Pre-isolation at LIGO Livingston—status and plans

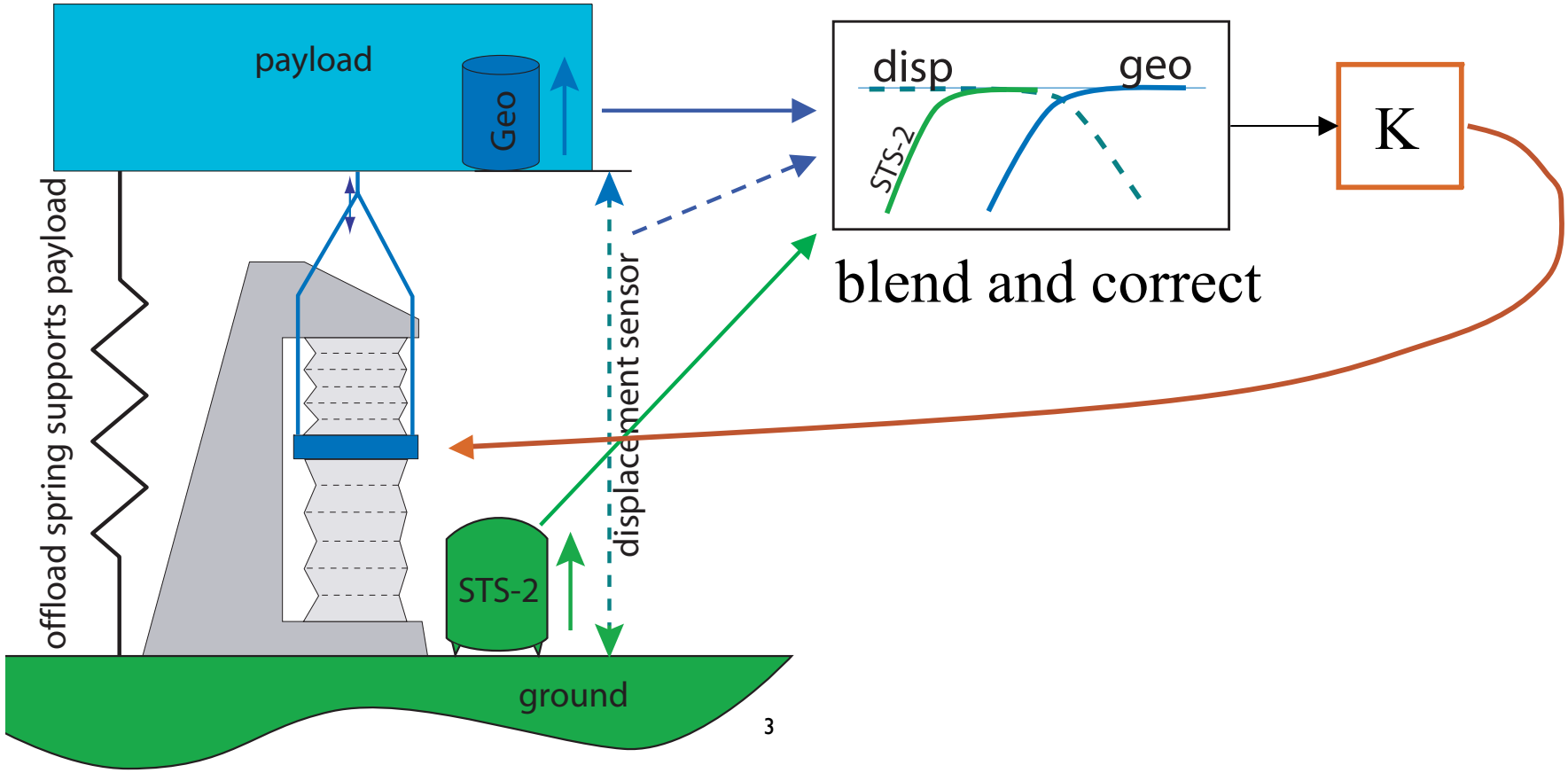
Joe Giaime, for the seismic team and LLO.

Development history

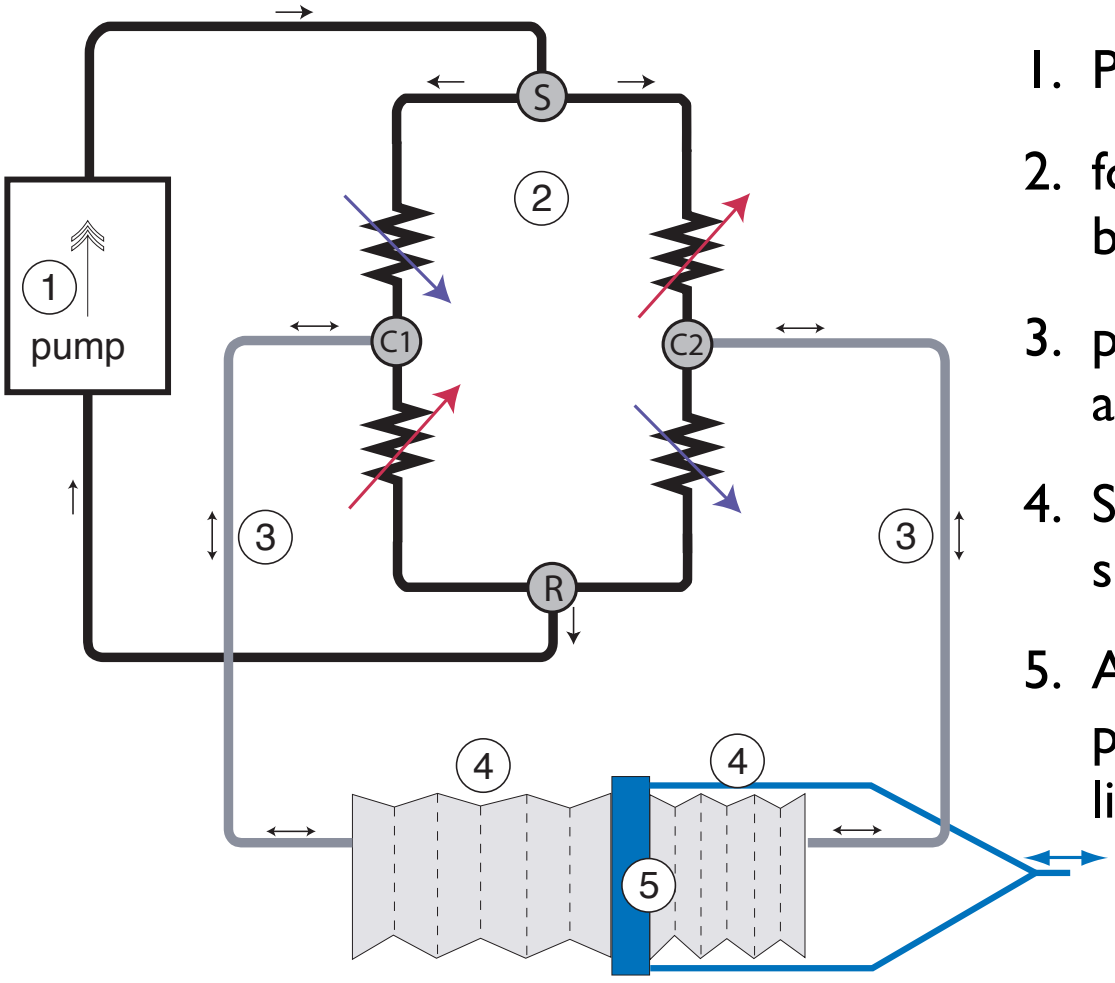
- Decades of R&D on quiet hydraulics with Dan DeBra at Stanford, focussing on use of laminar flow oil to actuate machine tool assemblies.
- Recent development & prototyping of zero-stiction balanced bellows quiet hydraulic actuators, by DeBra, Hardham, Lantz et al, intended for use in Advanced LIGO pre-isolation stage. 2-DOF test stand experiment.
- Study by Hua et al of effective control filter techniques for 'sensor correction' active seismic isolation at sub-hertz frequencies.
- Design of third-generation actuator, payload suspension springs, and external housing for HEPI by Hardham, Hammond, Mason, Kern, Lacour, etc.
- Tests at LASTI (ongoing) by Mason, Hardham, Coyne, Lantz, Mittleman, Ottaway, Sarin, Macinnis, etc. New 'safe' fluid in use, tested at CIT.
- Re-implementation of control system and electronics for LIGO/VME environment and GDS by Bork, Sarin, Abbott(s), etc.
- Mass production and installation at LLO, by Kern, Abbott, Spjeld, Lacour, Traylor, Overmier, Mailand, and many more.
- general organization by Coyne, Kern, Abbott, Lantz and Giaime.

Low-frequency pre-isolation

- At each tank corner pier, there is a sensor/actuator set, vertical and horizontal.
- Each DOF controlled with respect to HEPI displacement sensors and geophones.
- Displacement sensor corrected for floor motion as measured by Streckeisen STS-2., in x, y, z DOF's.



