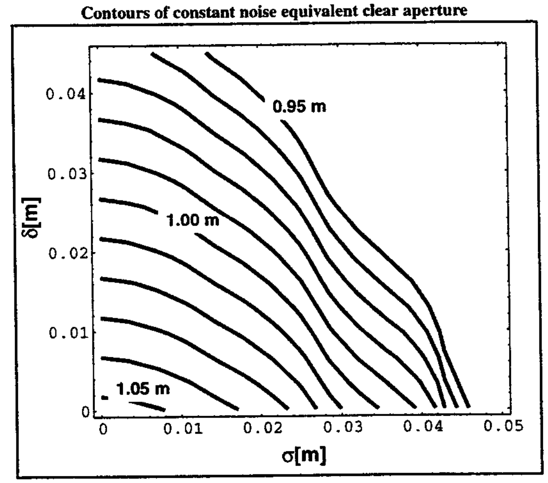
Lazzarini

21 May, 1996
0940-1040

(Times are EDT)

Noise Equivalent Clear Aperture (NECA)

Contours of constant noise equivalent clear aperture



- Initial expected clear aperture w/o alignment included is > 1.05 m
- 1.00 m clear aperture may be maintained with as much as 3.5 cm (on radius) random errors or 2.5 cm settlement (bias).
- Both quantities are less stringent than presently expected achievable alignment tolerances during installation.

