R&D Overview

David Shoemaker

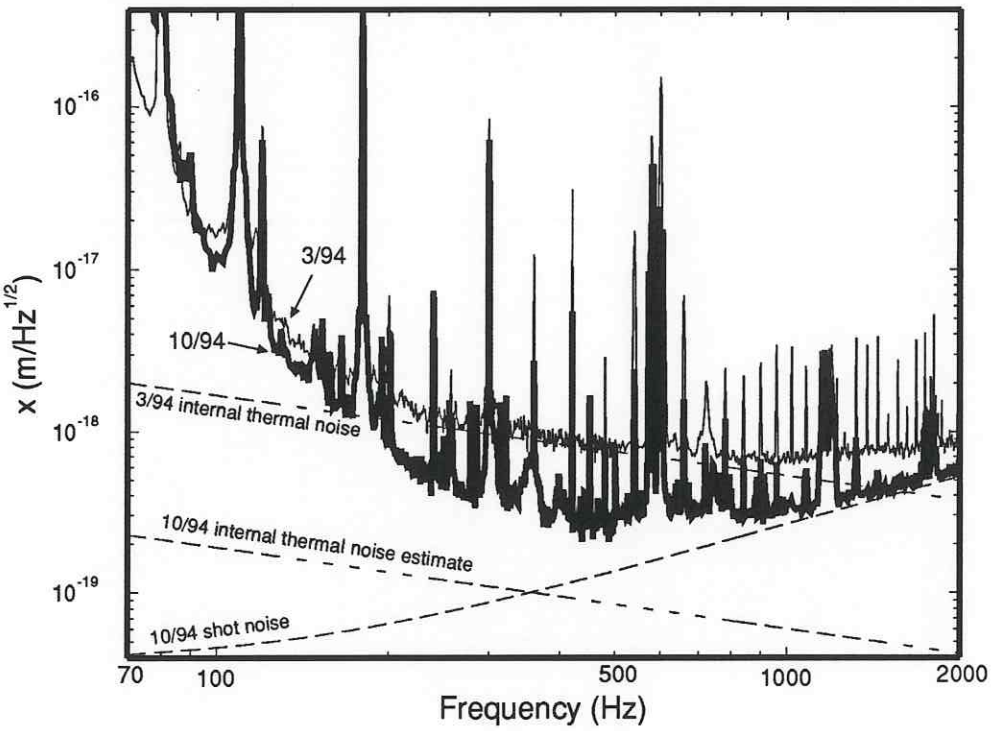
NSF LIGO Review 22 May 95

- Overall Goal of R&D: Support detector technology
  - close coordination with Detector
  - tasks and schedules planned to deliver information when needed
- Highlights of R&D Program since September review
  - more detailed reports tomorrow, 23 May
- Cost and Schedule overview

40m Interferometer Research

THERMAL NOISE STUDIES (Thesis for Aaron Gillespie)

- thermal noise of substrate, pendulum significant for LIGO
  - no direct experimental observations to verify models
  - opportunity to observe in 40m by changing test masses
- thermal noise in compound test masses carefully calculated
  - measurements on 40m in good agreement
- new monolithic masses studied separately
  - coupling of control/sensing magnets/fins, suspension wires...
- installed in 40m
- new (improved!) spectrum consistent with thermal noise model



40m Interferometer Research (con't)

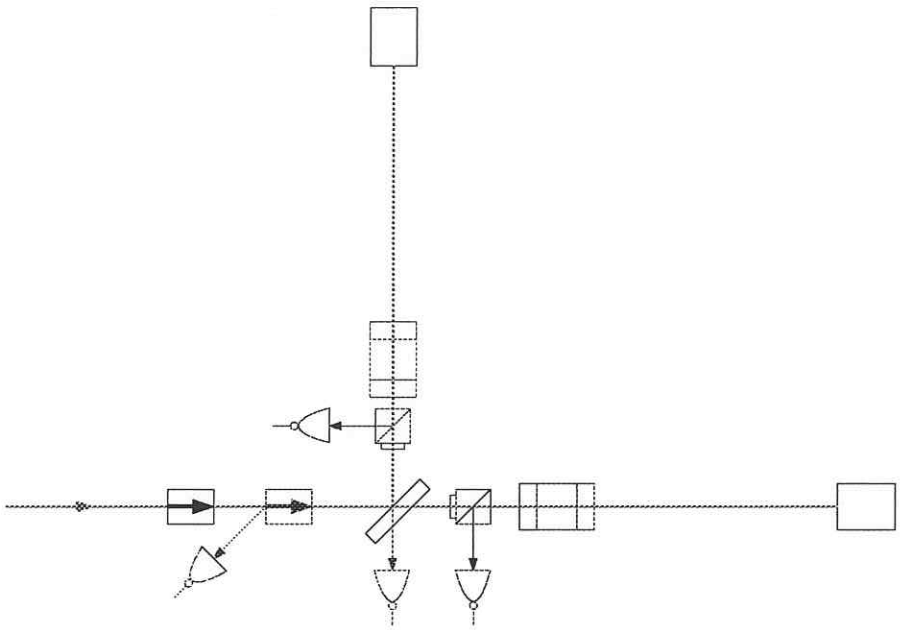
WRAP-UP OF '94 CONFIGURATION CHARACTERIZATION