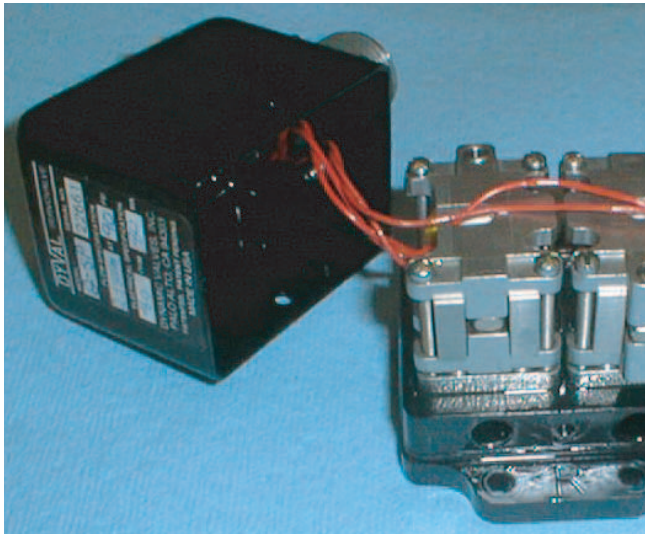
Hydraulic bridge actuation



1. Pressure-stabilized pump.
2. four-valve flow-resistance bridge.
3. pipes connect bridge to actuator.
4. Stiction-free bellows on each side of actuated plate.
5. Actuated plate connected to payload through 1-DOF linkage.

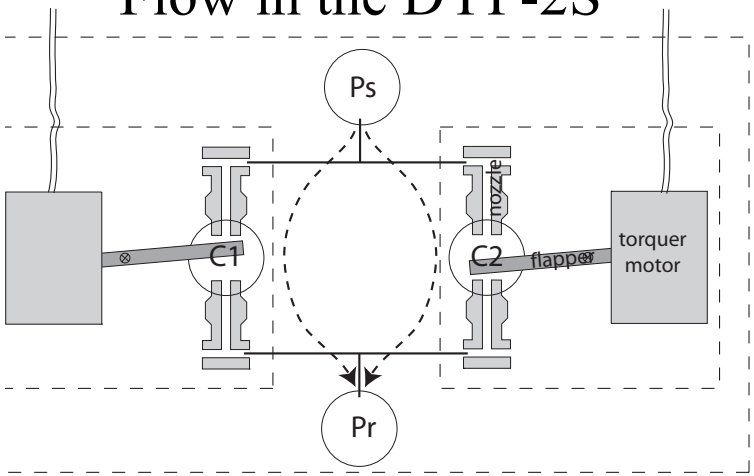
Valve modification

- Hardham, Lantz, DeBra designed new nozzles for valve, to allow laminar flow and large linear bridge response.
- New nozzles procured, but need to be installed and adjusted by hand.



Parker DYP-2S valve

Flow in the DYP-2S

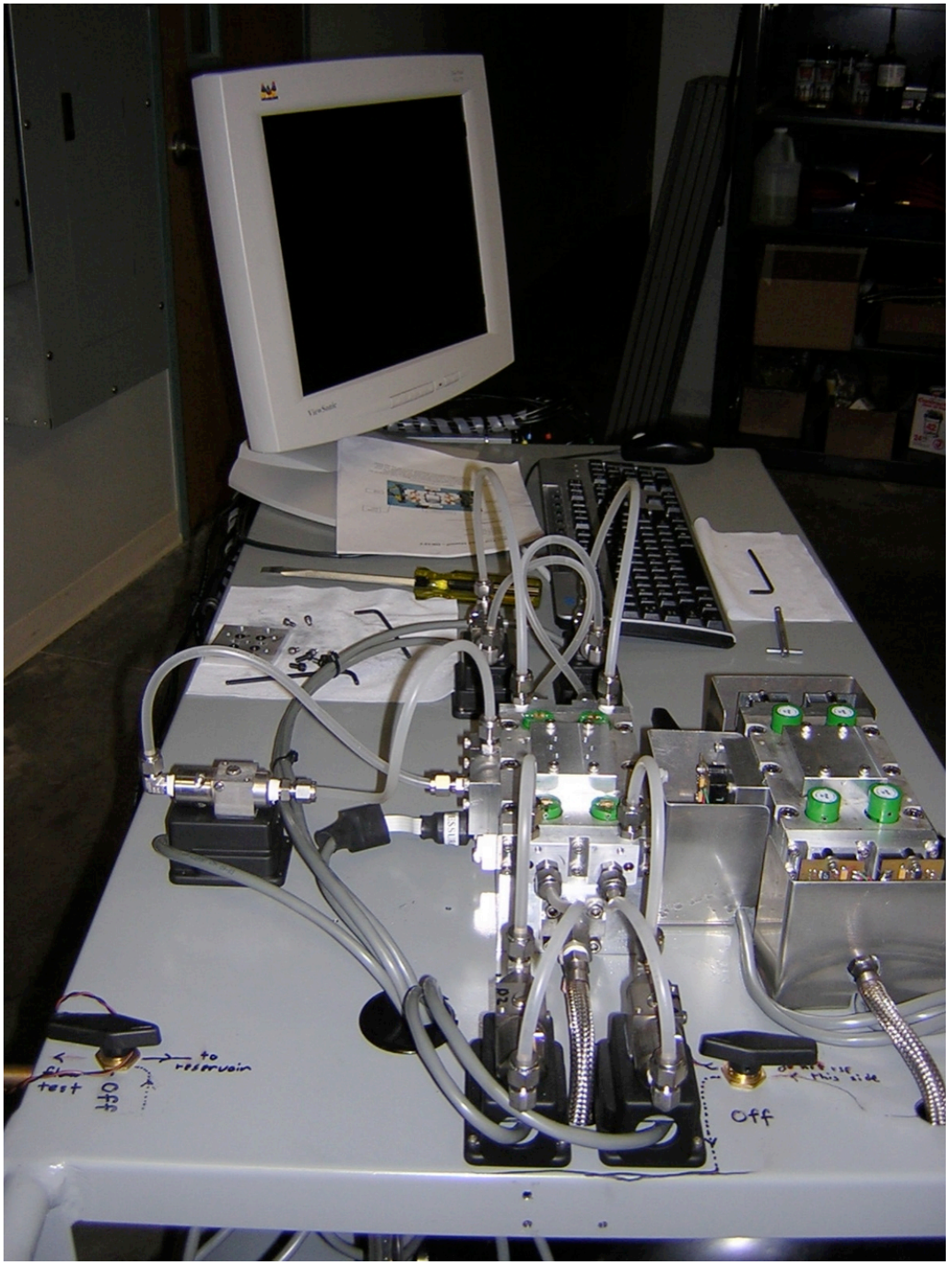


DYP-2S valve

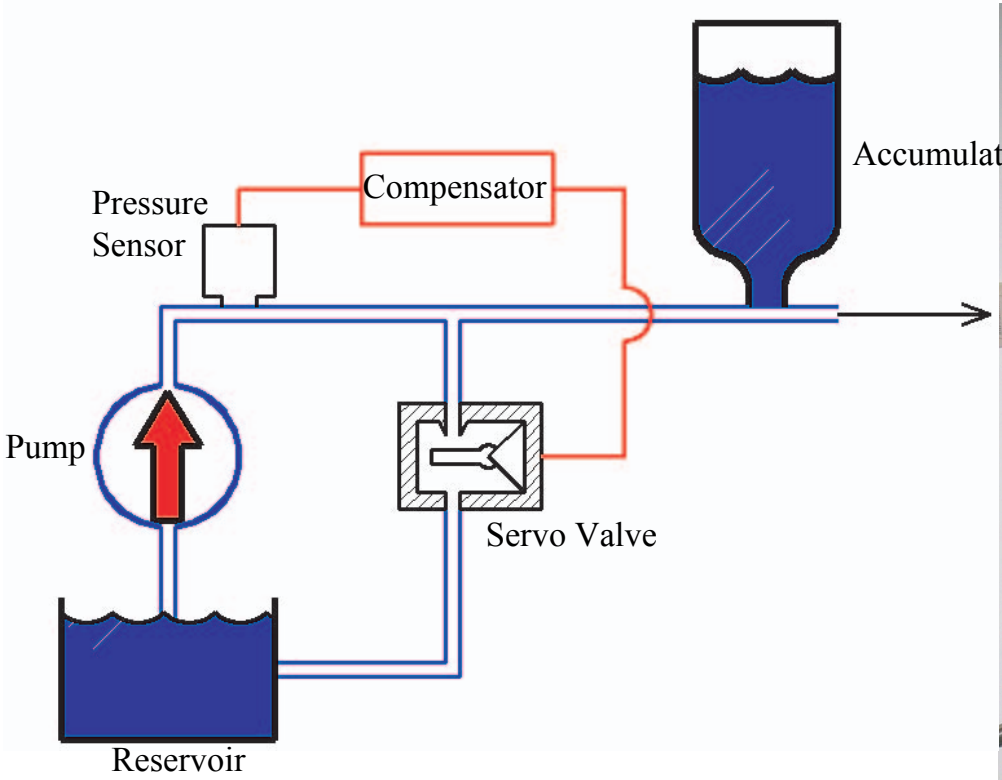
The new nozzle

Valve calibration stand

- Valve adjustment jig designed at Stanford by Ganguli and Campbell.
- Replicated at LLO by Kern, Sellers, Abbot and Carter.
- Reworked after new 'safe' fluid destroyed the pressure sensors, and other surprises.
- 40 valves completed so far, by Carter & Evans.