Vacuum Equiptment System

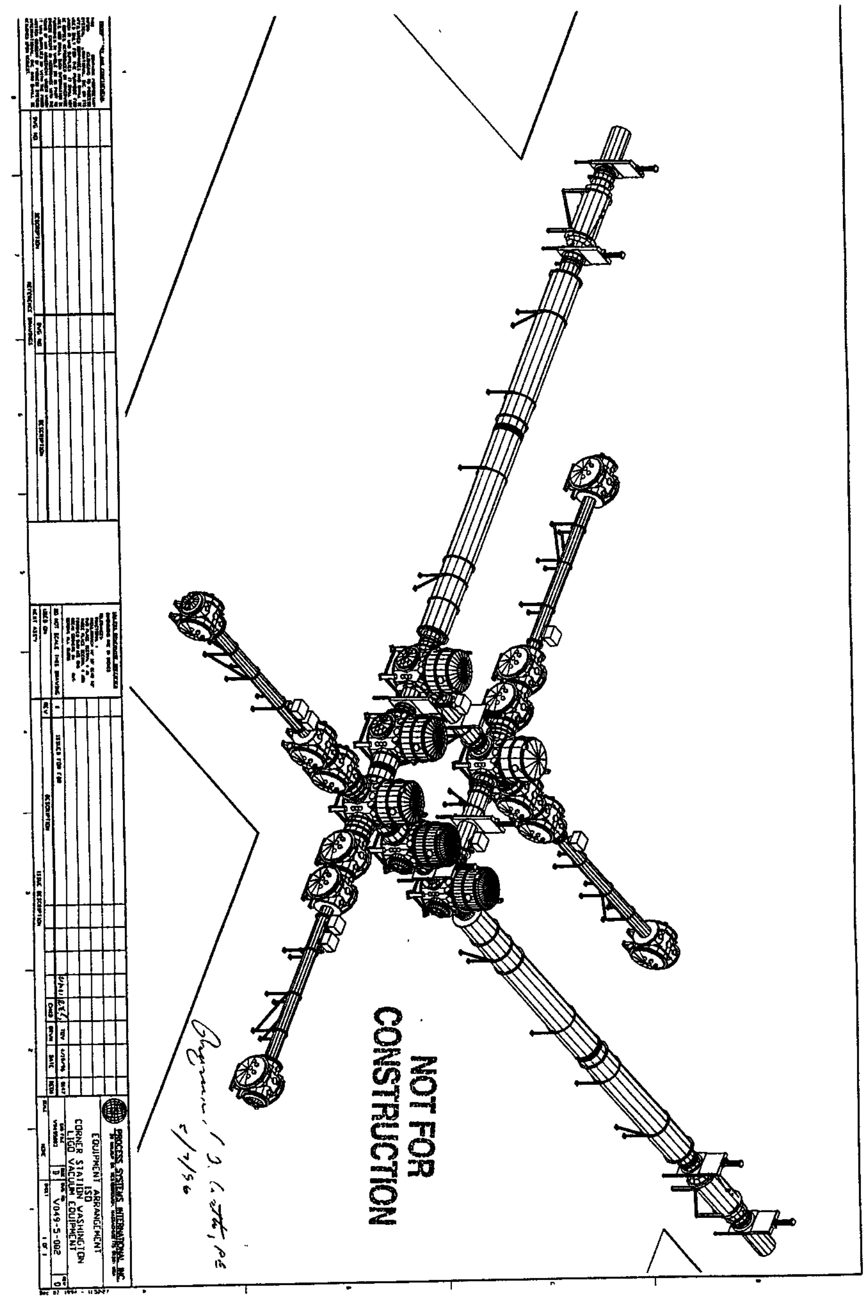
Worden

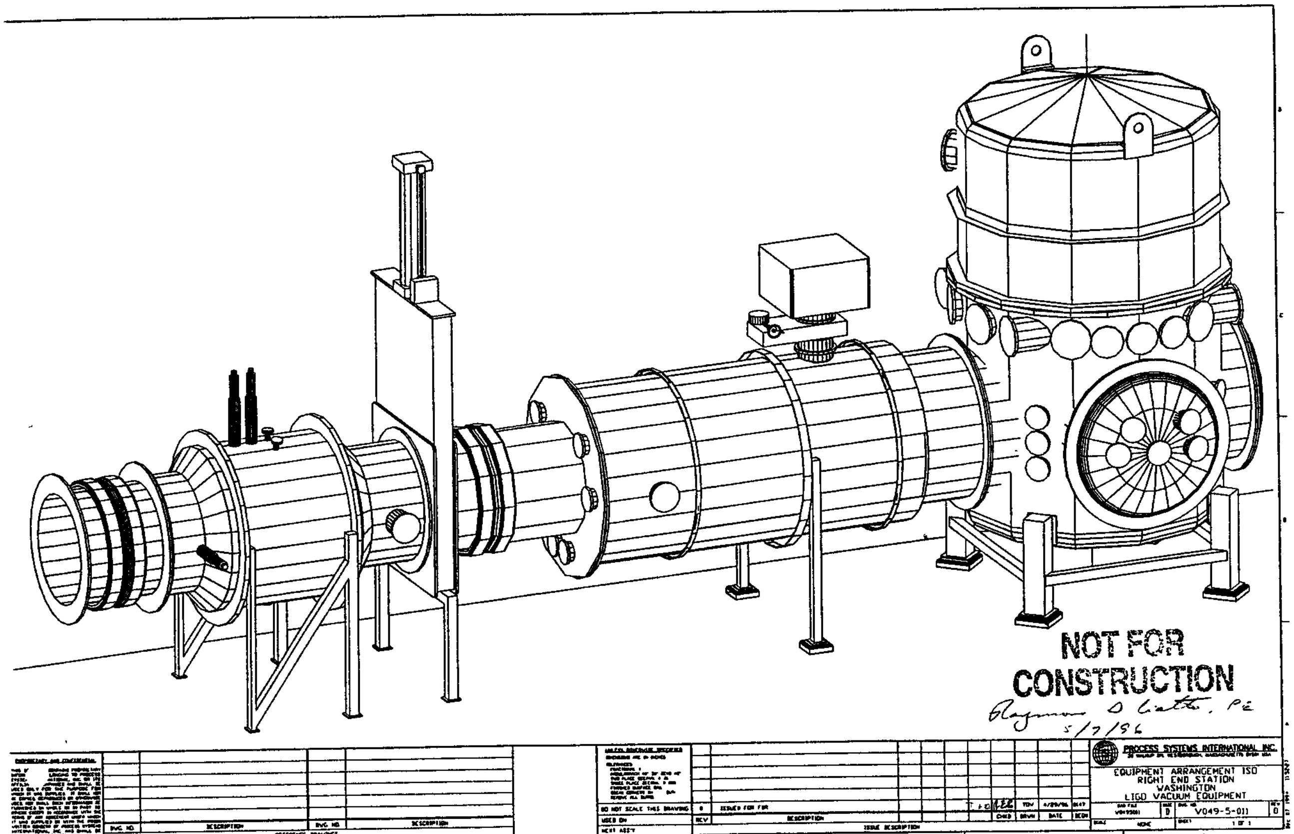
21 May, 1996
1055-1140

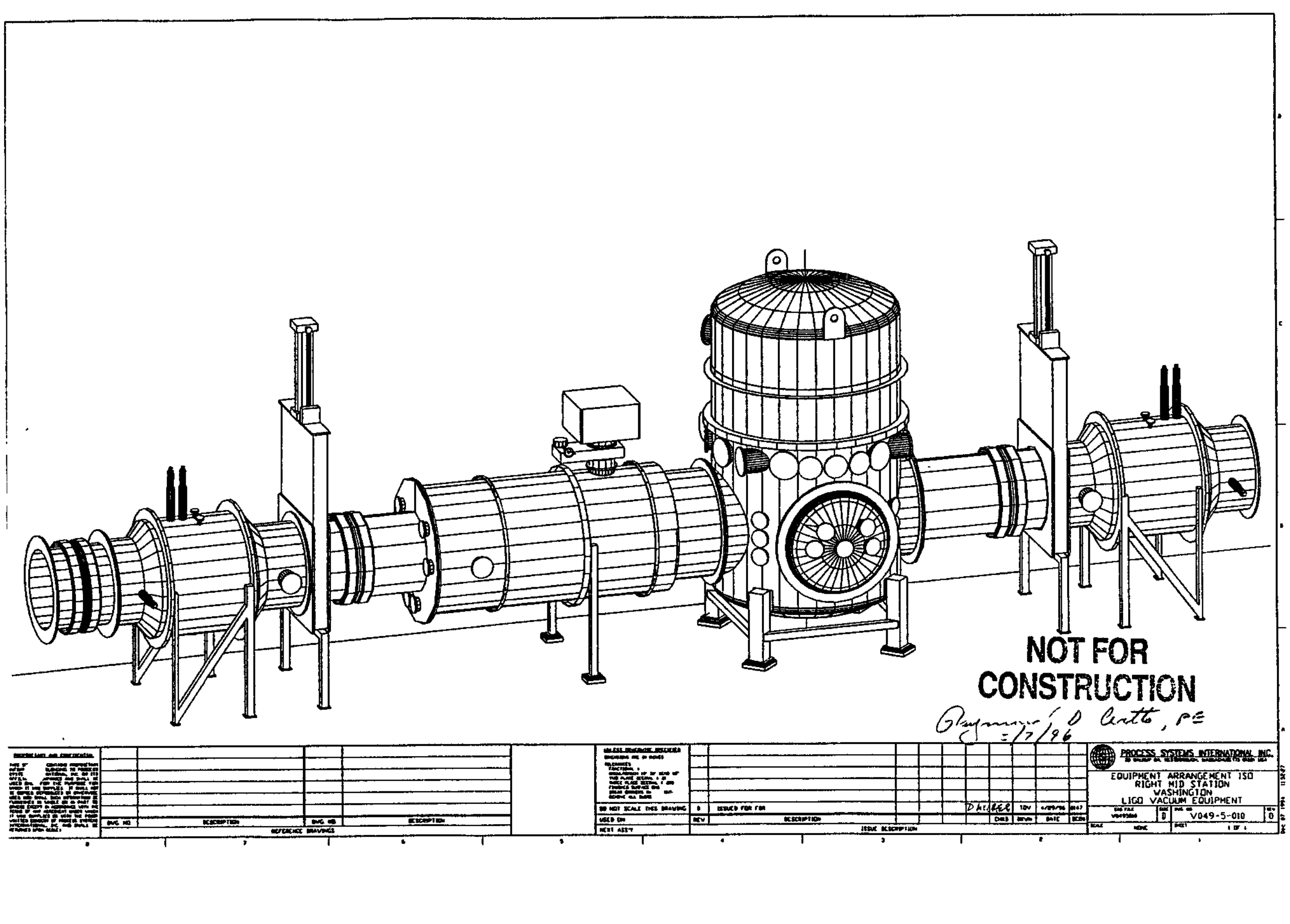
(Times are EDT)

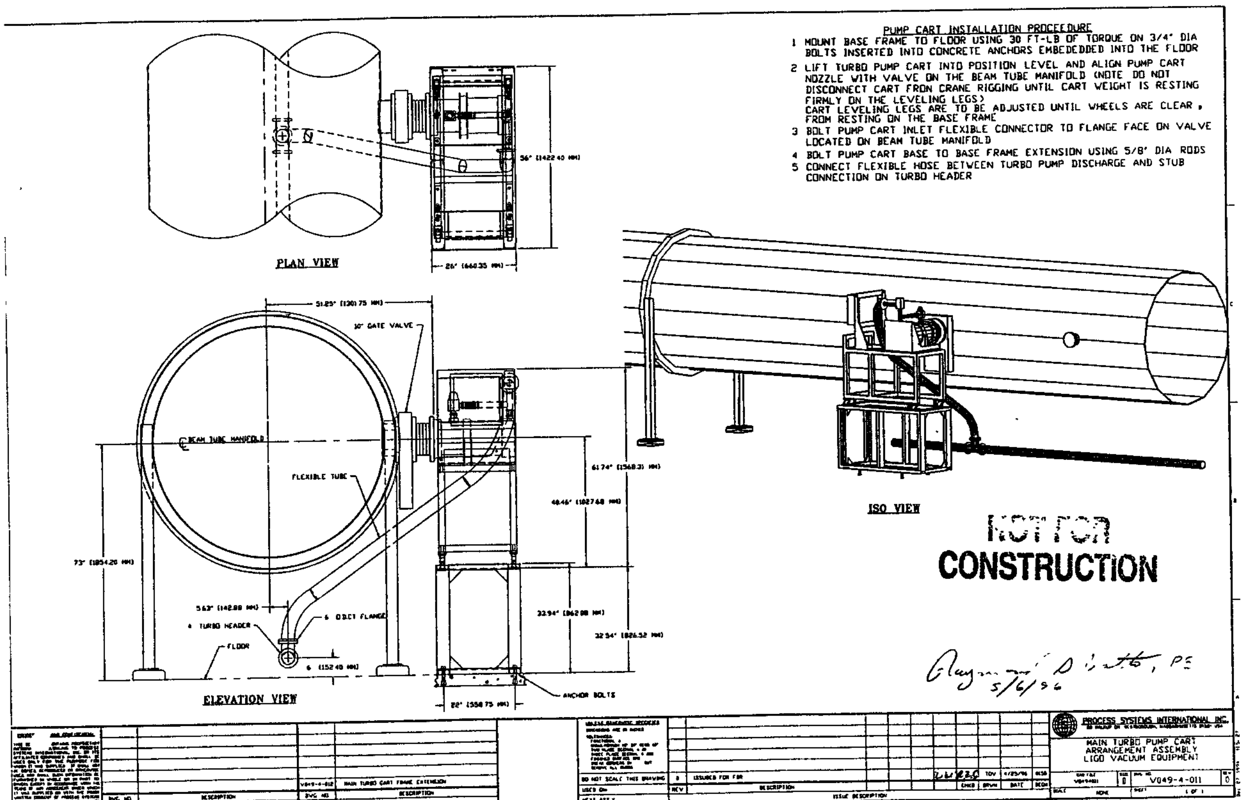
VACUUM EQUIPMENT STATUS MAY/96

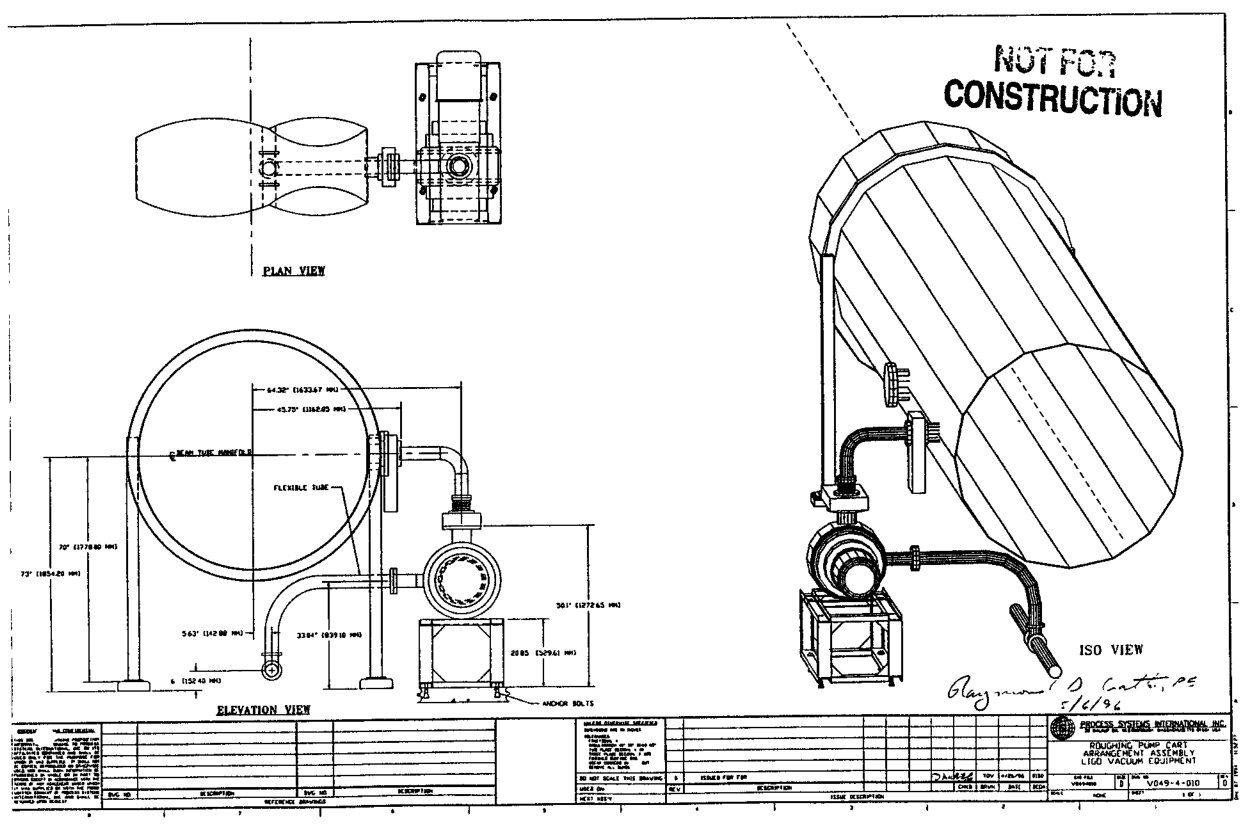
- Items on order:
  - >>All pump carts - from Edwards Vacuum Products.
  - >>Large gate valves - From GNB Corp.
  - >>Ion Pumps - Varian Vacuum Products.
  - >>Small gate valves - Varian Vacuum Products.
  - >>Purge Air Compressors.
  - >>LN2 dewars.
  - >>Bakeout blankets.
  - >>Prototype BSC - RANOR
  - >>SS Plate, heads, flange forgings.
- Major tasks for Summer/96:
  - >>Prototype BSC testing.
  - >>80K pump testing.
  - >>Begin HAM prototype.
  - >>Begin Fab of portable clean rooms.