- long data streams (28 hours)
  - most interferometer data to date in form of spectrum
  - time series more important for real data analysis
  - non-gaussian statistics
  - operational issues
  - analysis for coalescing binaries
- pre-'95 configuration 'done'

40m Interferometer Research (con't)

RECOMBINATION RECONFIGURATION

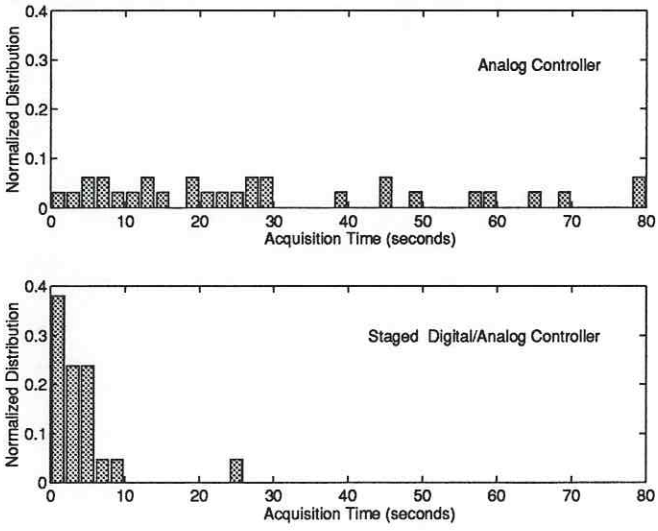
- modeling of LIGO configuration well advanced
- very eager to have experimental verification
  - tests of acquisition and linear control modeling and procedures
  - improved common-mode noise rejection for displacement studies
- status
  - arms asymmetrized for modulation technique
  - arm beams brought to interference on beamsplitter
  - major changes made, debugging/realigning
  - first interference and locking tests underway



40m Interferometer Research (con't)

GUIDED-LOCK ACQUISITION

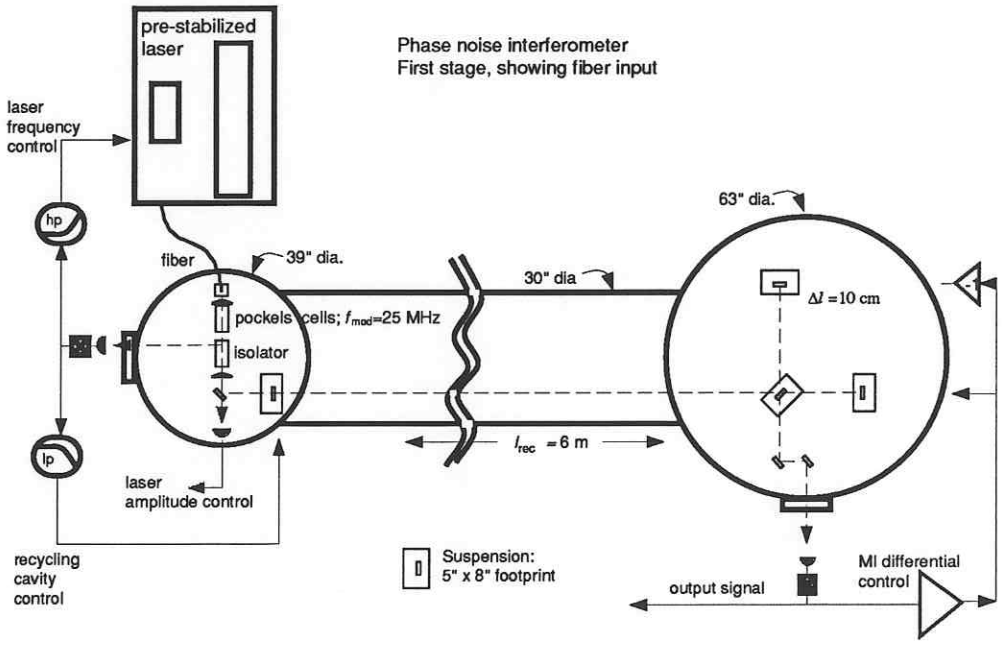
- traditional brute-force method for acquiring 'lock' of cavity
  - system moves very quickly through resonance - non-adiabatic
  - very wide-bandwidth, high-force servo control
  - short effective duty-cycle
- better idea: reduce test-mass velocity
  - analyze signal output in time domain of unlocked system
  - calculate relative velocity of test masses
  - apply force X duration to 'brake' masses
  - THEN acquire lock
- success
  - considerably reduced locking time
  - valuable information for locking strategies
  - good technical experience for hardware/software



Phase Noise Research

OBJECTIVES

- displacement sensitivity under study in 40m
- LIGO requires also high phase sensitivity ($10^{-10}\,\mathrm{rad}/\sqrt{\mathrm{Hz}}$)
  - present 40m uses ~130 mW
  - Garching interferometer functioned with 1 W
  - LIGO requires roughly 75 W
- PNI will demonstrate this sensitivity, at this power
  - confirms shot-noise formula
  - solve many technical problems along the path
  - non-recycled Michelson initial configuration; recycling mid-95