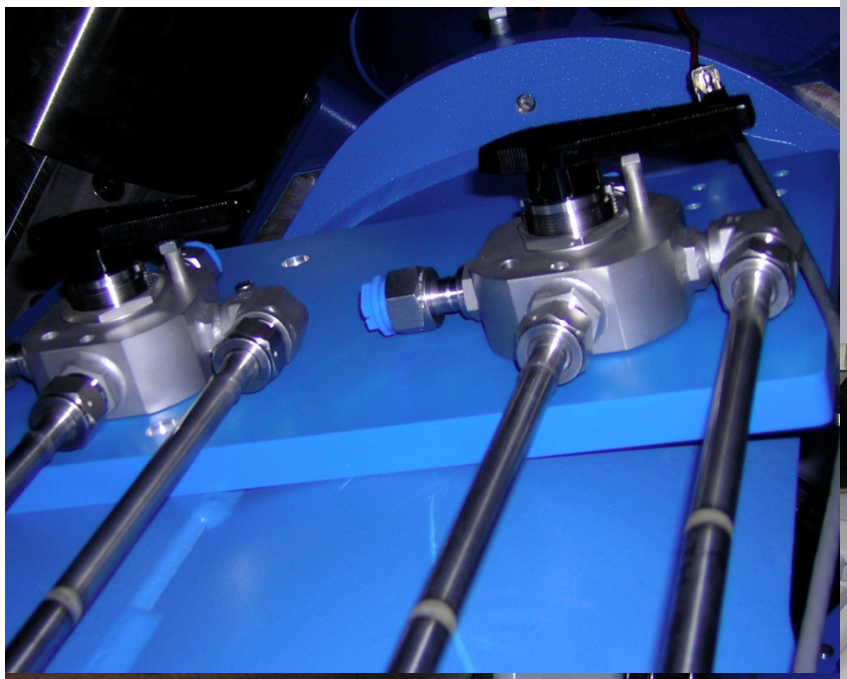


Pump stand



Design by Ken Mailand

Plumbing and wiring.



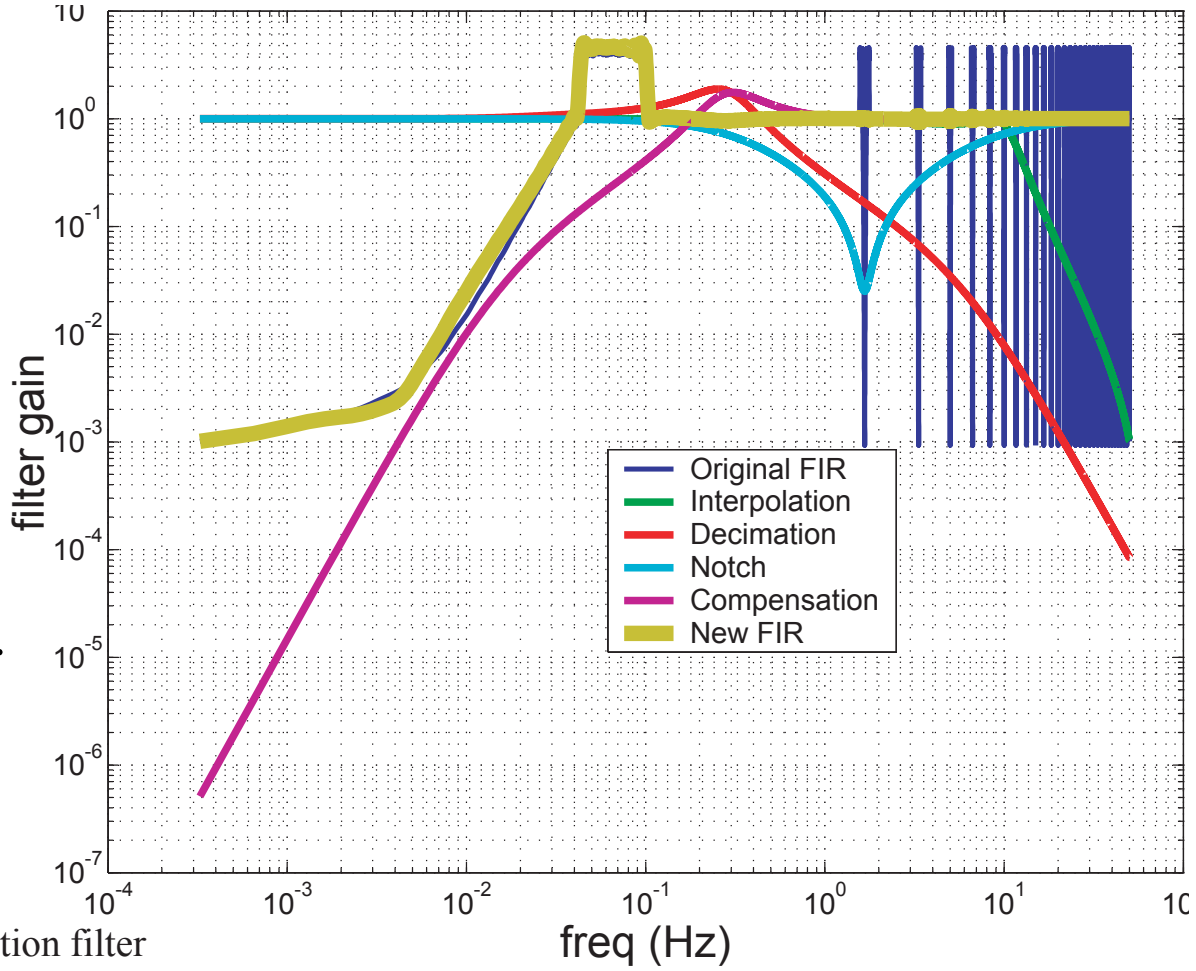
Abbots,
Kern,
Excel,
Hanson,
etc.

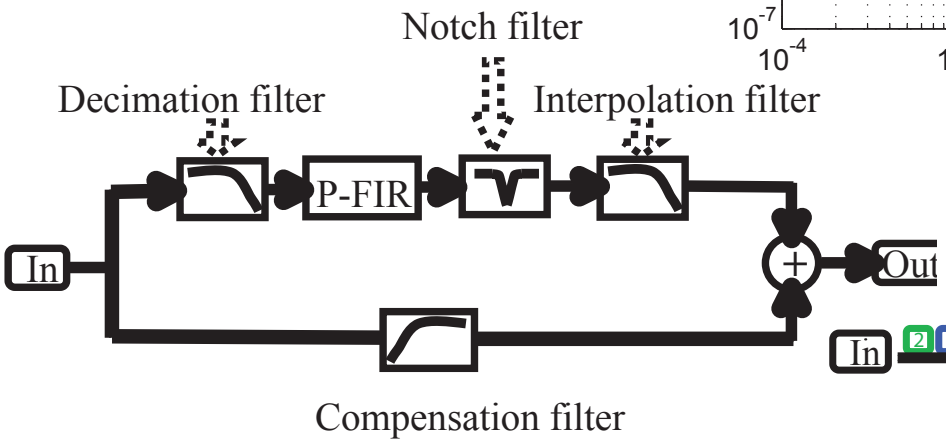
Mass production

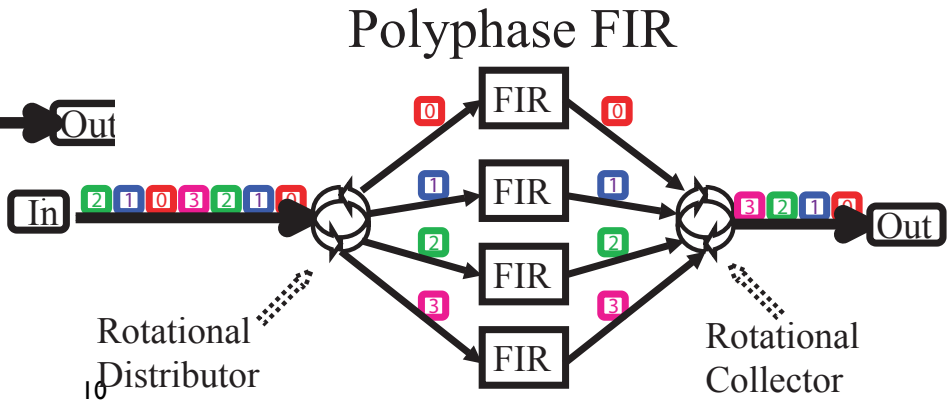
9 LLO & 2 LASTI tanks, lots of parts!

Efficient polyphase FIR (W. Hua)