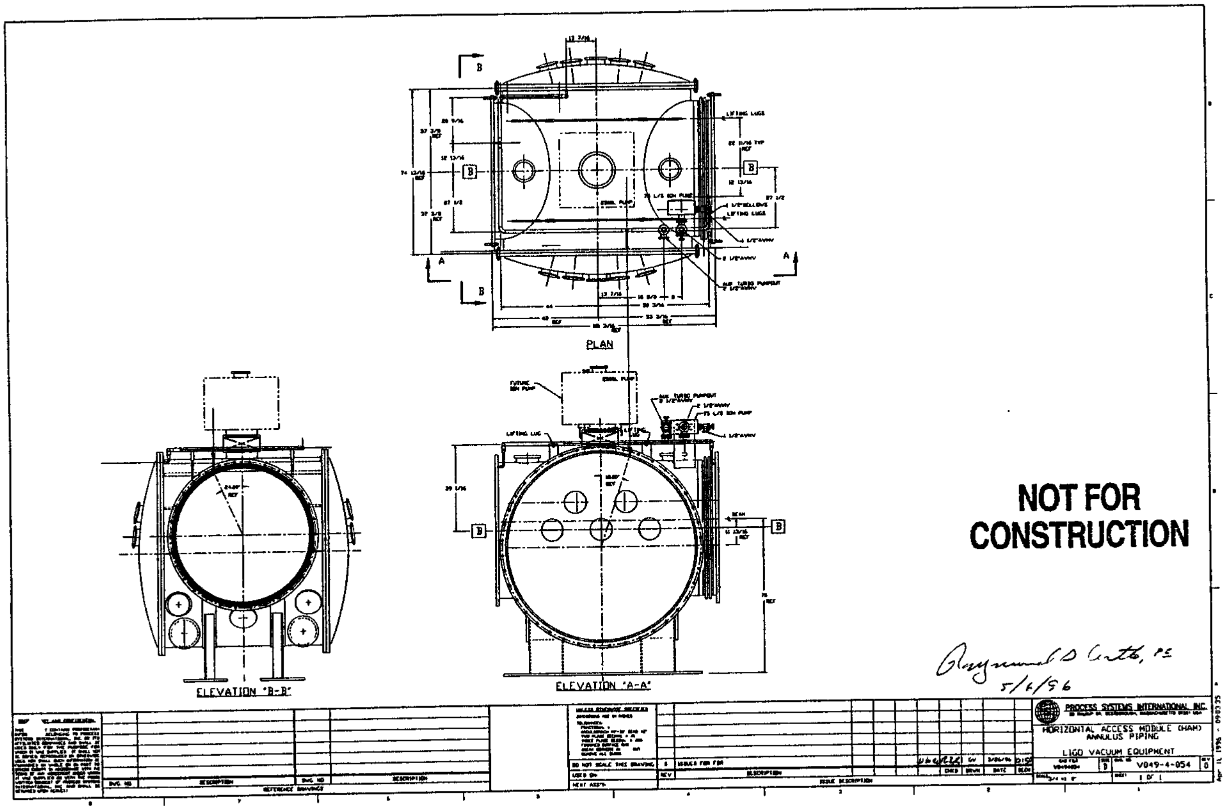


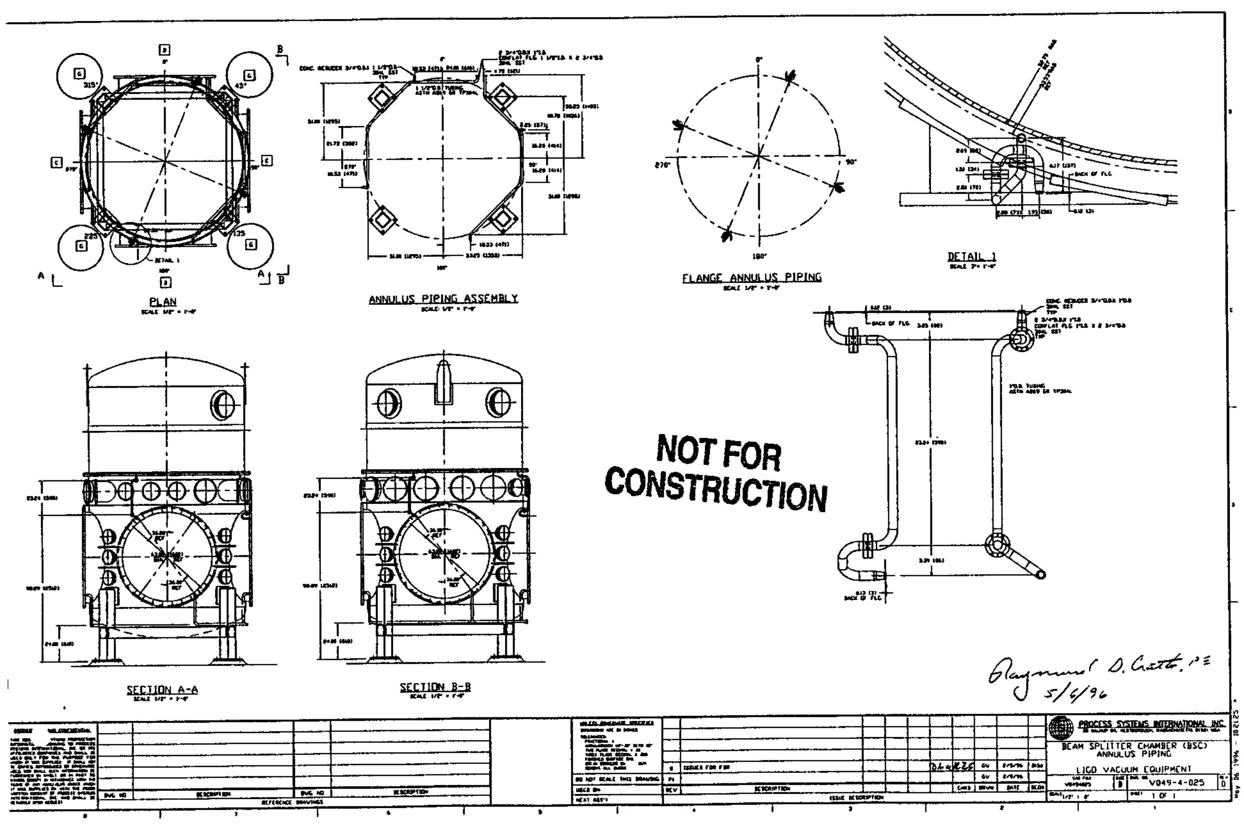

NOT FOR CONSTRUCTION
PROCESS SYSTEMS INTERNATIONAL, INC.
EQUIPMENT ARRANGEMENT ISO
RIGHT END STATION
WASHINGTON
LIGO VACUUM EQUIPMENT
V049-5-011
DO NOT SCALE THIS DRAWING
ISSUED FOR FDR
DESCRIPTION
ISSUE DESCRIPTION
REFERENCE DRAWINGS


NOT FOR CONSTRUCTION
PROCESS SYSTEMS INTERNATIONAL, INC.
EQUIPMENT ARRANGEMENT ISO
RIGHT MID STATION
WASHINGTON
LIGO VACUUM EQUIPMENT
V049-5-010
DO NOT SCALE THIS DRAWING
ISSUED FOR FDR
DESCRIPTION
ISSUE DESCRIPTION
REFERENCE DRAWINGS


PUMP CART INSTALLATION PROCEDURE
1 MOUNT BASE FRAME TO FLOOR USING 30 FT-LB OF TORQUE ON 3/4" DIA BOLTS INSERTED INTO CONCRETE ANCHORS EMBEDDED INTO THE FLOOR
2 LIFT TURBO PUMP CART INTO POSITION LEVEL AND ALIGN PUMP CART NOZZLE WITH VALVE ON THE BEAM TUBE MANIFOLD (NOTE DO NOT DISCONNECT CART FROM CRANE RIGGING UNTIL CART WEIGHT IS RESTING FIRMLY ON THE LEVELING LEGS) CART LEVELING LEGS ARE TO BE ADJUSTED UNTIL WHEELS ARE CLEAR, FROM RESTING ON THE BASE FRAME
3 BOLT PUMP CART INLET FLEXIBLE CONNECTOR TO FLANGE FACE ON VALVE LOCATED ON BEAM TUBE MANIFOLD
4 BOLT PUMP CART BASE TO BASE FRAME EXTENSION USING 5/8" DIA RODS
5 CONNECT FLEXIBLE HOSE BETWEEN TURBO PUMP DISCHARGE AND STUB CONNECTION ON TURBO HEADER
PLAN VIEW
ELEVATION VIEW
ISO VIEW
BEAM TUBE MANIFOLD
10" GATE VALVE
FLEXIBLE TUBE
TURBO HEADER
FLOOR
ANCHOR BOLTS
NOT FOR CONSTRUCTION
Raymond D Catto, PE
5/6/96
PROCESS SYSTEMS INTERNATIONAL, INC.
MAIN TURBO PUMP CART ARRANGEMENT ASSEMBLY LIGO VACUUM EQUIPMENT
V049-4-011


NOT FOR CONSTRUCTION
PLAN VIEW
ELEVATION VIEW
ISO VIEW
BEAM TUBE MANIFOLD
FLEXIBLE TUBE
ANCHOR BOLTS
Raymond D Catto, PE
5/6/96
PROCESS SYSTEMS INTERNATIONAL, INC.
ROUGHING PUMP CART ARRANGEMENT ASSEMBLY LIGO VACUUM EQUIPMENT
V049-4-010


PLAN
ELEVATION "B-B"
ELEVATION "A-A"
NOT FOR CONSTRUCTION
Raymond D. Catto, PE
5/6/96
PROCESS SYSTEMS INTERNATIONAL INC.
HORIZONTAL ACCESS MODULE (HAM)
ANNULUS PIPING
LIGO VACUUM EQUIPMENT
V049-4-054
1 OF 1


PLAN
ANNULUS PIPING ASSEMBLY
FLANGE ANNULUS PIPING
DETAIL 1
SECTION A-A
SECTION B-B
NOT FOR CONSTRUCTION
Raymond D. Catto, PE
5/6/96
PROCESS SYSTEMS INTERNATIONAL INC.
BEAM SPLITTER CHAMBER (BSC)
ANNULUS PIPING
LIGO VACUUM EQUIPMENT
V049-4-025
1 OF 1

Detector Systems Design

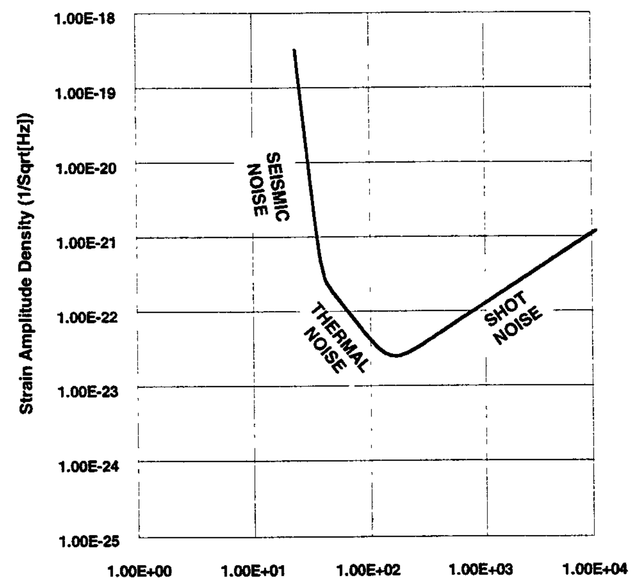
Shoemaker

21 May, 1996
1300-1320

(Times are EDT)

dhs 20 May 96

Starting Point: SRD



- 3 ‘primary’ noise sources
- all other sources: ‘technical’
- Gaussian, non-stationary noise; availability
  - no work on non-stationary noise; a little on availability.