Phase Noise Research (con't)

INTERFEROMETER CONSTRUCTION

- seismic isolation stacks
- vacuum system modifications
- mirror suspensions and control systems
- laser frequency stabilization
- soft-wall clean rooms

STATUS

- first interference observed!
- characterization in air of sensing/control
- close to pumpdown, first low-noise measurements

Phase Noise Research (con't)

CHARACTERIZATION OF ACTIVE ISOLATION SYSTEM

- 'beta' test of commercial system
  - active servo system, measures ground noise, feedback
  - six degrees of freedom
  - at MIT, suppresses local non-stationary noise (trucks, subways...)
  - for LIGO, can reduce controller dynamic range, up-conversion
- system functional
  - required collaborative work between Barry, Inc. and LIGO staff
  - significant reduction in noise: factor 100 in vertical, 2-30 Hz
  - still short of prediction in horizontal, but
  - makes qualitative difference in seismic environment

Some other significant R&D efforts

TABLE-TOP CONFIGURATION STUDIES

- definition of initial LIGO (Thesis for J. Giaime)
- wavefront sensing research
  - first complete test of proposed length control system
  - development of design process for LIGO
  - detailed test of alignment sensor/control system

NUMERICAL OPTICS MODELING

- predictions of signal/noise for real mirror maps
  - leads to specifications for LIGO mirror figure
- working toward studies of advanced configurations
  - good graduate student thesis

SUSPENDED MODE CLEANER

- major review on 21 April
  - culmination of design, construction, characterization
- preparation for moving to 40m lab well underway

TEST MASS *'Q'* MEASUREMENTS

- characterization of internal, suspension thermal noise
- initial measurements just starting
  - scaling of *Q* appears to be understood

Organization, Schedule and Cost

ORGANIZATION, TRACKING

- Stan Whitcomb (leader), David Shoemaker (deputy)
  - both look across project R&D
  - deal with local opportunities, problems locally
- goals, means, milestones negotiated in yearly SOWs
- monthly reports from major tasks
- take earned value for milestones achieved

STATUS

- most projects on schedule, some several-week delays
- delays mostly 'R&D' causes
  - discoveries requiring new procedures/meriting further research
  - longer debugging/analysis times
- no present/anticipated delays with impact on LIGO schedule

COST

- standard report includes history of R&D
  - big offset from previous years cost/performance
  - fractional variances small
- more detailed study shows good budget/performance

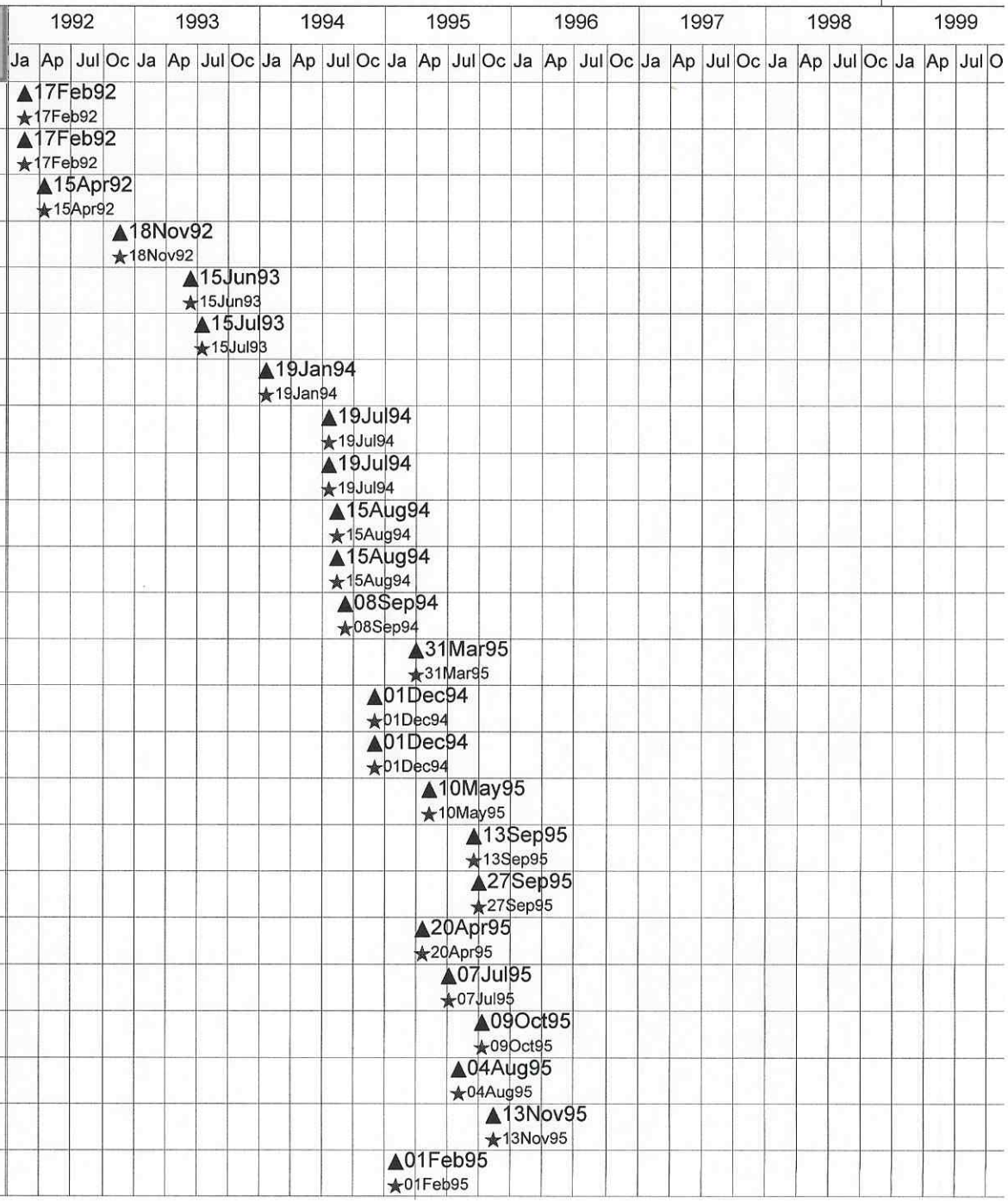
Start:	01Apr95	Milestone	▲
Finish:	01Apr95	BaselineMS	★
Time Now:	01Apr95		
Project:	Untitled #1		
Run:	18May95		
Page:	1 of 5		