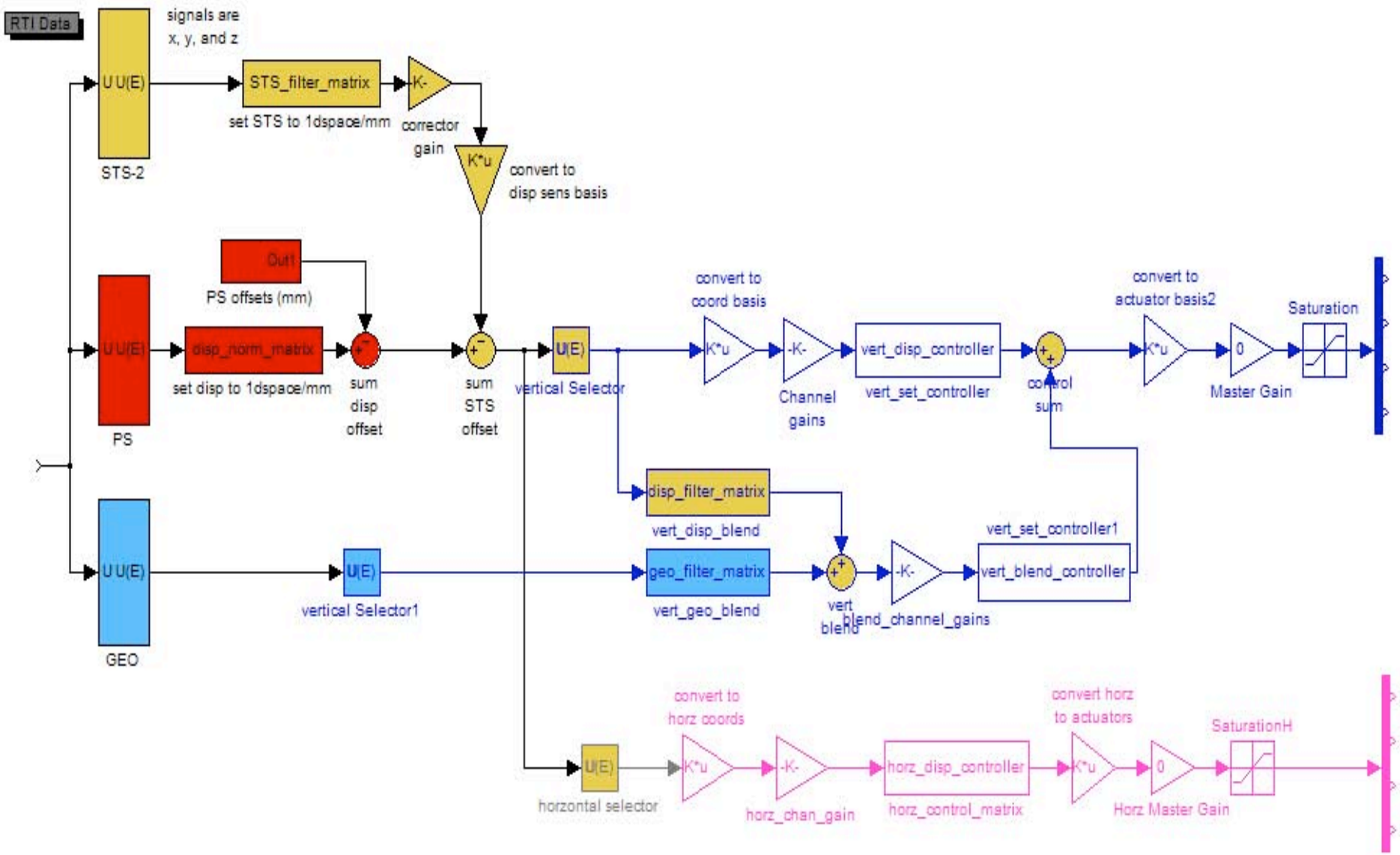
- Eliminates low-frequency noise and artifacts from sensor correction signal.
- Avoids excessive phase and amplitude mismatch in band.
- Computationally efficient.