Generalities

Requirements Flowdown

- all requirements down to 'no inter-subsystem trade-offs'
  - present DRDs mix of system and subsystem requirements
  - physics/models to determine both developed in DRD
  - SYS enforces consistency in this process between subsystems
  - extract system requirements for SYS DRD
- status of requirements flowdown
  - most system requirements in place
  - most DRDs reviewed (all but IO have seen one round)
  - remaining problems to be highlighted here
- integration with Integration Noise Model
  - as models developed and values adopted, added to Noise Model
  - will allow check of trades, rapid iteration
  - seismic, thermal, shot largely in place
  - many technical noises yet to be implemented
  - not yet a tool for SYS
- some other urgent SYS activities
  - interfaces between subsystems (IICDs)
  - optics layout (wedges, lengths; scattered light)
  - vacuum materials, contamination, procedures (Kapton wiring)
  - non-Gaussian noise, availability requirements (stress release)
  - integration and test plans

Requirements

PSL

Concept: Nd:YAG oscillator/amplifier, stabilized to rigid cavity
Power: 10W coupled into TEM_{00} mode
Frequency noise: $4\times10^{-2}\ \mathrm{Hz}/\sqrt{\mathrm{Hz}}$ (100 Hz), TBD (10 kHz)
Intensity noise: 1×10^{-7} (f>40 Hz)
Beam jitter: TBD

IOO

Concept: triangular mode cleaner, reflective matching telescope
Mode cleaner length: 12-15 m
Efficiency: 0.60 (from input to light coupled to COC TEM_{00} mode)
Frequency noise at output: 1e-4 (100 Hz), 1e-5 (10kHz) [10% SNR]
Intensity noise at output: (same as input to 4 kHz) [10% SNR]
Beam jitter at output: (nominal 1/800 of input) [10% SNR]

LSC

Concept: single carrier, single modulation (possible second mod.)
Recycling cavity length: 7-10 m
Asymmetry: (as needed) +/- 16 cm nominal
Modulation frequencies: TBD 45 MHz
Modulation depth: (as needed) 0.5 nominal
Photodiode QE: 0.8; Sensing noise: [10% SNR]
Power at dark port: 600 mW
Power reflected from interferometer: 400 mW
Calibration precision: TBD
Servo constraints: [10% SNR]*4
Acquisition time: 160 sec

Requirements

ASC

Concept: Wavefront sensing, single frequency, two modulations
Alignment of COC: (shot noise sensitivity) $\sim 3\times10^{-9}$ rad [10% SNR]
Centering of COC: (thermal noise of pitch mode): 1mm [10% SNR]
Alignment of MC: (coupling efficiency: >0.99 of ideal alignment)
Centering of MC: (thermal noise of pitch mode)
Sensing noise: [10% SNR] longitudinal, [10% SNR] angular

COC

Optic size: 25 cm x 10 cm (BS: 4cm TBD)
Loss per optic per bounce: 50 ppm
Possible contamination before cleaning: 100 ppm
Arm storage time mismatch: 0.01
Beamsplitter balance: TBD
Figure: (better than or equal to HDOS * 9/4)
Contrast defect: 1×10^{-3}
Sideband modal purity: >0.94 TEM00
AR Coating R: 5e-4<T<1e-3
Recycling Gain: 30
Sideband transmission to GW port: 0.86
ETM transmission: 1<T<10 ppm
Knee frequency: 90 Hz
Wedges: TBD
Mechanical losses of bare substrate: 3e-7 (average of first 8 modes)

Requirements

(Seismic Environment)

Seismic noise: Livingston at low freq., LIGO 'Standard' at high freq.
Tidal motion: as per the literature

SUS

Concept: single sling suspension, steel wire; magnet and coil pushers
Attenuation, H-->H: (0.74/f)^2
  V-->H: 3e-4 * (11/f)^2
  Angle: (0.6/f^2)*10^-3 (centering)
Mechanical losses of substrate with attachment: (as possible; meets SRD)
  Pendulum: 7×10^{-6}, Internal 4×10^{-7} (with attachments)
  Pitch/Yaw: 5×10^{-4}, 8×10^{-4}
Resonances in GW band: no violation of SRD (joint analysis with SEI)
Control noise: [10% SNR]

SEI

Passive stack concept: SS and Viton
On-line Actuator concept: flexure, 100 μm range, $f < 0.03$ Hz
Active controller ($f > 0.03$ Hz) concept: No active control
Attenuation: (to meet SRD; vertical with 3×10^{-4} rad will dominate)
Stack Q: TBD
Resonances in GW band: no violation of SRD (joint analysis with SEI)
Thermal noise of last stage: [10% SNR]
On-line actuator noise: [10% SNR]

Issues in noise 'flowup'

Sum of mentioned excess noise terms

- seismic domain (f<50 Hz): (not significant; moves wall by $1.005^{1/14}$)
- thermal domain (30<f<200)
  - IOO: 3
  - LSC: 5
  - ASC: 3
  - SUS: 1
  - SEI: 2
- shot domain (f>100)
  - IOO: 3
  - LSC: 5
  - PSL: 5
  - ASC: 1
- roughly 15-20@0.005 each; 10% worse amplitude sensitivity
- NOTE: no present sensitivity margin to accommodate this

Noise terms not mentioned

- stationary and fluctuating excess phase noise
  - spurious interferometers, scattered light
- mechanical noise terms
  - stress release in suspension
  - grinding, groaning, plastic deformation
- like GWs: LOTs of surprises.

Missions of 40m research program

Spero

21 May, 1996
1320-1350

(Times are EDT)

MISSION OF 40 m LABORATORY RESEARCH PROGRAM

To provide the main experimental basis for the detection of gravitational waves by LIGO. The design and operation of initial and subsequent generations of detectors will be supported by the following means:

- Conducting a program of experimental physics investigations to identify, measure, and reduce noise sources that can limit sensitivity.
- Developing an infrastructure for the LIGO operating environment including documented operating procedures, personnel training, methods of automated control, and laboratory safety.
- Developing diagnostic tests and performance measures.
- Testing of LIGO designs on all levels: component, subsystem, and configuration.
- Testing methods of data collection, extraction, and analysis, including collaborative data runs with other gravitational wave detection projects.
- Contributing to the body of scientific and technical knowledge via internal and external publications.
- Exploring methods for improving sensitivity and reliability beyond initial LIGO goals.

Structure of 40 m Research Program

Robert Spero

10 May 1996

1 Modes of operation

- The 40 m laboratory operates in three primary modes:
  1. Problem Solving
  2. Detector Science
  3. Installation
- In addition, there will be ongoing Background Tasks that can be conducted mostly independent of interferometer operation.

2 Management of Tasks and People

- Main Tasks have Task Leader and Coleader
  - Spero and Task Leader select workers
  - Task Leader plans shifts in consultation with Durance
  - At least one of Task Leader and Coleader present for most of day
  - Worker availability coordinated with other Detector tasks
- Workers fall into one of three categories

  A Task Leader or Coleader

  B Key workers, with recent interferometer operation experience

  C Support workers, including those receiving training and those with special knowledge
- Opportunities to multiplex Main Tasks will be exploited.

3 Problem Solving Mode

- Difficult problems (e.g. lock acquisition, unreliable operation) that preclude any other use of interferometer
- Goal: restore operation
- Requires intense lab presence and thinking from most experienced people available
- Not the best time for training
- Typical lab presence: 3 workers
- 14 hour working day
-

Start Time	End Time	Description
7:00	9:00	Warmup, diagnostics, maintenance, alignment
9:00	21:00	Complete coverage by either Task Leader or Coleader, with approximately one hour of overlap.

Notes:

1. Substitute coverage can be provided for Task Leader or Coleader during lunch, meetings, or other temporary absences.
2. Short lab meeting approximately midway through shift, during overlap between Task Leader and Coleader
3. The 7:00 to 9:00 period will occasionally start at 7:00, for major maintenance tasks such as software upgrades.

4 Detector Science Mode

- Investigations of predictable duration, such as transfer function measurements or standard noise investigations.
- Typical lab presence: 3 workers
- Multiple investigations can be swapped on one-day timescales
- Good time for training
- Daily structure similar to Problem Solving Mode
- Approximately one weekend shift

5 Installation Mode

- Applies to installation or modification of apparatus
- Typical lab presence: 5 workers
- Installation typically benefits from larger workforce rather than stretched day
- Templates tailored to type of installation
- Best use of resources may be shorter, more intensive day
- Can provide good training opportunities

Performance of 40m interferometer, related to LIGO goals

Spero

21 May, 1996
1400-1420

(Times are EDT)

Status of 40 m Interferometer May, 1996

- Performance

  ›› Sensitivity of recombined system poorer than separate-cavities configuration, at all frequencies.

  ›› Factor of 3 above shot noise above 600 Hz, measurements and calculations continuing.

  ›› Beamsplitter motion contributes to noise below 300 Hz.

- Recent findings

  ›› Lock acquisition sequencing requires electronic sign reversal after second cavity resonates, under ordinary circumstances -- not yet implemented.

  ›› Acquisition possible without sign reversal if mode matching is poor (early result, recently understood) or modulation index is high (shown by recent tests).