Research & Development

Open Plan Professional by Welcom Software

LIGO

Activity ID	Activity Desc.	WBS
13210020	THESIS - P. FRITSCHEL	1.3.2.1
13210030	THESIS - M. STEPHENS	1.3.2.1
13210040	PAPER IN SCIENCE - "LIGO..."	1.3.2.1
13210050	NSF TECHNICAL REVIEW	1.3.2.1
13210120	NSF TECHNICAL REVIEW	1.3.2.1
13210130	PAPER IN PHYSICS LETTERS A-"THERMAL..."	1.3.2.1
13220020	THERMAL NOISE WORKSHOP AT CALTECH	1.3.2.1
13220030	SNOWMASS WORKSHOP	1.3.2.1
13220040	PAPER IN PHYSICS LETTERS A-"SUSPENSION."	1.3.2.1
13220050	THESIS - J. KOVALIK	1.3.2.1
13220060	THESIS - M. REGEHR	1.3.2.1
13220070	NSF TECHNICAL REVIEW	1.3.2.1
13220105	M/C LAB TEST COMPLETED	1.3.2.2.1
13220110	M/C ACCEPTANCE REVIEW	1.3.2.2.1
13220115	M/C DESIGN OF VACUUM HDWR COMPLETED	1.3.2.2.1
13220120	M/C PROCUREMENT OF NEW VACUUM ITEMS COMP	1.3.2.2.1
13220125	M/C PUMP DOWN WITH STACK SUPPORTS	1.3.2.2.1
13220130	M/C STACK INSTALLATION COMPLETE	1.3.2.2.1
13220140	M/C DECISION ON BEAM CONTROL UNITS	1.3.2.2.1
13220145	M/C B/C OPTICAL COMPONENTS IN HOUSE	1.3.2.2.1
13220150	M/C ALIGNMENT OF B/C COMPONENTS COMPLETE	1.3.2.2.1
13220155	M/C LASER LOCKED TO REFERENCE CAVITY	1.3.2.2.1
13220160	M/C LASER LOCKED TO MODE CLEANER	1.3.2.2.1
13220165	M/C NEW ELECTRONIC MODULE DESIGN COMP	1.3.2.2.1



Start:	01Apr95	Milestone	▲
Finish:	01Apr95	BaselineMS	★
Time Now:	01Apr95		
Project:	Untitled #1		
Run:	18May95		
Page:	2 of 5		