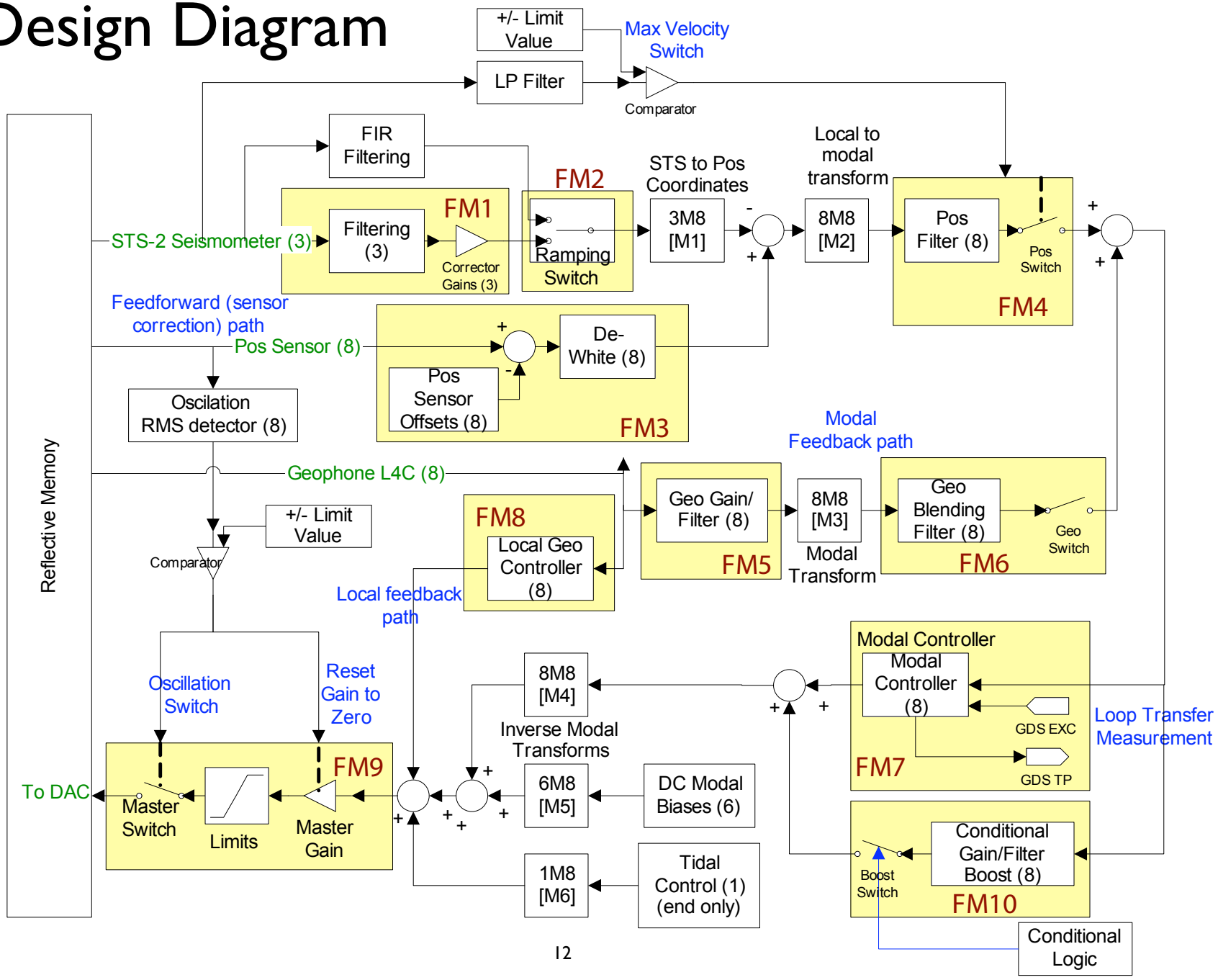




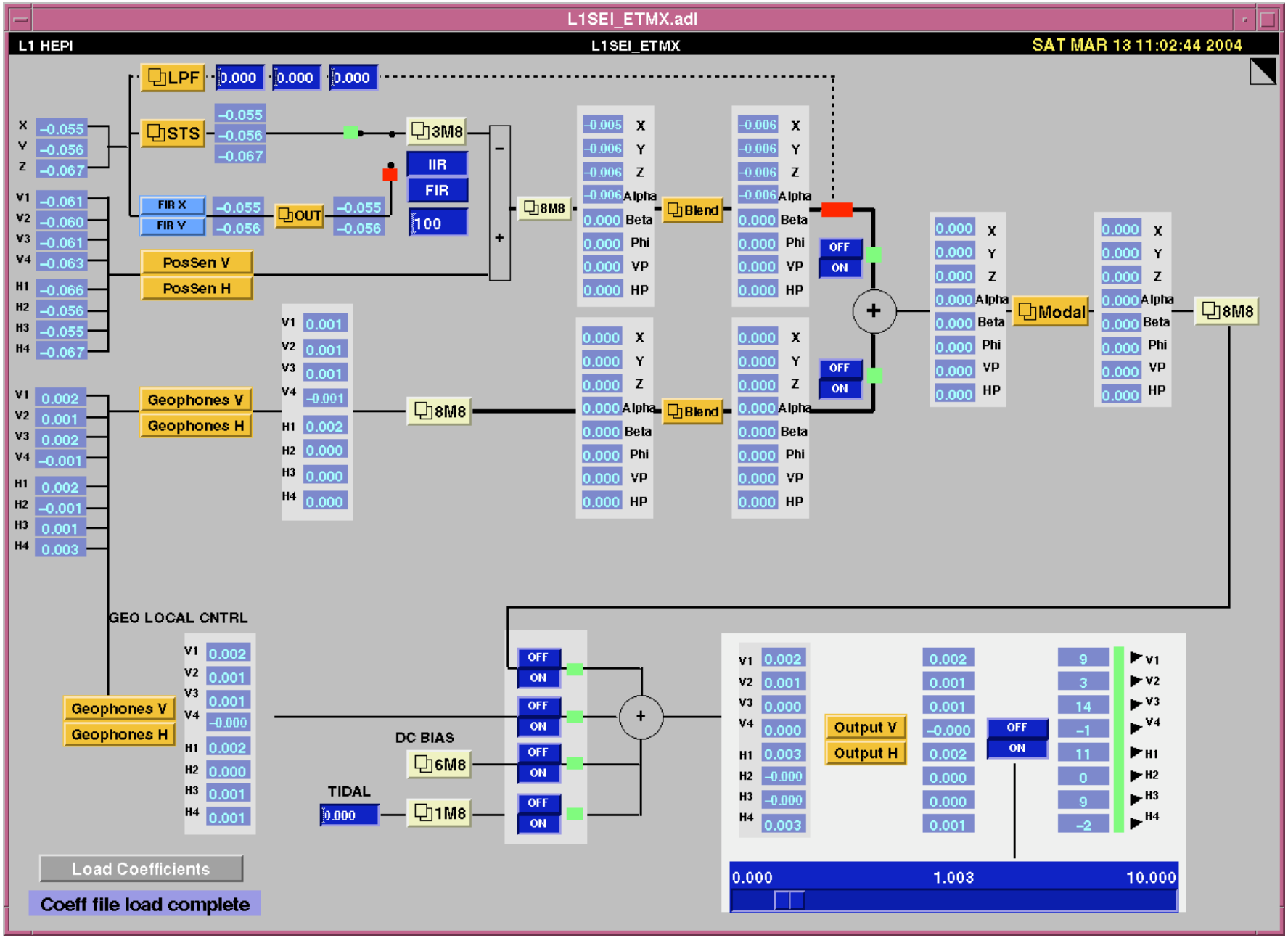
Simulink block diagram from LASTI



Design Diagram



EPICS control panel at LLO



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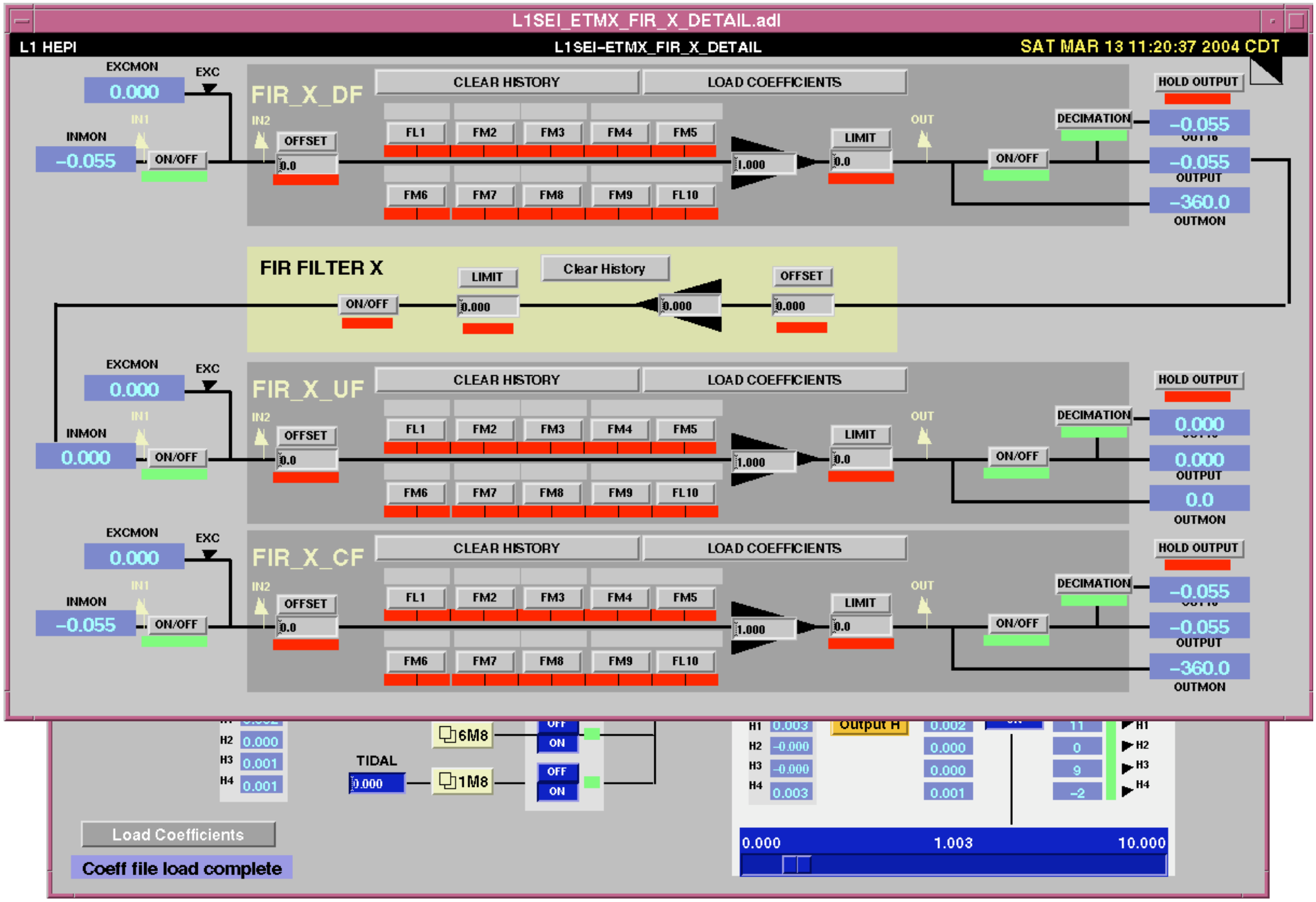
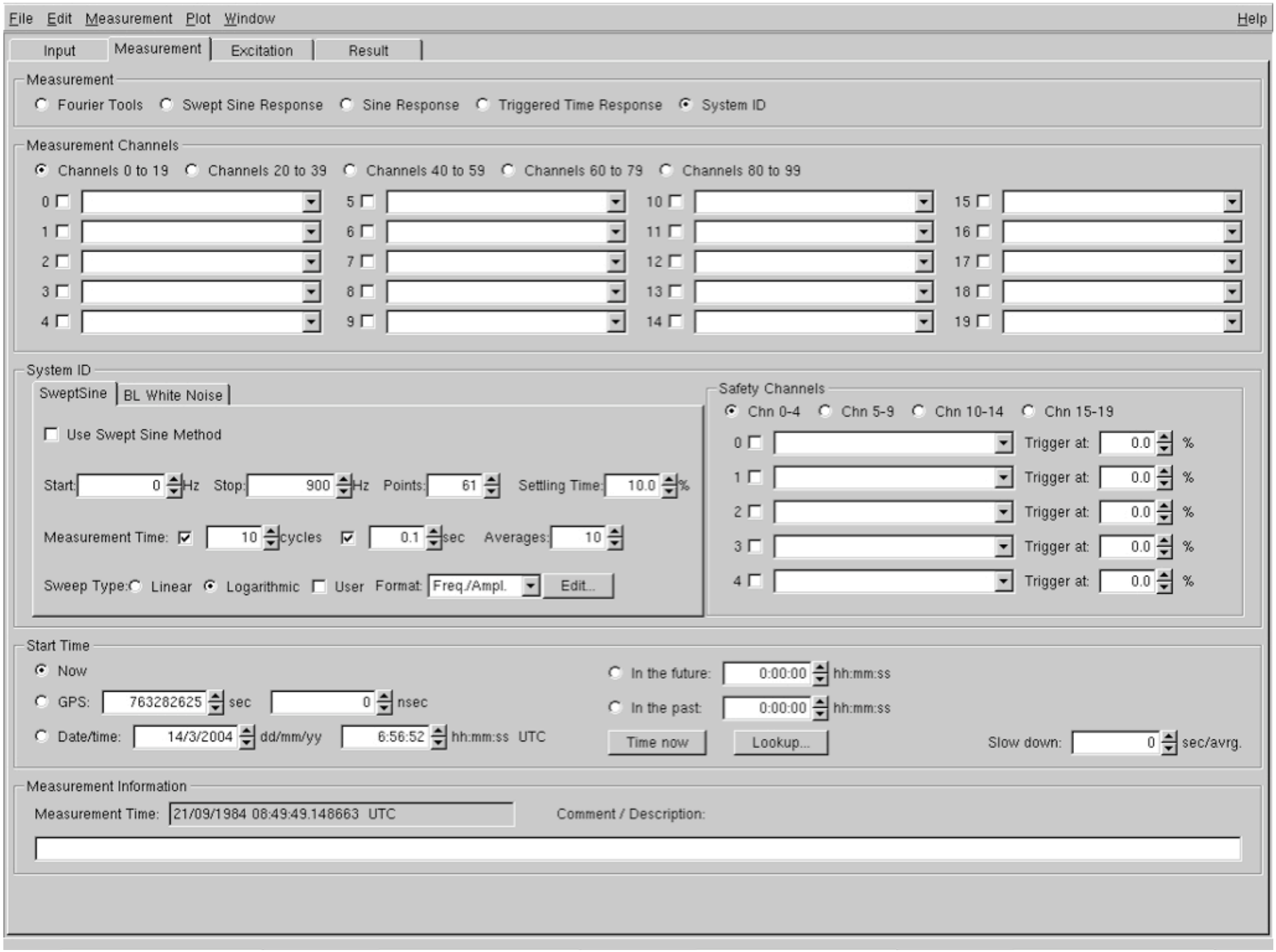


DMT-based sys-id (Sarin)

- System identification needs to be carried out on 9 HEPI systems, each with 8 actuators and 16 sensors.
- Previous sys-id was done with dSpace-based code written by Hua.
- At LLO, it is better to use existing DMT environment, so Sarin wrote new application for DMT DTT suite.
- Efficient swept sine and band-limited white noise modes
- Built-in watchdog monitoring of user-defined channels, to permit unattended operation.