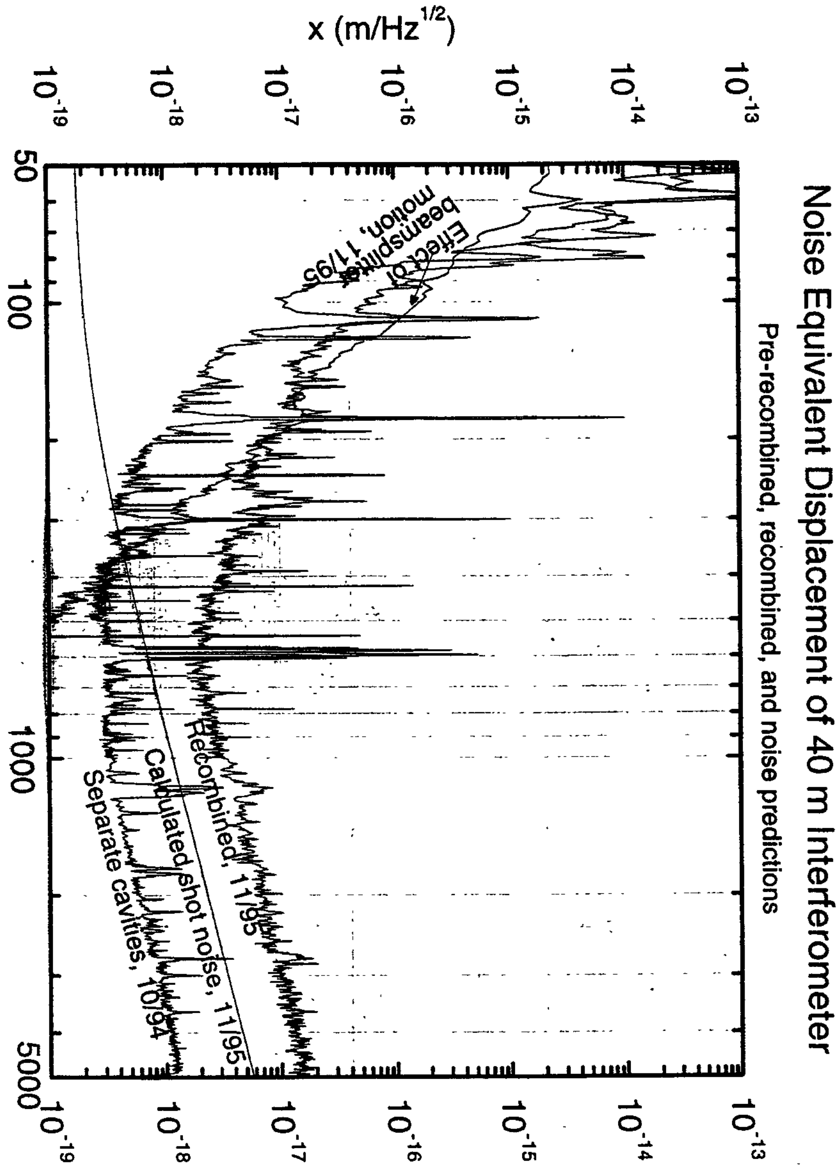
- Short-term plan

  ›› Complete acquisition studies, with eye toward recycling

  ›› Resume noise and "matrix element" studies

  ›› Installation of new suspensions, recycling

LIGO-G950000-00-M



Three-month Plan for 40 m Laboratory Research

Robert Spero

10 May 1996

1 Completion of Recombined Configuration Measurements

1.1 Develop Methods for Locking All Three Degrees of Freedom

- Problem-solving mode.
- Requires experiments, more complete modeling of lock acquisition, and possibly additional hardware.
- Follow-on tasks to be multiplexed.
- Task leader = RS, Coleader = AK
- Expected duration: 2 weeks
- Expected completion: 24 May, 1996

1.2 Acquire reproducible spectra with previous sensitivity.

- Mode: Detector Science
- Task leader = TL, Coleader = RS
- Expected duration: 1 week
- Expected completion: 31 May, 1996

1.3 Investigate beamsplitter motion effects, and control of Michelson interferometer

- Mode: Detector Science
- Task leader = TL, Coleader = FR

1.4 Measure the "matrix element" cross couplings

- Experiments to be compared with calculations
- Results needed to verify LIGO designs
- Mode: Detector Science
- Task leader = JL, Coleader = TL

1.5 Measure and calculate shot noise

- Measurement to be compared with Shot Noise Calculation Background Task
- Mode: Detector Science
- Task leader = TL, Coleader = BK

2 Install and verify performance of new vertex mass suspension

Task leader: SK

2.1 Install suspension

- Mode: Installation
- Duration: 1 June – 21 June
- Start date: completion of recombined configuration measurements

2.2 Performance measurement

- Mode: Detector Science
- Duration: 21 June – 19 July

3 Install and test high-transmission vertex mirrors

Overall responsibility: JL, RS, SW

3.1 Installation

- Mode: Installation
- Duration: 4 weeks

3.2 Shakedown

- Mode: Detector Science
- Duration: 8 weeks

4 Background Tasks

1. Theoretical study of shot noise sensitivity (BK).
2. Slow monitoring system install and test (AK).
3. Documentation of configuration, procedures, and preparation of training materials (DD).
4. Data collection and analysis (JM).
5. Power distribution and ground loops investigation multiples of line frequency (JH, AK).

Resources

AA	Alex Abramovici
DB	Dave Barker
RB	Rolf Bork
GB	GariLynn Billingsley
JC	Jordan Camp
MC	Mark Coles
DD	Denise Durance
JSH	Janeen Hazel
JWH	Jay Heefner
DJ	Doug Jungwirth
SK	Seiji Kawamura
BK	Bill Kells
AK	Andy Kuhnert
JL	Jennifer Logan
TL	Torrey Lyons
JM	Jim Mason
SM	Shinji Miyoki
FR	Fred Raab
MR	Malik Rakhmanov
GS	Gary Sanders
RLS	Rick Savage
LS	Lisa Sievers
RES	Robert Spero
SV	Steve Vass
BW	Brent Ware
SW	Stan Whitcomb

ISC Design

Zucker

21 May, 1996
1420-1440

(Times are EDT)

ISC DESIGN

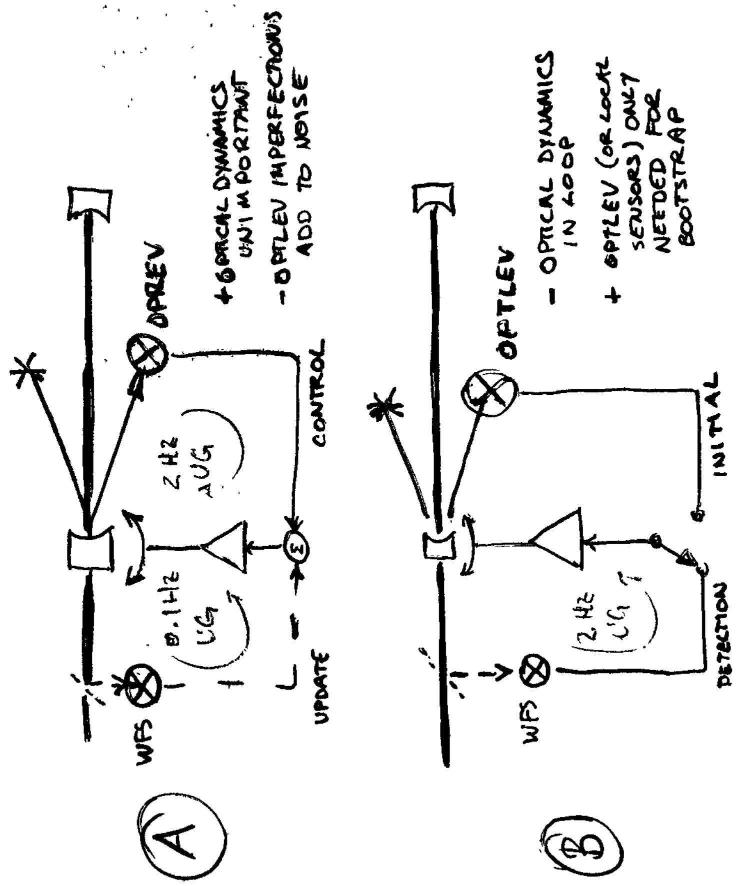
MEZ 5/21/96

- TASK STATUS
- DESIGN ISSUES: "NEW ASC"
- STRATEGIC TESTING

ZUCKER 1

ASC: PARADIGM SHIFT(s)

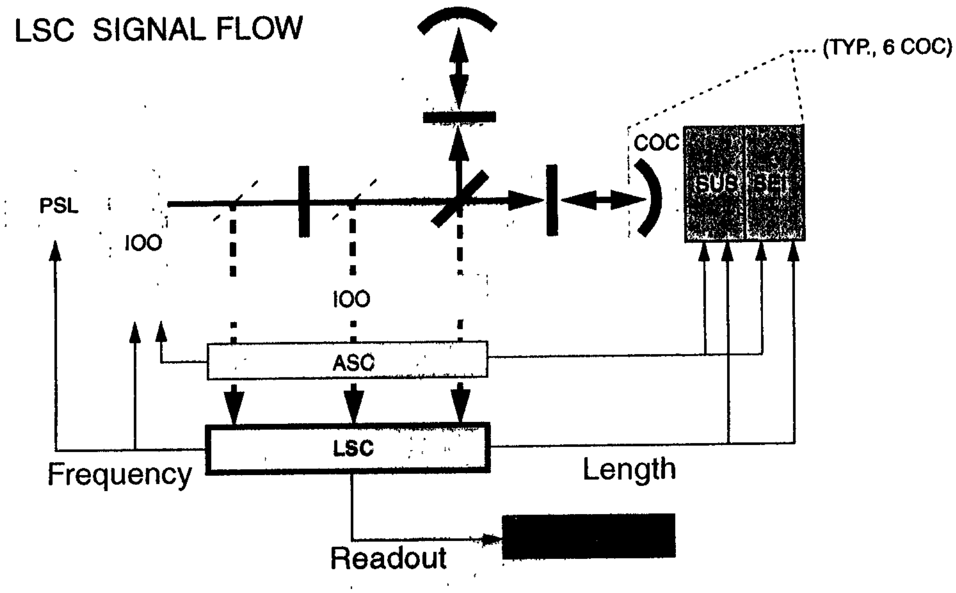
- FSSC SHELVED
- NONRESONANT SB NEEDED
- 'ACTIVE' WFS ROLE