Research & Development

Open Plan Professional by Welcom Software

LIGO

Activity ID	Activity Desc.	WBS	1992				1993				1994				1995				1996				1997				1998				1999			
			Ja	Ap	Jul	Oc	Ja	Ap	Jul	Oc	Ja	Ap	Jul	Oc	Ja	Ap	Jul	Oc	Ja	Ap	Jul	Oc	Ja	Ap	Jul	Oc	Ja	Ap	Jul	Oc	Ja	Ap	Jul	O
13220170	M/C NEW SERVOS OPERATIONAL INDIVIDUALLY	1.3.2.2.1																	▲27Dec95 ★27Dec95																
13220175	M/C NEW SERVOS FULLY OPERATIONAL	1.3.2.2.1																	▲11Jan96 ★11Jan96																
13220180	MODE CLEANER TEST REVIEW	1.3.2.2.1																	▲11Jan96 ★11Jan96																
13220305	40m TMS DESIGNED FINALIZED	1.3.2.2.2														▲15Jun95 ★15Jun95																			
13220310	40m TMS DESIGN REPORT COMPLETED	1.3.2.2.2														▲29Jun95 ★29Jun95																			
13220316	40m TMS FAB OF MECH PARTS & ELECT COMPL.	1.3.2.2.2															▲29Aug95 ★29Aug95																		
13220321	40m TMS MECH FIT CHECK/ELECT CHECK COMPL	1.3.2.2.2															▲01Sep95 ★01Sep95																		
13220326	40m TMS OPS CHECK WITH DUMMY MASS COMPL	1.3.2.2.2															▲18Sep95 ★18Sep95																		
13220330	40m TMS BALANCING COMPLETE	1.3.2.2.2															▲26Sep95 ★26Sep95																		
13220335	40m TMS VACUUM PREPARATION COMPLETE	1.3.2.2.2															▲11Oct95 ★11Oct95																		
13220340	40m TMS FAB OF ONE PROTOTYPE COMPLETE	1.3.2.2.2															▲11Oct95 ★11Oct95																		
13220345	40m TMS PROTOTYPE BENCH ASSEMBLY COMP	1.3.2.2.2															▲02Oct95 ★02Oct95																		
13220350	40m TMS PROTOTYPE INSTALLATION COMPLETE	1.3.2.2.2															▲09Oct95 ★09Oct95																		
13220355	40m TMS PROTOTYPE CHARACTERIZATION COMP	1.3.2.2.2															▲30Oct95 ★30Oct95																		
13220365	40m TMS PROTOTYPE TEST REVIEW	1.3.2.2.2															▲29Nov95 ★29Nov95																		
13220370	40m TMS DESIGN MODS COMPLETE (AS REQ'D)	1.3.2.2.2															▲30Nov95 ★30Nov95																		
13220376	40m TMS REV DESIGN REPORT COMP(AS REQ'D)	1.3.2.2.2															▲15Dec95 ★15Dec95																		
13220380	40m TMS FAB REMAINING SUSPENSIONS COMP	1.3.2.2.2																	▲29Feb96 ★29Feb96																
13220385	40m TMS INSTALLATION/SHAKEDOWN COMPLETE	1.3.2.2.2																	▲30Apr96 ★30Apr96																
13220390	40m TMS FINAL REPORT COMPLETE	1.3.2.2.2																	▲28May96 ★28May96																
13220402	PNI SOFTWALL CLEANROOM INSTALLED	1.3.2.2.5													▲31Mar95 ★31Mar95																				
13220404	PNI VAC SYS SUPPORT STRUCTURE INSTALLED	1.3.2.2.5													▲03Jan95 ★03Jan95																				
13220406	PNI SEISMIC ISO STACKS INSTLD IN VAC SYS	1.3.2.2.5													▲01Feb95 ★01Feb95																				
13220408	PNI SEISMIC ISO SYS ACTIVE ISOs INSTLD	1.3.2.2.5													▲15Mar95 ★15Mar95																				

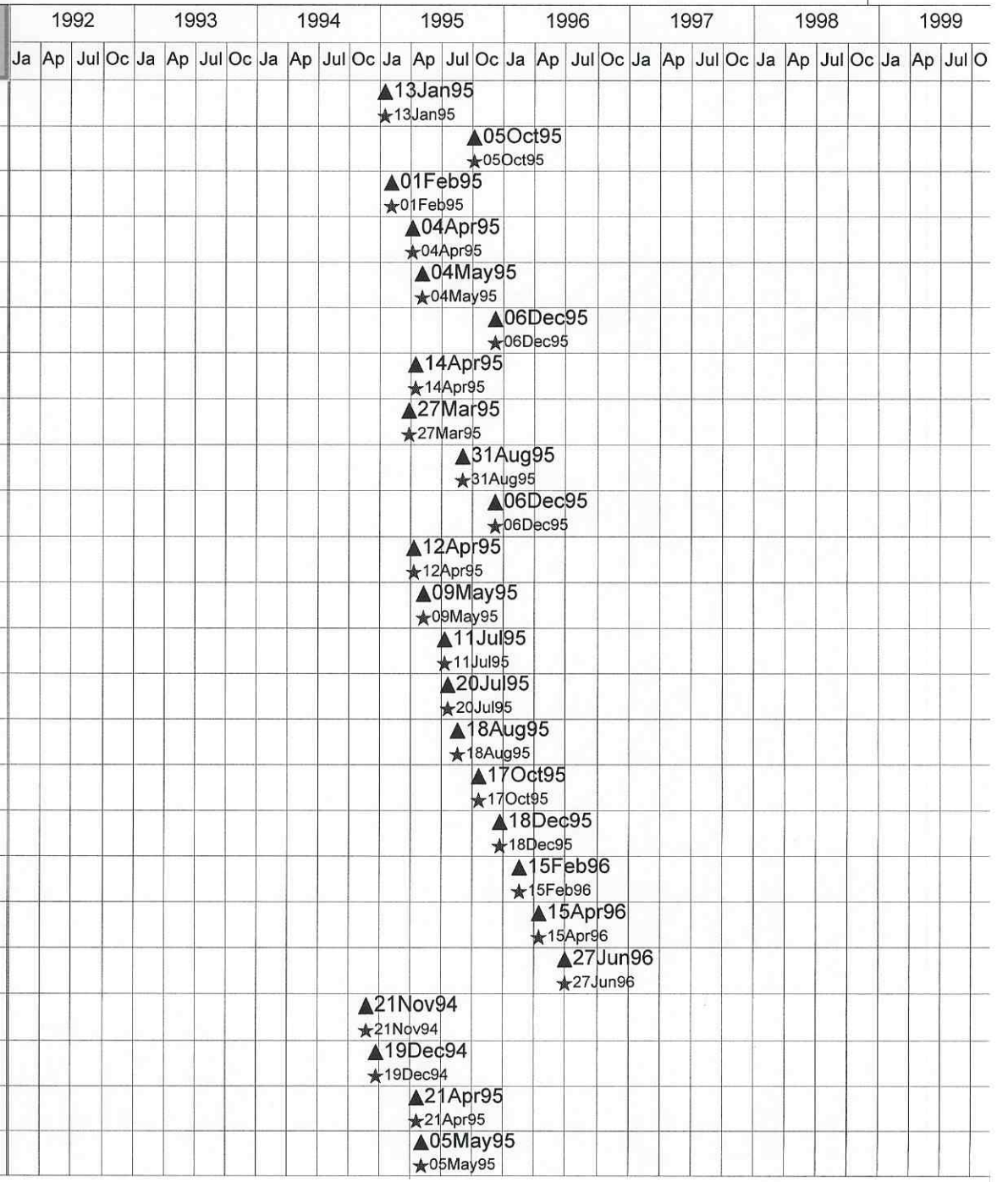
Start:	01Apr95	Milestone	▲
Finish:	01Apr95	BaselineMS	★
Time Now:	01Apr95		
Project:	Untitled #1		
Run:	18May95		
Page:	3 of 5		