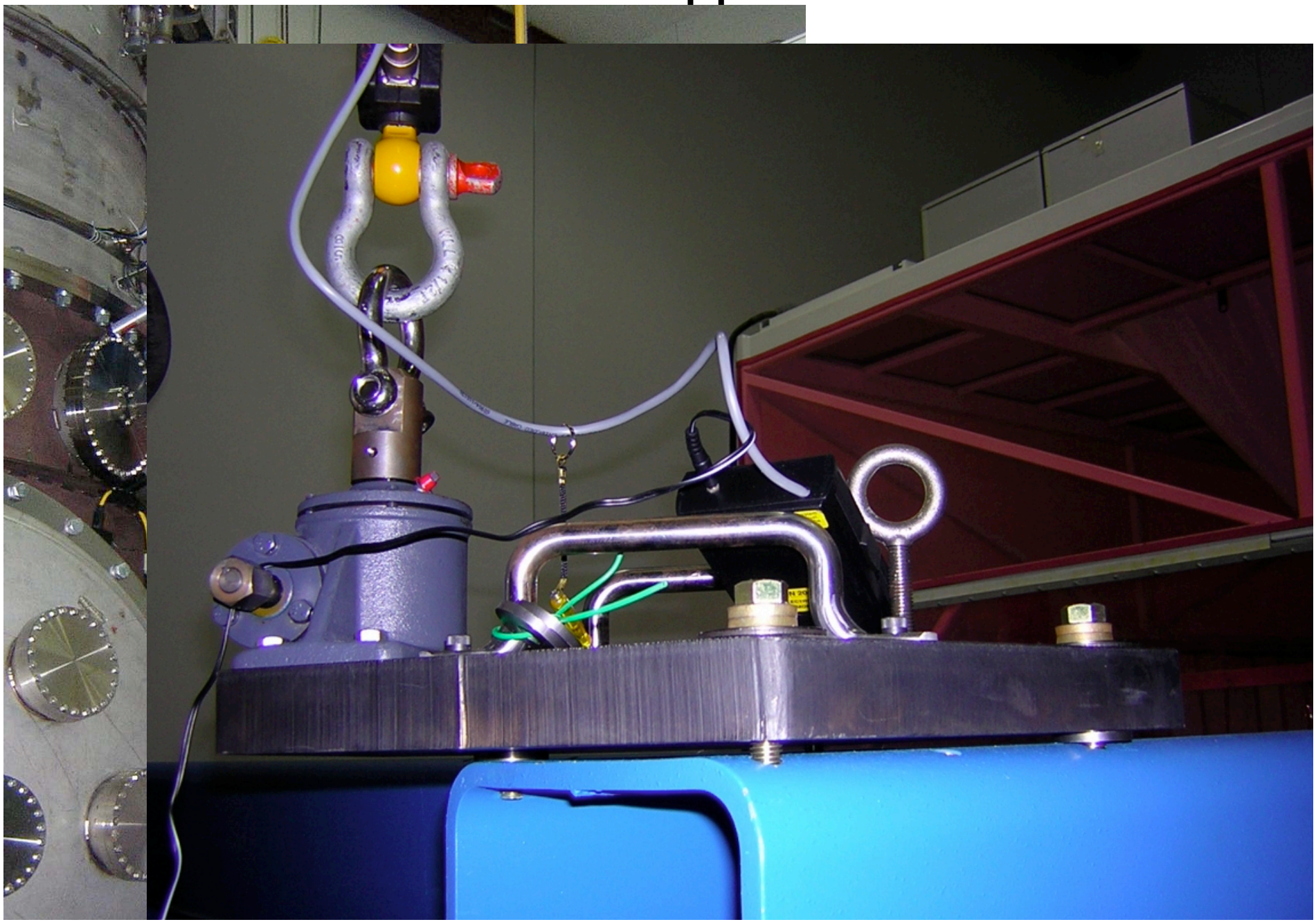

File Edit Measurement Plot Window Help
Input Measurement Excitation Result
Measurement
Fourier Tools Swept Sine Response Sine Response Triggered Time Response System ID
Measurement Channels
Channels 0 to 19 Channels 20 to 39 Channels 40 to 59 Channels 60 to 79 Channels 80 to 99
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
System ID
SweptSine BL White Noise
Use Swept Sine Method
Start: 0 Hz Stop: 900 Hz Points: 61 Settling Time: 10.0 %
Measurement Time: 10 cycles 0.1 sec Averages: 10
Sweep Type: Linear Logarithmic User Format: Freq./Ampl. Edit...
Safety Channels
Chn 0-4 Chn 5-9 Chn 10-14 Chn 15-19
0 1 2 3 4 Trigger at: 0.0 %
Start Time
Now
GPS: 763282625 sec 0 nsec
Date/time: 14/3/2004 dd/mm/yy 6:56:52 hh:mm:ss UTC
In the future: 0:00:00 hh:mm:ss
In the past: 0:00:00 hh:mm:ss
Time now Lookup...
Slow down: 0 sec/avrg.
Measurement Information
Measurement Time: 21/09/1984 08:49:49.148663 UTC
Comment / Description:

Installation

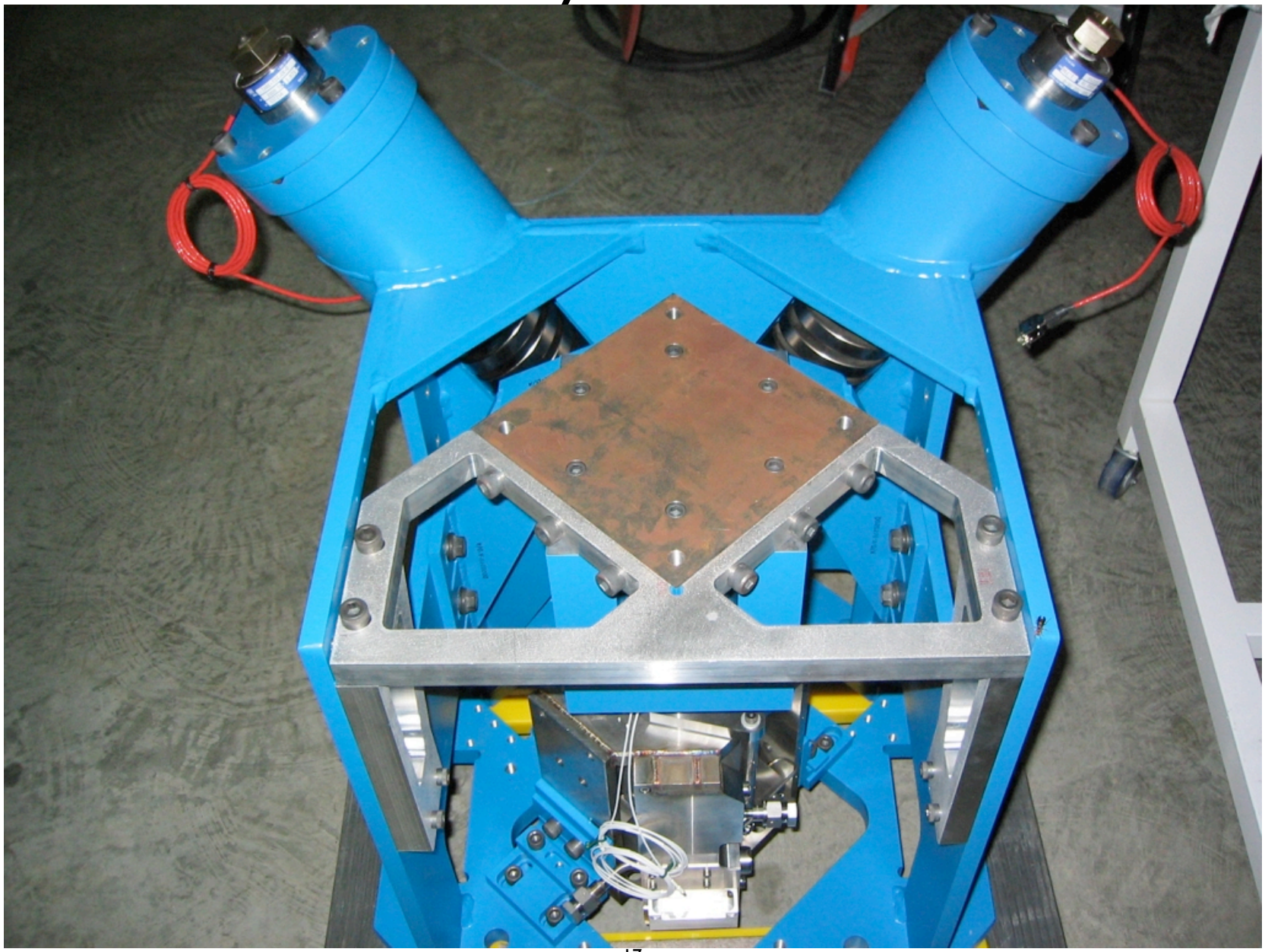
- We are replacing the old fine and coarse actuation systems in the BSCs, and the coarse actuation and piers in the HAMs.
- The payload is instrumented with 12 dial gauges and two optical lever signals, so allow exact repositioning after installation.
- Each corner is supported from directly above the spring attachment point, the coarse actuator is retracted, the HEPI package installed, and the load is transfered smoothly.
- Each actuator/housing/spring assembly aligned on the bench, then attached to the crossbeam with shimming at a single interface.
- After all 4 are in place, springs to be re-tensioned (read out by load cells) and payload returned to initial position and alignment.