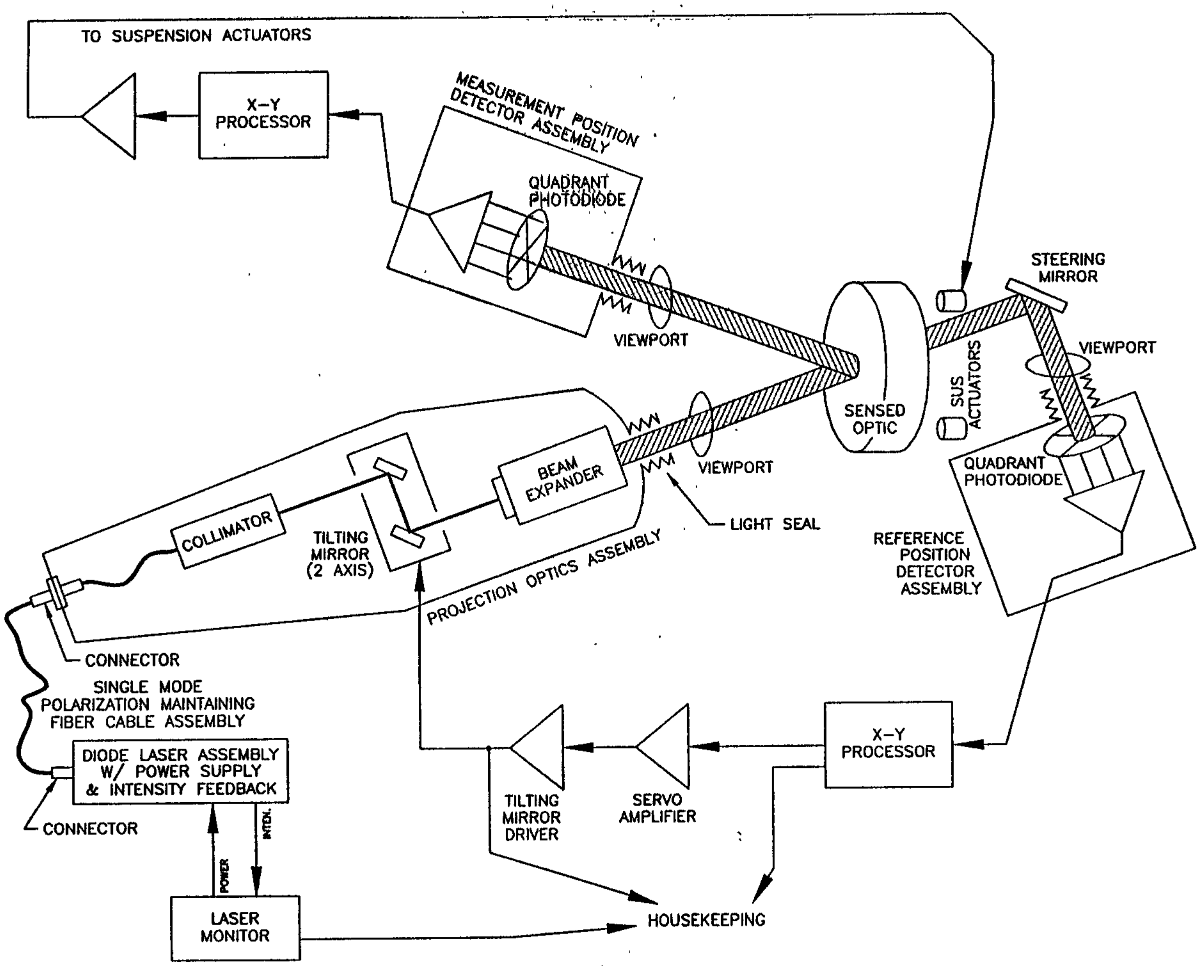
ISC Schedule Milestones

Milestone	Planned Date
LSC DRR	4/96
LSC PDR	10/96
LSC FDR	6/97
ASC DRR (II)	6/96
ASC PDR	10/96
ASC FDR	10/97
BEGIN INST. WA	7/98
BEGIN INST. LA	1/99

LSC Context (Cont'd)

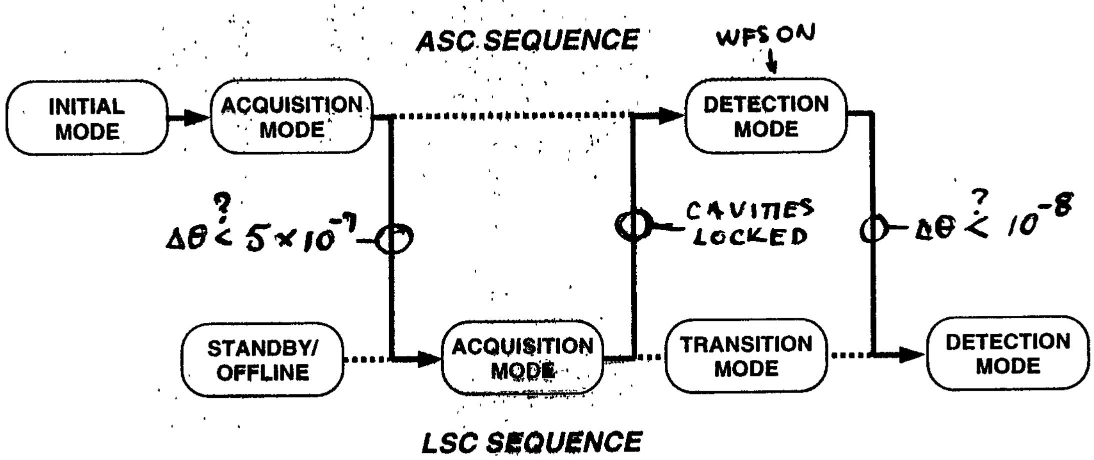


Zucker 3b



Zucker 3a

LSC Modes (cont'd): LSC/ASC sequencing



ZUCKER 5

ASC FOCI:
ACQUISITION ALIGNMENT CONCEPT

DRIFT BUDGET
LSC "CAPTURE RANGE"
OPTICAL LEVER PERFORMANCE
OSEM DRIFT
STACK ∡ DRIFT

— NONRESONANT SIDEBAND
(EFFECT ON SNR ??)

— WFS OPTICAL PLANT DYNAMICS

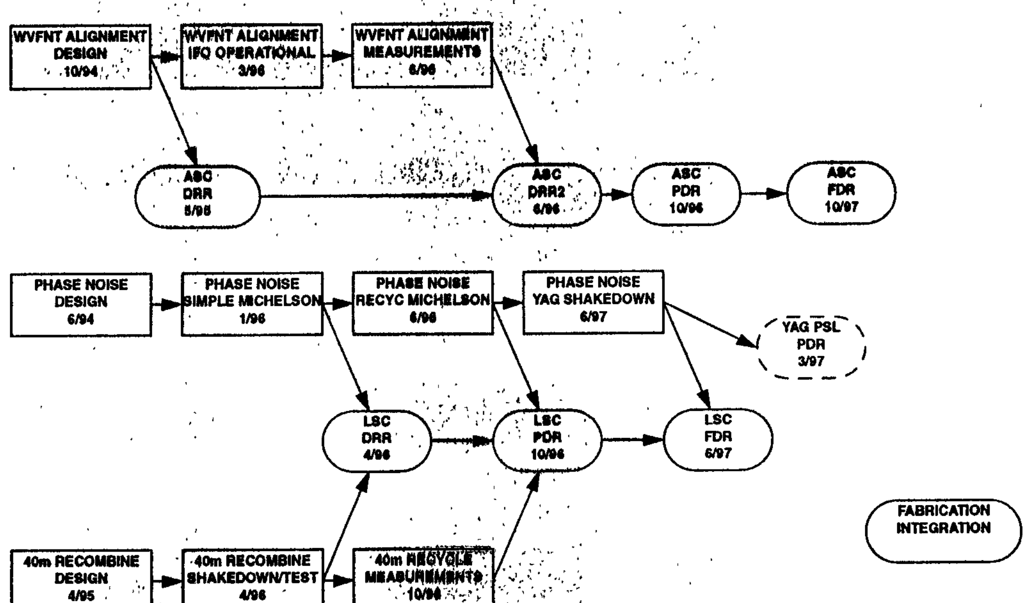
ZUCKER 4

ISC: STRATEGIC TESTING

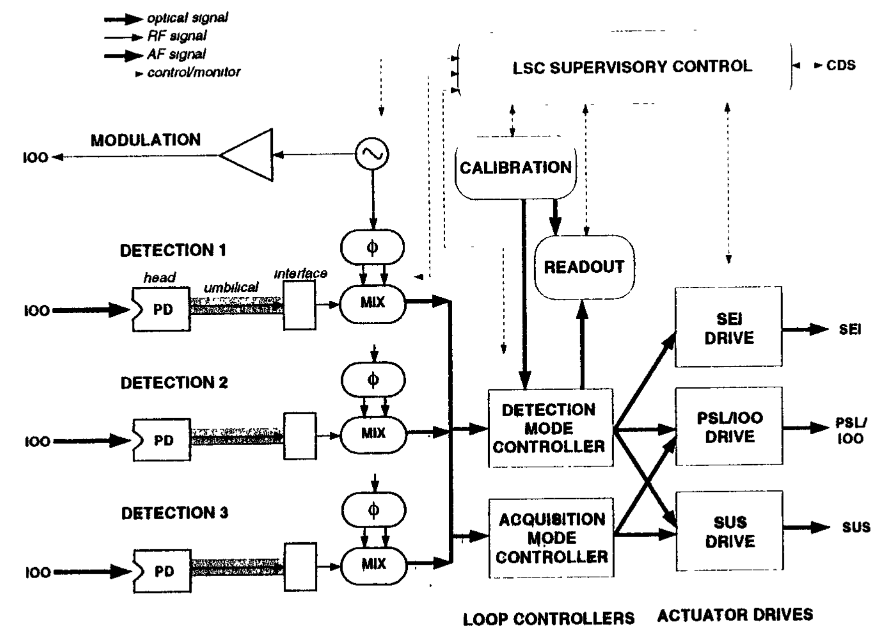
ASC: WFS → FMI
WFS → PNI
WFS → 40m (?)
DIGITAL CONTROL DEMO → ? (PNI?)
INIT. ALIGN. ALGORITHM → ? (40m?)

LSC: RFPD TEST → PNI
ACQ MODEL VALIDATION → 40m
RECYCLING DEMO → 40m
RF MOD / DEMOD → 40m
ACQ SEQUENCER / GLC TEST → ? (40m?)
HIGH-SNR SIGNAL ELECTRONICS → ?
DIGITAL CONTROL DEMO → ?
IFO DIAG. S/R TEST DEMO → ?