Research & Development

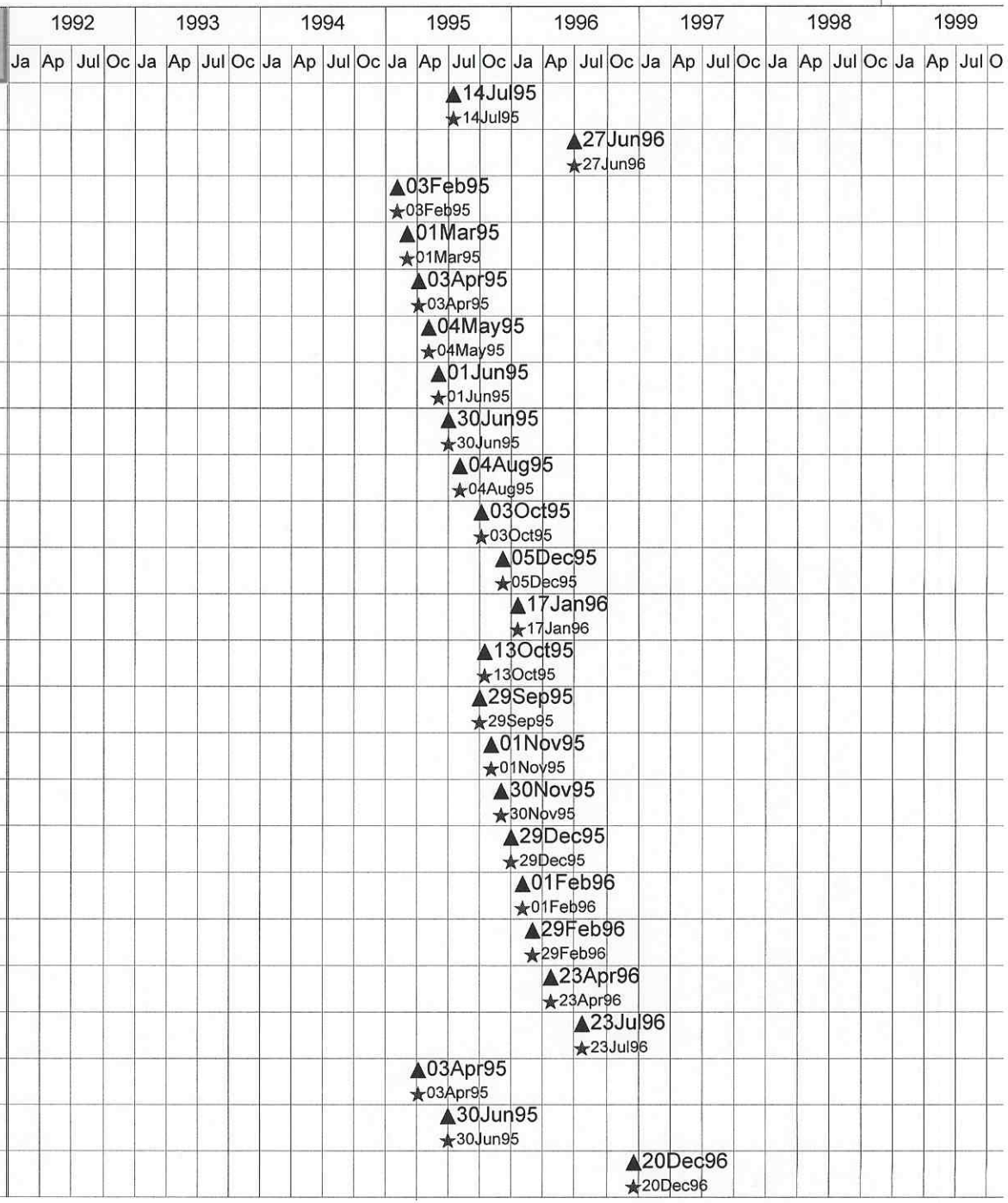
Open Plan Professional by Welcom Software