Load support

Load support



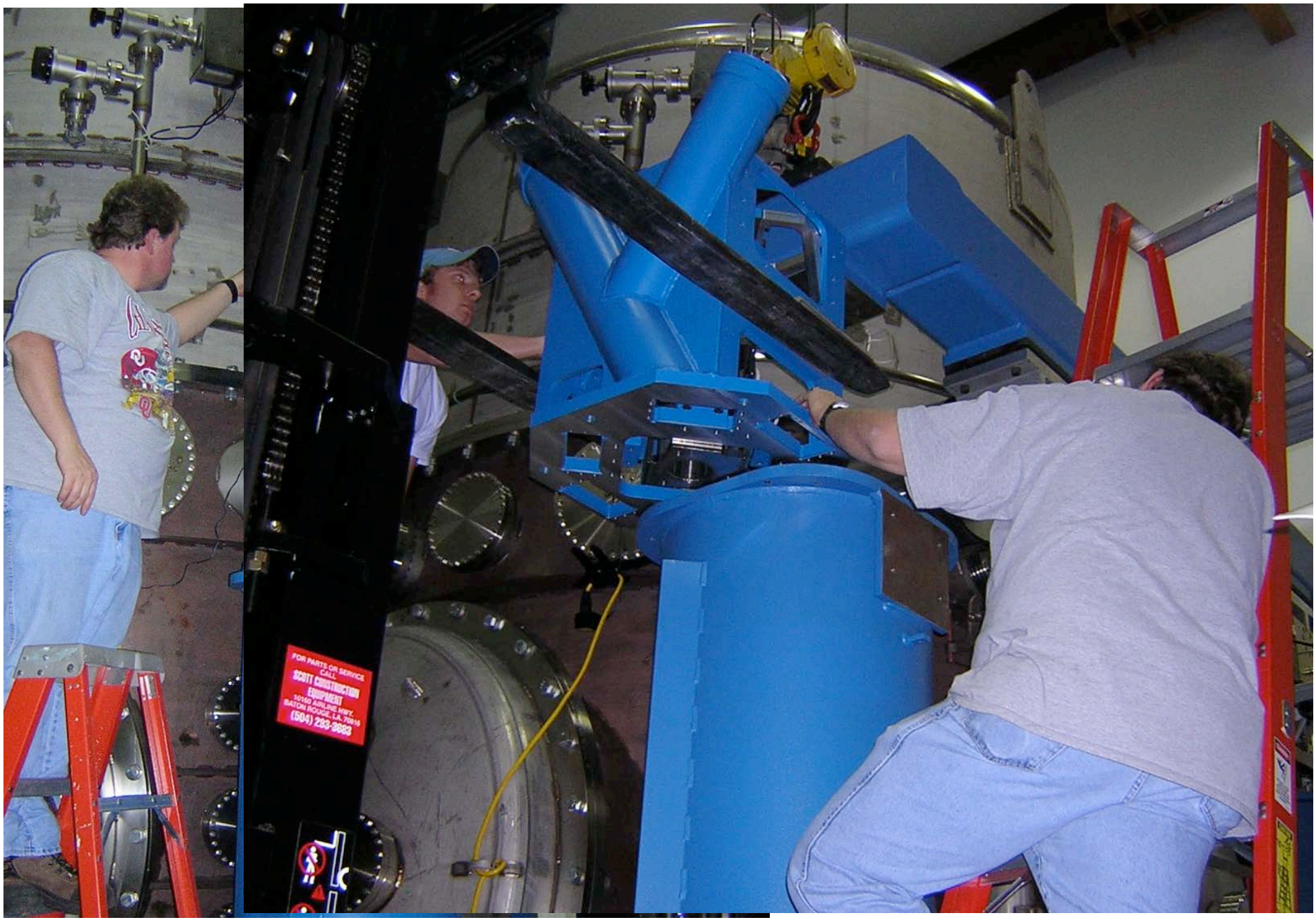
Ready to install



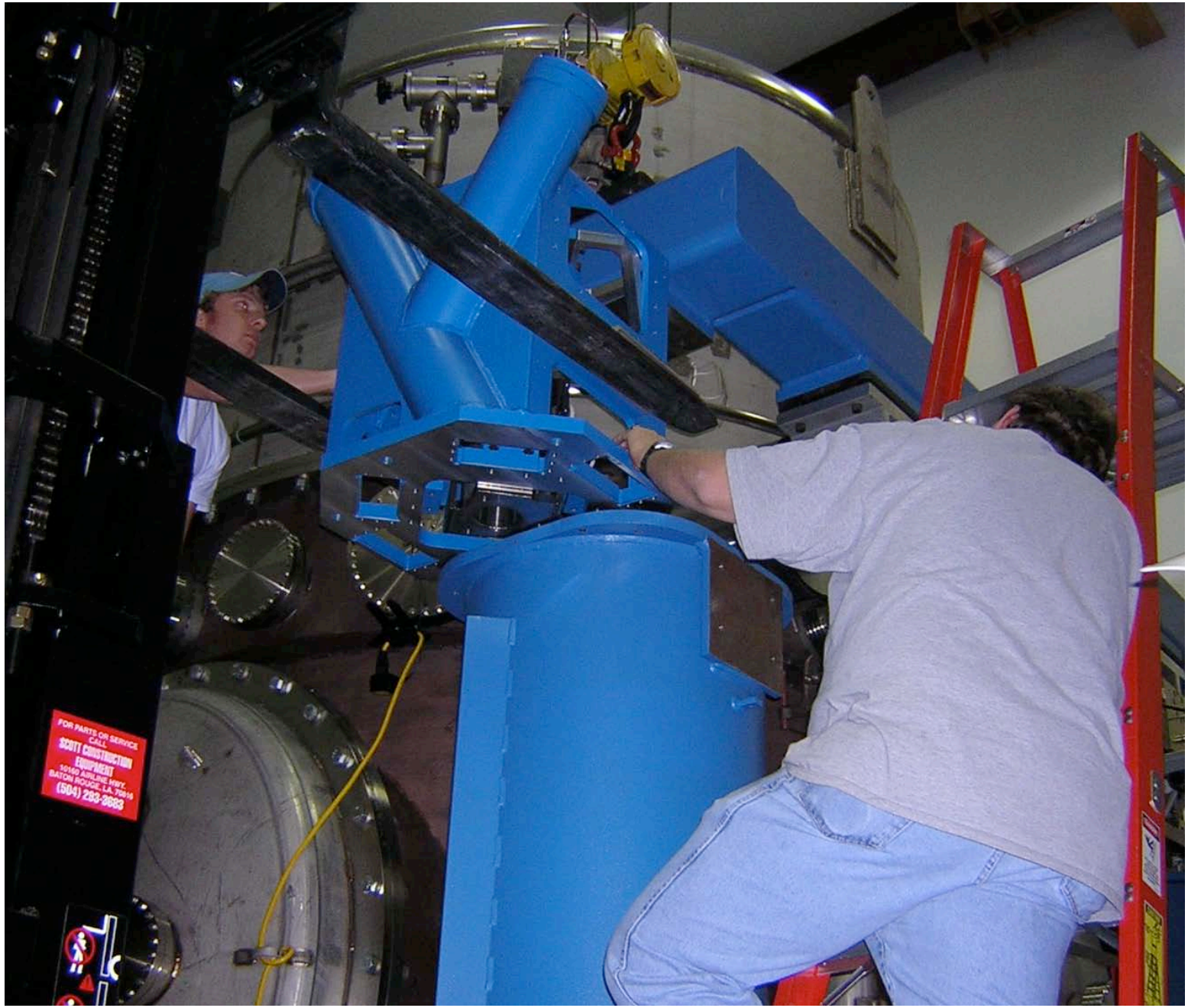
Out with the old …

Out with the old …

In with the new …



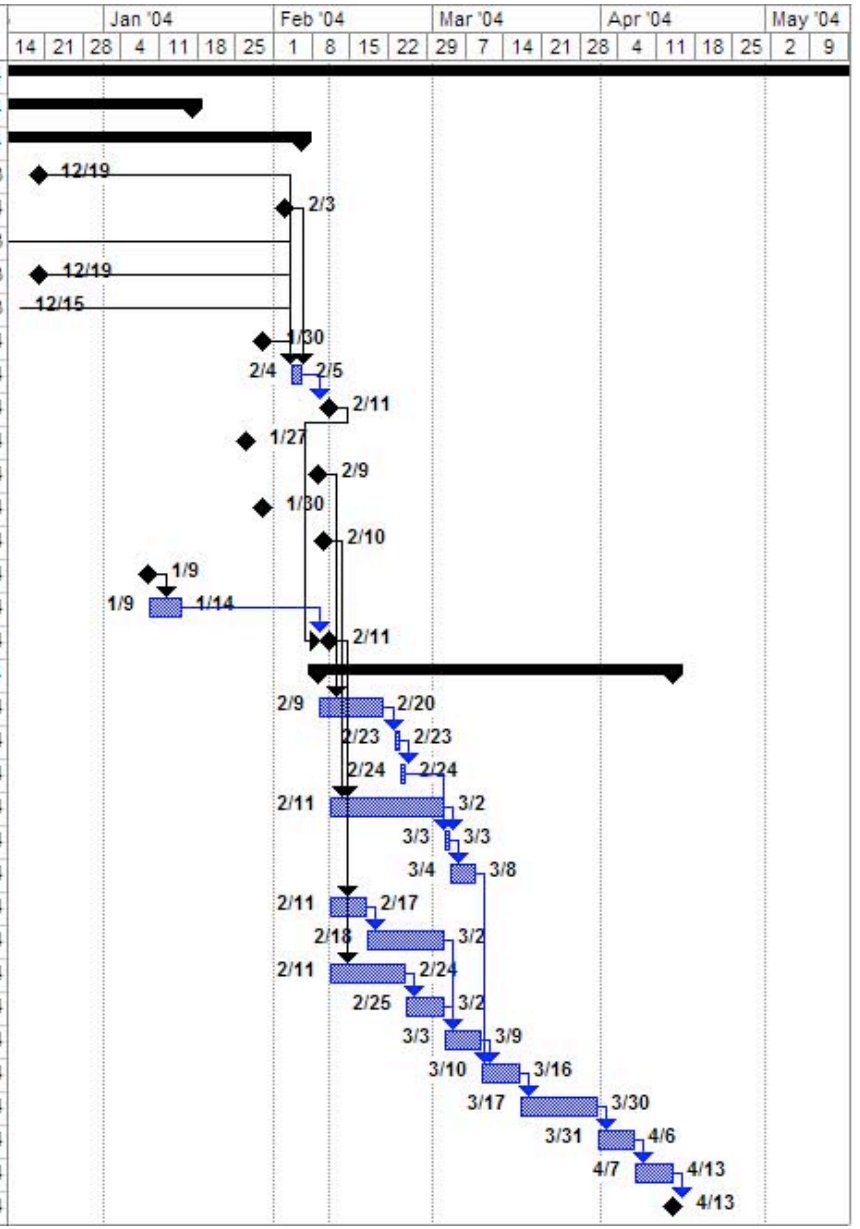
In with the new …



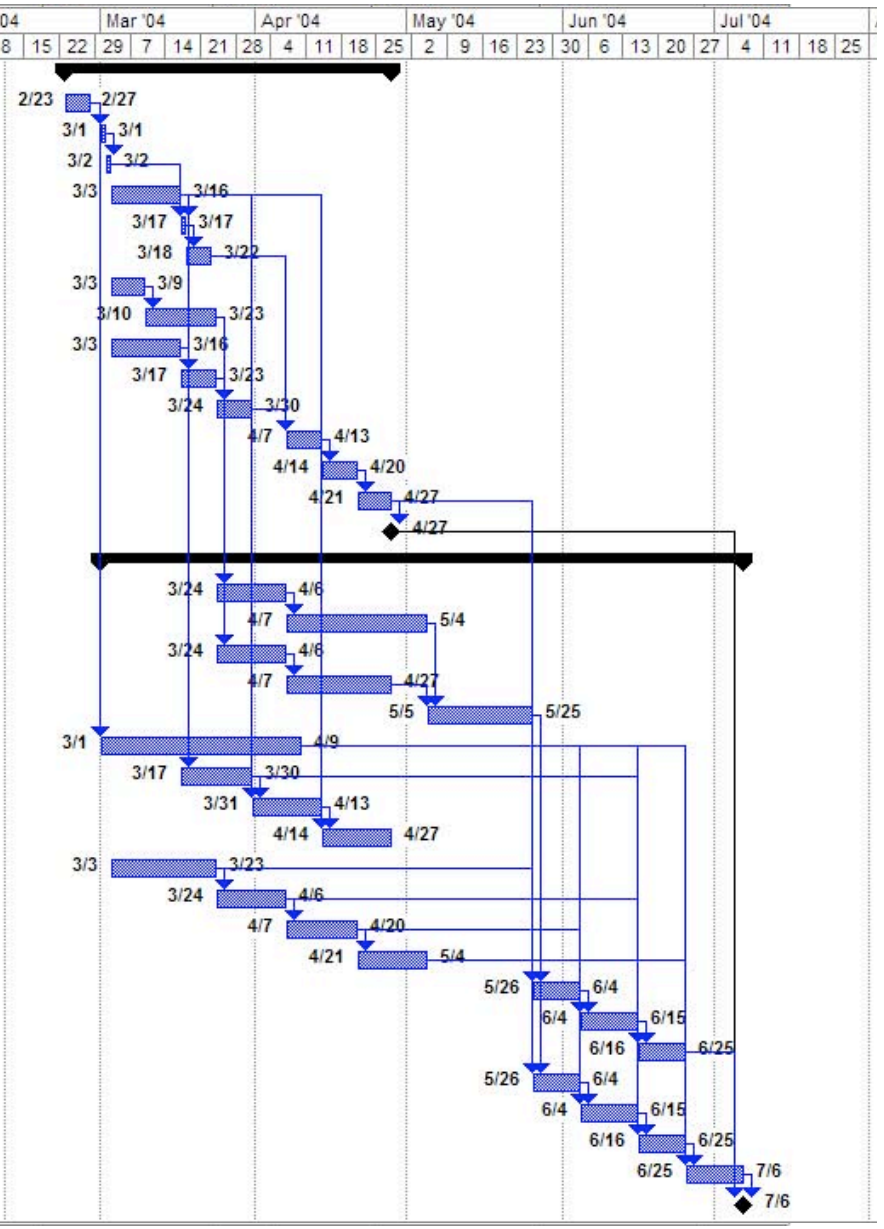
Schedule

- Current status:
  - ETMX actuator installation nearly complete (dry)
  - ETM plumbing largely complete
  - ETM pump stations in place; readying for fluid circulation through bypass path. (All pump stations built.)
  - More than half of the actuators have been delivered, and most other hardware is in-house.
  - Electronics largely ready; the balance is expected soon.
- Outlook:
  - Plan was to spend 3 weeks for the first installation of each tank, then 2 weeks for subsequent ones. We began about 2 weeks late, but it looks like we may avoid schedule expansion.
  - ETMX should be 'wet' next week, and sys-id may begin the following week.

ID	Task Name	Duration	Start	Finish
182	**Assembly, Installation & Commission**	**152 days**	**12/1/03**	**7/6/04**
183	**LASTI Controls Development Completion**	**30 days**	**12/1/03**	**1/16/04**
186	**1st Article Fit Check (Housing Assembly)**	**43 days**	**12/2/03**	**2/5/04**
187	1st production spring set	0 days	12/19/03	12/19/03
188	1st production EPI housing available	0 days	2/3/04	2/3/04
189	1st production actuator available (tested)	0 days	12/2/03	12/2/03
190	1st production HAM pier	0 days	12/19/03	12/19/03
191	1st production set of EPI brackets	0 days	12/15/03	12/15/03
192	1st production EPI boot	0 days	1/30/04	1/30/04
193	first article assembly @Southbridge	2 days	2/4/04	2/5/04
194	Readiness Review	0 days	2/11/04	2/11/04
195	Piping Contract Selection	0 days	1/27/04	1/27/04
196	Piping Contract Start	0 days	2/9/04	2/9/04
197	Pump Station Assembly & Leak Test Completed	0 days	1/30/04	1/30/04
198	Receive 1set Housings & 'boots'	0 days	2/10/04	2/10/04
199	S3 run end (w/ 3 day extension)	0 days	1/9/04	1/9/04
200	post-S3 calibration, characterization	4 days	1/9/04	1/14/04
201	Ready to start Installation	0 days	2/11/04	2/11/04
202	**X-End (west)**	**47 days**	**2/9/04**	**4/13/04**
203	install X end station pump/fluid lines & He leak t	2 wks	2/9/04	2/20/04
204	evacuate distribution system & fill lines	1 day	2/23/04	2/23/04
205	check-out pump	1 day	2/24/04	2/24/04
206	install X-end BSC 4 mechanicals	3 wks	2/11/04	3/2/04
207	evacuate & fill actuators with fluid	1 day	3/3/04	3/3/04
208	check-out pressure regulation	3 days	3/4/04	3/8/04
209	install VME rack in Lab	1 wk	2/11/04	2/17/04
210	run intra-rack cabling & check	2 wks	2/18/04	3/2/04