ISC Implementation; R&D Inputs

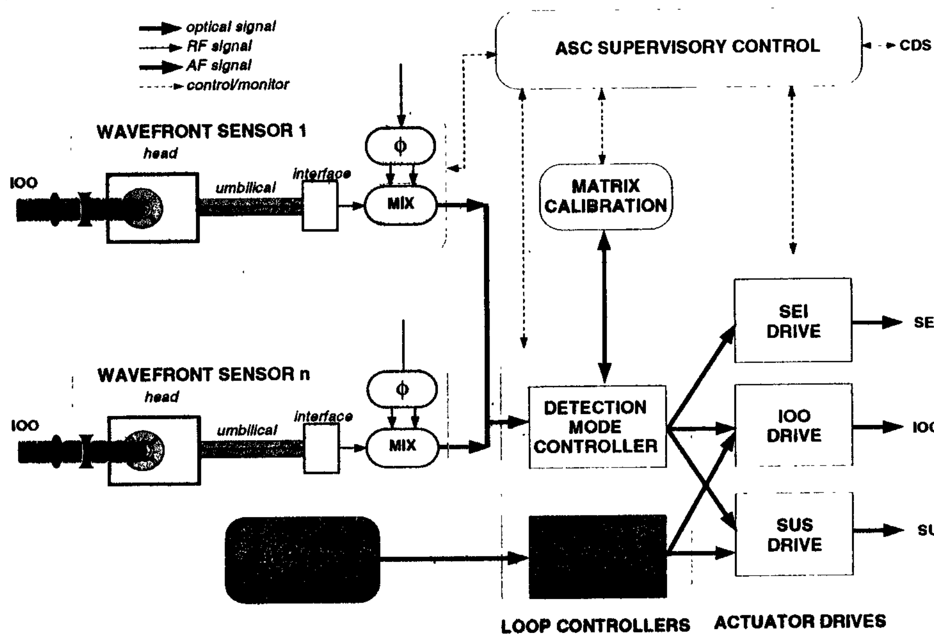


LSC Functional Block Diagram



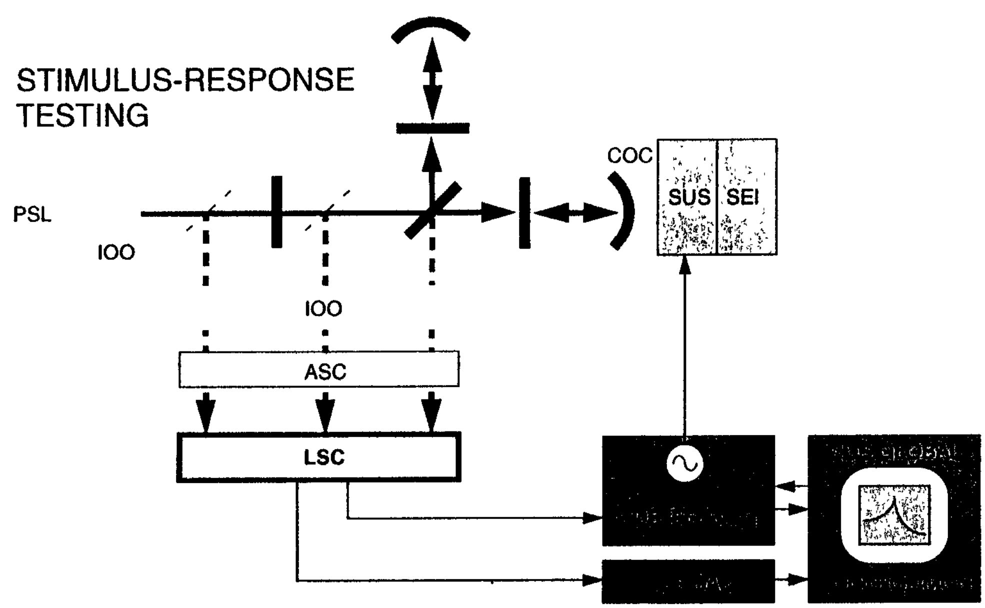
Zucker 8

ASC Functional Block Diagram



Zucker 7

Diagnostic Capabilities



PNI status/update

Saha

21 May, 1996
1440-1515

(Times are EDT)

The Phase Noise Interferometer: Current Status

Recapitulate:

The goal is to show that the fringe noise at the anti-symmetric port of a suspended Michelson interferometer can be brought down to 10^{-10} rad/$\sqrt{\mathrm{Hz}}$ around 200 Hz.

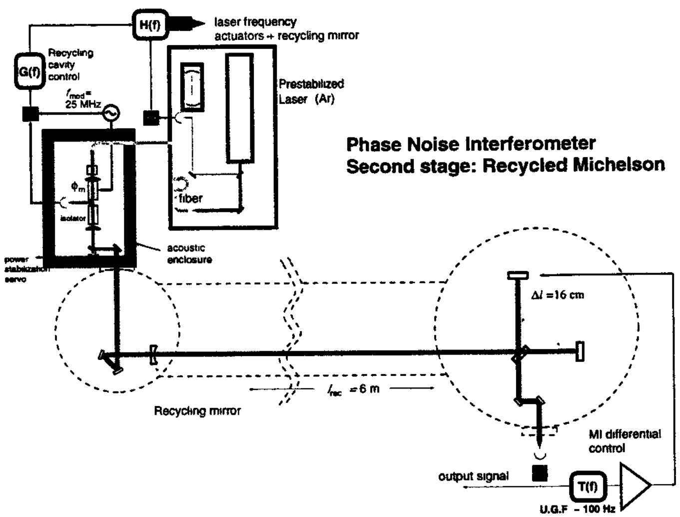
Work has been organized in two phases:

First Phase: Develop a Michelson interferometer with suspended optics. Operate at low powers and identify problems in control of suspended optics and reaching quantum noise limited sensitivity at these power levels. Prepare for Recycling. (Completed)

Second Phase: Recycle light lost at the symmetric port, with the interferometer held at a dark fringe, to build up power to tens of watts. Identify problems in reaching quantum noise limited sensitivity consistent at this high power level. (Ongoing)

The Phase Noise Interferometer: Layout

The interferometer in its second phase has a layout as given below:



The Phase Noise Interferometer: Current Efforts

Most of our current efforts were towards evolving a servo configuration that

(a) acquires resonance for the recycling cavity (or the common path) and maximal destructive interference at the anti-symmetric port (or the differential path);

(b) once acquired, keeps the the system in its desired state despite environmental (mainly seismic) disturbances;

(c) provides frequency noise stabilization down to 10^{-2} Hz/$\sqrt{\text{Hz}}$.

Challenges faced were:

(a) as the common path reaches resonance, the gain in the differential path control changes by many orders of magnitude – must have a servo for the differential path that can withstand gain changes by that order without oscillating or saturating;

(b) given the noise in our environment the common path requires a wide bandwith for acquisition – must have actuators that are well behaved within this bandwidth.

The Phase Noise Interferometer: Current Efforts

Servo configurations tried were:

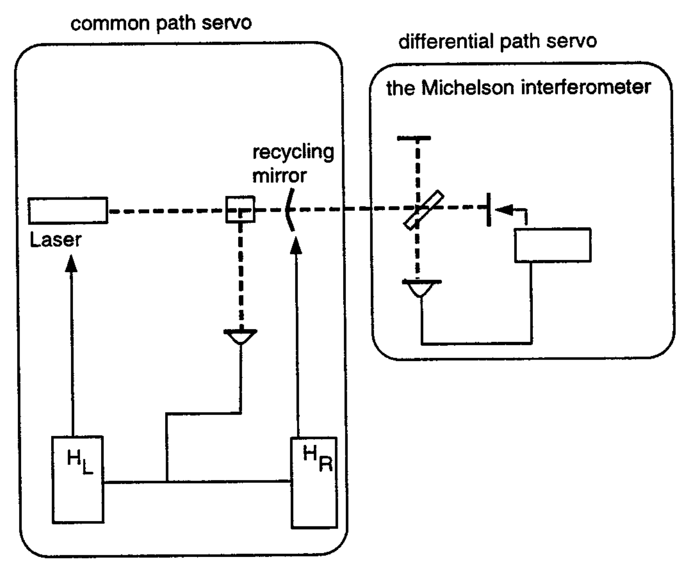
(a) Slave the laser frequency to follow the length changes of the recycling cavity at all frequencies above 10s of Hz; at low frequencies, have the recycling cavity length follow the laser frequency. This gave us some idea of the optical performance of the system and the working of the differential path.

(b) Start with a pre-stabilized laser locked to a "quiet" reference cavity and fix the recycling cavity length to the frequency of the laser – a noisy environment causes problems in acquisition and stability of resonance. This gave us an idea of the frequency noise of the "pre-stabilized laser".

(c) Start with a pre-stabilized laser locked; fix the recycling cavity length up to 100 Hz by comparing its variation with the resonant length given the laser frequency; above that frequency correct the laser frequency by seeing how it deviates from resonance with the recycling cavity length. This is our desired mode of operation. We are tailoring this configuration right now for the right gain and cross-over from one actuator to another.