LIGO

Activity ID	Activity Desc.	WBS
13220410	PNI SUSPENSION CONTROL TEST CONCLUDED	1.3.2.2.5
13220412	PNI MODE CLEANER SUSPENSION ELEC RECD	1.3.2.2.5
13220414	PNI LASER LOCKED TO REF CAVITY	1.3.2.2.5
13220416	PNI IN-VACUUM CABLING INSTALLED	1.3.2.2.5
13220418	PNI PHASE SENSING/CNTRL ELECRONICS READY	1.3.2.2.5
13220420	PNI MODE CLEANER SERVO ELECTRONICS READY	1.3.2.2.5
13220422	PNI IN-VACUUM INPUT OPTICS INSTALLED	1.3.2.2.5
13220424	PNI MODE CLEANER COATINGS ORDERED	1.3.2.2.5
13220426	PNI MODE CLEANER COATED MIRRORS DELVRD	1.3.2.2.5
13220428	PNI MODE CLEANER IN/OUTPUT OPTICS READY	1.3.2.2.5
13220430	PNI MICHELSON SUSPENDED OPTICS INSTALLED	1.3.2.2.5
13220432	PNI NON-RECYCLED MICHELSON OPERATIONAL	1.3.2.2.5
13220434	PNI PERF RPRT ON NON-RECYCLED MICHELSON	1.3.2.2.5
13220436	PNI RECYCLING MIRROR INSTALLED	1.3.2.2.5
13220438	PNI RECYCLED MICHELSON OPERATIONAL	1.3.2.2.5
13220440	PNI PERF REPORT ON RECYCLED MICHELSON	1.3.2.2.5
13220442	PNI RECYCLED MICHELSON TESTS COMPLETE	1.3.2.2.5
13220444	PNI MODE CLEANER INTEGRATION COMPLETE	1.3.2.2.5
13220446	PNI OPERATIONAL	1.3.2.2.5
13220450	PNI TEST REVIEW	1.3.2.2.5
13220505	40m RCB DESIGN COMPLETE	1.3.2.2.4
13220510	40m RCB ARMS MOVED	1.3.2.2.4
13220520	40m RCB OPTICS INSTALLATION COMPLETE	1.3.2.2.4
13220525	40m RCB FIRST DISPLACEMENT SPECTRUM	1.3.2.2.4



Activity ID	Activity Desc.	WBS
13220530	40m RCB SHAKEDOWN COMPLETE	1.3.2.2.4
13220605	RECYCLING TEST REVIEW	1.3.2.2.4
13220702	FMIWF LASER FREQ STABILIZATION OPERATION	1.3.2.2.6
13220704	FMIWF LASER/MODULATION SYSTEM COMPLETE	1.3.2.2.6
13220706	FMIWF CONCEPTUAL DESIGN COMPLETE	1.3.2.2.6
13220708	FMIWF IFO DETAILED CONFIG COMPLETE	1.3.2.2.6
13220710	FMIWF POINTING/ACTUATORS/WF FAB COMP	1.3.2.2.6
13220712	FMIWF MECH MODS(CLEAN AIR/STIFFNRS) COMP	1.3.2.2.6
13220714	FMIWF INTERFEROMETR OPTICS ALIGNED	1.3.2.2.6
13220720	FMIWF INDIVIDUAL CAVITY LOCKED	1.3.2.2.6
13220722	FMIWF MICHELSON LOCKED	1.3.2.2.6
13220725	FMIWF IFO LENGTH CNTRL OPERATION	1.3.2.2.6
13220727	FMIWF POINTING SYSTEM INSTALLED/CALIB	1.3.2.2.6
13220729	FMIWF ALIGNMENT SENSORS INSTALLED	1.3.2.2.6
13220731	FMIWF ALIGNMENT SENSORS COMPLETE	1.3.2.2.6
13220733	FMIWF COMPUTER PHYSICAL INTERFACE COMPL	1.3.2.2.6
13220735	FMIWF COMPUTER S/W COMPLETED & TESTED	1.3.2.2.6
13220737	FMIWF FIRST ALIGNMENT DATA	1.3.2.2.6
13220741	FMIWF 1st ALIGN SIGNAL MATRIX CALCULATED	1.3.2.2.6
13220744	FMIWF QUANT DISCRIMINANT MATRIX COMPL	1.3.2.2.6
13220746	FMIWF EXPERIMENT DOCUMENTATION COMPLETE	1.3.2.2.6
13220750	FMIWF REPORT-THEORY OF WVFNT SENSING DUE	1.3.2.2.6
13220755	FMIWF REPORT-FMI DETAILED DESIGN	1.3.2.2.6
13220765	FMIWF FINAL REPORT (PhD THESIS)	1.3.2.2.6