211	install cable tray	2 wks	2/11/04	2/24/04
212	install & test field cabling	1 wk	2/25/04	3/2/04
213	install electronics, check out	1 wk	3/3/04	3/9/04
214	perform system identification	1 wk	3/10/04	3/16/04
215	implement control laws & measure isolation pe	2 wks	3/17/04	3/30/04
216	supervisory control check out	1 wk	3/31/04	4/6/04
217	test with full IFO	1 wk	4/7/04	4/13/04
218	x-end HEPI done	0 days	4/13/04	4/13/04



ID	ID	Task Name	Duration	Start	Finish
182	219	**Y-End (south)**	**47 days**	**2/23/04**	**4/27/04**
183	220	install Y end station pump/fluid lines & He leak	1 wk	2/23/04	2/27/04
186	221	evacuate distribution system & fill lines	1 day	3/1/04	3/1/04
187	222	check-out pump	1 day	3/2/04	3/2/04
188	223	Install Y-end BSC 5 mechanicals	2 wks	3/3/04	3/16/04
189	224	evacuate & fill actuators with fluid	1 day	3/17/04	3/17/04
190	225	check-out pressure regulation	3 days	3/18/04	3/22/04
191	226	install VME rack in Lab	1 wk	3/3/04	3/9/04
192	227	run intra-rack cabling & check	2 wks	3/10/04	3/23/04
193	228	install cable tray	2 wks	3/3/04	3/16/04
194	229	install & test field cabling	1 wk	3/17/04	3/23/04
195	230	install electronics, check out	1 wk	3/24/04	3/30/04
196	231	perform system identification	1 wk	4/7/04	4/13/04
197	232	implement control laws & measure isolation pe	1 wk	4/14/04	4/20/04
198	233	supervisory control check out	1 wk	4/21/04	4/27/04
199	234	y-end HEPI done	0 days	4/27/04	4/27/04
200	235	**Corner Station**	**92 days**	**3/1/04**	**7/6/04**
201	236	install VME racks in Clean Storage Rm	2 wks	3/24/04	4/6/04
202	237	run intra-rack cabling & check	4 wks	4/7/04	5/4/04
203	238	install cable tray	2 wks	3/24/04	4/6/04
204	239	install & test field cabling	3 wks	4/7/04	4/27/04
205	240	install electronics, check out	3 wks	5/5/04	5/25/04
206	241	install vertex pump/fluid lines & He leak test	6 wks	3/1/04	4/9/04
207	242	Install BSC 1 mechanical	2 wks	3/17/04	3/30/04
208	243	Install BSC 2 mechanical	2 wks	3/31/04	4/13/04
209	244	Install BSC 3 mechanical	2 wks	4/14/04	4/27/04
210	245	Install H1 mechanical	3 wks	3/3/04	3/23/04
211	246	Install H2 mechanical	2 wks	3/24/04	4/6/04
212	247	Install H3 mechanical	2 wks	4/7/04	4/20/04
213	248	Install H4 mechanical	2 wks	4/21/04	5/4/04
214	249	ITMx	1.5 wks	5/26/04	6/4/04
215	250	ITMy	1.5 wks	6/4/04	6/15/04
216	251	BSC	1.5 wks	6/16/04	6/25/04
217	252	H1	1.5 wks	5/26/04	6/4/04
218	253	H3	1.5 wks	6/4/04	6/15/04
219	254	H2	1.5 wks	6/16/04	6/25/04
220	255	H4	1.5 wks	6/25/04	7/6/04
221	256	HEPI done	0 days	7/6/04	7/6/04



Bold, new idea: train the staff **before** new system is installed

LASTI HAM results (Mittleman)