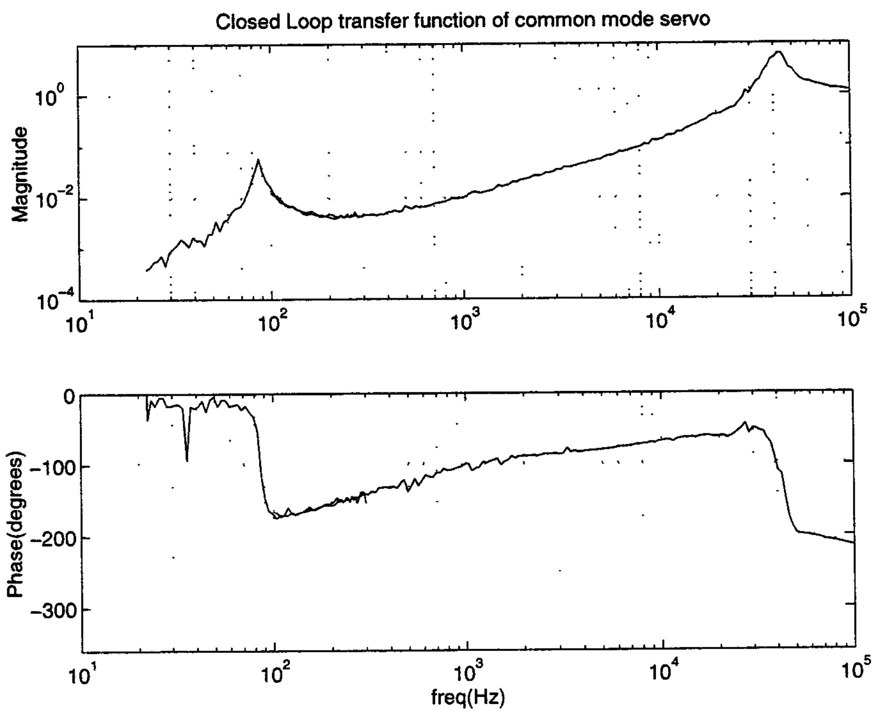
The Phase Noise Interferometer: Current Efforts

A simplified servo schematic for the third configuration is given below:



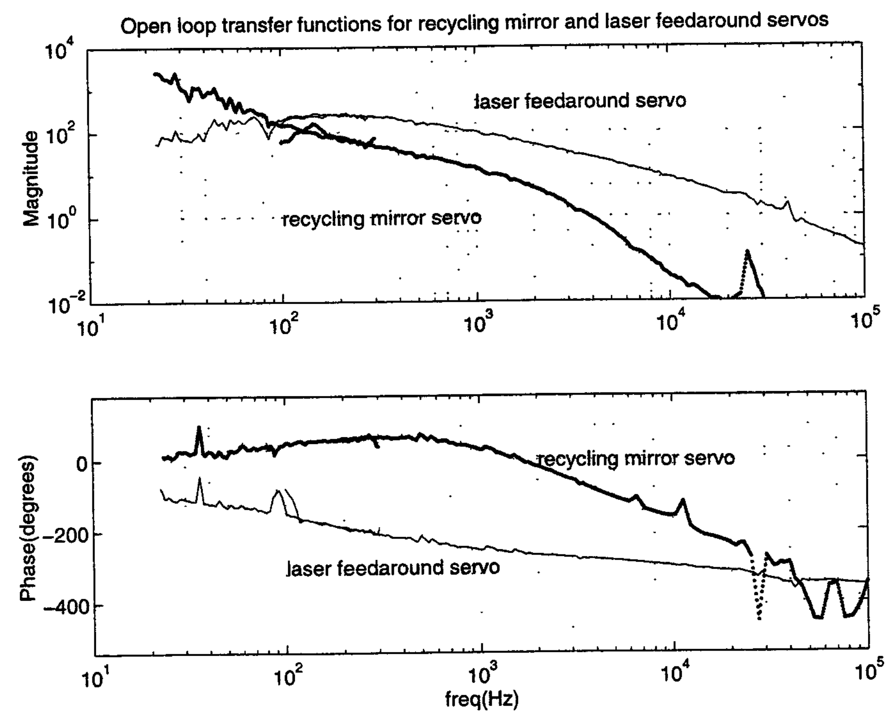
The Phase Noise Interferometer: Current Efforts

The measured closed loop transfer function for the common path is as follows:



The Phase Noise Interferometer: Current Efforts

The measured transfer functions for H_R and H_L and their crossover are shown below:



The Phase Noise Interferometer: Optical Performance

Some measures of the optical performance of the recycled Interferometer will now be presented.

Recycling Gain

• Measurements of the light level transmitted through the cavity (with non-resonant sidebands that were taken into account) indicate a gain of around 450;

• Measurement of ring down times with the resonant recycling cavity also indicate a gain of around 450.

⤳ The circulating power inside the cavity at this moment – inferred from these measurements – is 37.5 mW $\times$ 450 = 17 watts.

Contrast Defect

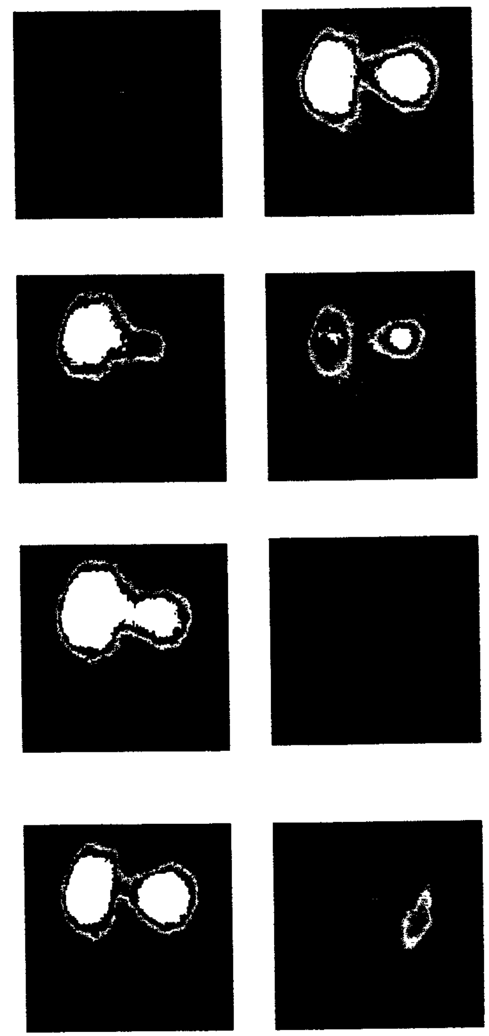
• Measurements of the bright fringe with the non-recycled Michelson and that of the dark fringe with the resonant recycling cavity indicate a contrast defect of about 3×10^{-4};

• Measurement of loss through the ring-down method indicate about 890 ppm above the transmission of the recycling mirror. A contrast defect of 300 ppm is consistent with this loss, given the other losses in the system.

⤳ Note that a contrast defect of this order can be entirely explained by the asymmetry present in the two arms of the Michelson interferometer.

How does the dark port look at this level of contrast defect?

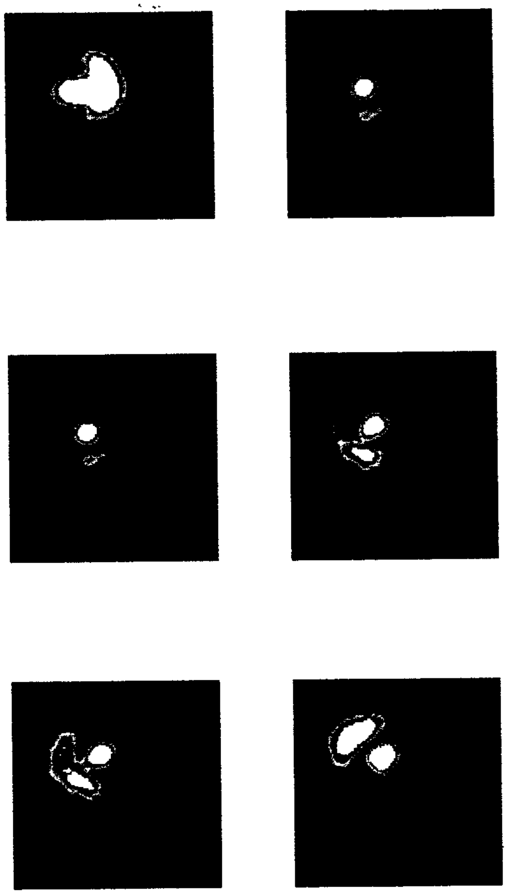
Spiricon Images of the Dark Port



May 18 1996 (sequential frames)

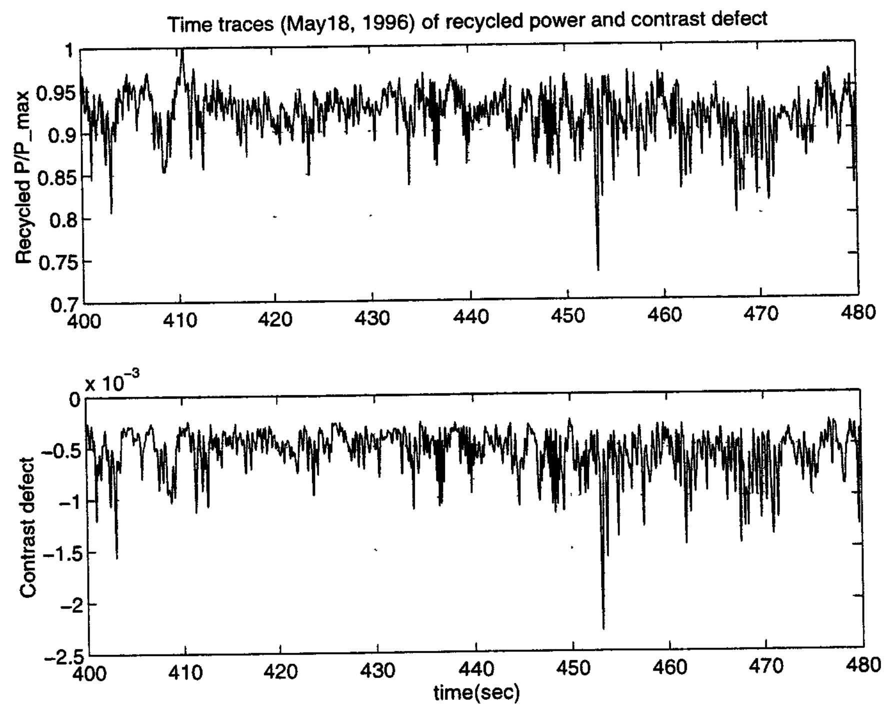
May 17 1996

Spiricon Images of the Dark Port



The Phase Noise Interferometer: Optical Performance

Correlated with the pattern fluctuations shown before are power changes in both the light transmitted through the cavity and that received at the anti-symmetric port, as the following time-traces show (at the dark port, more negative is more light):



The Phase Noise Interferometer: Optical Performance

Alignment Fluctuations

- The fact that the power changes are complementary (an increase at the dark port is accompanied by a decrease at the symmetric port) suggest that the power changes are caused by rms phase fluctuations at the dark port (the mean phase is brought to a null by the length control servo).
- The patterns at the dark port strongly indicate that this is via differential changes in the alignment of the Michelson mirrors (which affects the rms differential phase at the dark port). We are in the process of installing a wave-front sensing and correction scheme for differential misalignment.

This brings us to the present. As we implement the wave-front sensing and correction method, we are also tailoring the common mode path and working towards getting the side bands resonant in the recycling cavity. Noise measurements are going to be undertaken concurrently.