Milestone ▲
BaselineMS ★

Research & Development

Open Plan Professional by Welcom Software

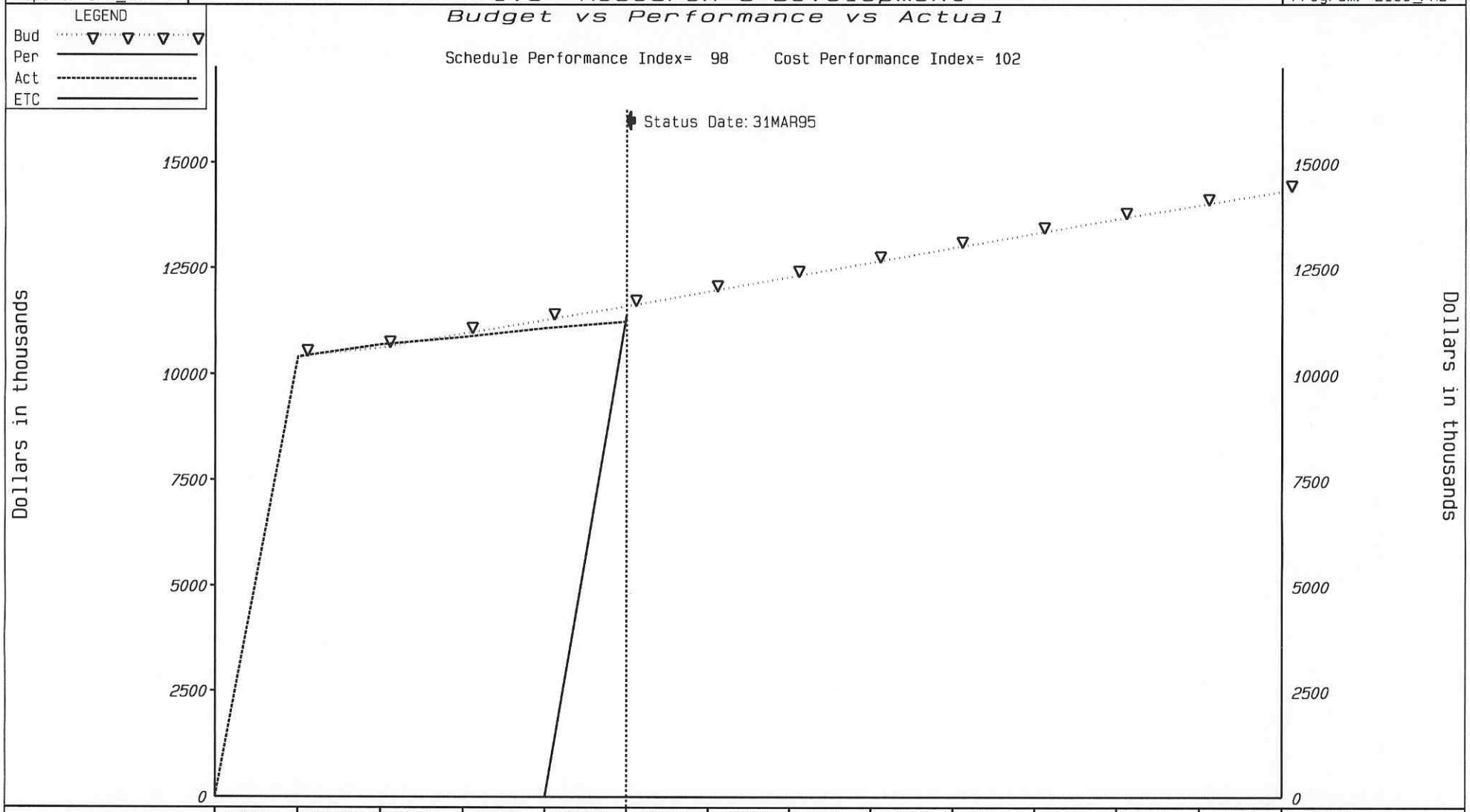
LIGO

Activity ID	Activity Desc.	WBS
13220905	PFQ T/M FIXT INITIAL FIT-CHCK (UNBAKD)	1.3.2.2.7
13220910	PFQ BAKED TEST MASS FIXTURE READY	1.3.2.2.7
13220915	PFQ VACUUM TEST COMPLETE	1.3.2.2.7
13220920	PFQ E/S DRIVE BOARD/CABLNG ELEC TST COMP	1.3.2.2.7
13220930	PFQ FIRST Qs-SIMPLE SINGLE LOOP SUSP	1.3.2.2.7
13220935	PFQ CHARACTERIZATION MEASUREMENTS COMP	1.3.2.2.7
13220940	PFQ MEASUREMENT RESULTS ANALYZED	1.3.2.2.7

COBRA (R)
Report: SPA_XM

LIGO PROJECT
1.3 Research & Development
Budget vs Performance vs Actual

Date: 18MAY95
Program: LIGO_PMB



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	10,407	10,609	10,935	11,258	11,586	11,935	12,285	12,636	12,992	13,337	13,681	14,007	14,326	K$
Performance	0	0	0	0	11,397									K$
Actual/Forecast	10,407	10,683	10,854	11,069	11,225									K$
Schedule Variance	-10,407	-10,609	-10,935	-11,258	- 189									K$
Cost Variance	-10,407	-10,683	-10,854	-11,069	172									K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index= Perf/Budg Cost Performance Index= Perf/Actual

*** Prepared by LIGO Project Controls Group ***