#39

List of 3/1/89

MEMO:phaseaop.tex
FROM: RW (Started December 17, 1988 completed December 30,1988)
TO: W.Althouse and F.Raab
CONCERNING: Draft on Phase A Operations

ASSUMPTIONS BEING MADE

1) LIGO schedule:

Design freeze of initial interferometer 4/91

Facilities at first site complete 1/94

Facilities at second site complete 1/95

THE STATE OF INTERFEROMETER RESEARCH BEFORE THE DESIGN FREEZE

1) The position sensitivity of a prototype at 1×10^{-17} cm/sqrt(Hz) between 100Hz to several kHz, a factor of 10 to 50 better than the performance of any interferometer at present, be demonstrated.

2) The optics for a 4 km system be demonstrated; the large mirrors tested, the mode matching optics and Pockel's cells at the requisite power of 10 watts.

3) The servo systems assembled and tested for beam pointing, position and fringe control.

4) 10 watts of input power demonstrated.

5) Recombination and recycling demonstrated with optics of the LIGO scale

6) Vibration isolation demonstrated at 100 Hz to achieve the initial sensitivity goal using LIGO size mirrors and test masses.

If this has not been accomplished by the design freeze, the estimates made later for the effort in the design and construction of the initial interferometer need to be changed.

PEOPLE INVOLVED IN SCIENCE AND TECHNOLOGY OF THE LIGO

Type of people	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Direction and management	3	3	3	3	3	3	3	3	3	3
PhD Scientists	11	11	12	12	12	12	12	12	12	12
LIGO Engineering	4	4	5	5	5	5	5	5	5	5
Technical support	5	6	6	6	6	6	6	6	6	6
Graduate Students	6	6	7	7	8	8	8	8	8	8
Site specific people	0	0	0	0	1	3	4	6	6	6

RESPONSIBILITIES OF THIS GROUP

A) INTERFEROMETERS

Beginning in summer of 1991, providing that the research requirements given above under expectations for the interferometer development prior to final design, have been met; the group will be involved in: the formal design, procurement and qualification of parts, construction, and testing of the initial interferometer. My expectation is that only part of the job can be done in industry and the bulk of the testing and construction will reside with the LIGO research group guided and organized by the project office. The formal design of the interferometer will result in: a set of drawings for mechanical, electronic and optical subsystems, a work breakdown structure and schedule, the design of the interferometer subsystem interfaces, a list of the required documentation, and the assignment of responsibility for each subsystem. The design will last 1 year and be completed in the summer of 1992. The various interferometer subsystems will be contracted to the research groups and tracked by the project office.

Estimates for manpower required in design and construction of the initial interferometer

Item or subsystem	Internal man years	Fraction of effort in industry
Interferometer design (analysis,drawings,WBS,schedule)	20	0.1 (optical design)
Isolation and suspensions systems	3	0.0
Pointing and alignment systems	2	0.0
Laser stabilisation and power enhancement	2	0.0
Optics testing facility design	1	0.2
Optics testing facility construction	1	0.3
Mirror testing and qualification	2	0.2
Optical component testing and qualification	2	0.2
Sensor development,fabrication and test	2	0.5 (fabrication)
Electronics fabrication and test	4	0.8 (fabrication)
Instrumentation system hardware	1	0.9
Instrumentation system software	2	0.0
Simulation,modelling and test for extrapolation	2	0.1 (ext.facilities)
Home facilities upgrade,design	2	0.0
Home facilities upgrade construction installation	3	0.5
Monitor and guide interf.construction	2	0.0
Documentation	1	0.0
TOTAL	52	

NOTE: The estimated internal manpower in the second column assumes that the fraction of effort in industry given in the third column is included in the effort.

The installation, testing, operation of the initial interferometer will be the job of the LIGO scientific team augmented by the project engineering staff. I expect that the initial receiver installation at both sites, diagnostic studies, qualification of the environmental monitoring system, debugging of the data acquisition and logging system and the preparation for initial data analysis will take a minimum of 3 years after the first site becomes operational.

A major part of the task is the online software for data acquisition and logging, correlation analysis and diagnostic studies, and quick look capabilities. The off line data analysis software and bebugging is another substantial effort. The tasks associated with facility design and shakedown are listed separately but they are intimately coupled to the interferometer. The division between facility and interferometer tasks in this listing is therefore somewhat arbitrary.

Estimates for manpower in initial interferometer installation
and operation in initial gravitational wave search

Item or subsystem	Man years internal	Fraction of effort in industry
Interferometer installation (two sites) (first install.,debugging,iteration)	10	0.0
Interferometer diagnostic tests	8	0.0
Diagnostic software	2	0.0
Data analysis system design	1	0.5
Data analysis system hardware	0.5	0.5
Initial data analysis software	3	0.0
Monitor and guide installation	2	0.0
Documentation	1	0.0
TOTAL	27.5	

B) FACILITIES

I assume that the LIGO scientific and engineering staff will be responsible for design, monitoring the construction and qualification, and the shake down of the facilities. I arbitrarily divide the work in facility design and construction between functions which a general contractor should be able to handle with guidance provided by periodic reviews, such as the civil, power distribution and gross architectural work, and that part which requires more than cursory knowledge of the LIGO requirements. The facility subsystems that will consume the most LIGO staff time are: the tube vacuum, the instrumentation tank vacuum, power distribution conditioning and grounding, environmental control, environmental monitor, laser cooling, interferometer/facility mechanical interface, interferometer/facility electrical interface, instrumentation and data acquisition, facility control, data logging and archiving, and communications. The documentation is also a time consuming task.

Estimates for manpower on facilities design, construction and qualification

Item or subsystem	Man years internal	Fraction of effort in industry
Monitor and guide contractors (civil,architectural,electrical)	15	0.0
Tube vacuum system design	1	0.5
Tube vacuum system qualification	2	0.5
Instrumentation tank vacuum design	1	0.5
Instrumentation tank vacuum qual.	1	0.2
Interferometer/facility mech.intf.design	1	0.0
Interferometer/facility mech.intf.qual.	1	0.2
Interferometer/facility elec.intf.design	2	0.0
Interferometer/facility elec.intf.qual.	2	0.0
Laser cooling design/qual.	1	0.8
Power conditioning/grounding design	0.5	0.5
Environmental control design	0.5	0.8
Environmental control qual.	0.5	0.0
Noise monitoring system design	2	0.0
Data acquisition system design	1	0.5
Data storage and archiving system design	0.5	0.5
Noise monitoring system hardware	2	0.0
Data acquisition system hardware	1	0.8
Data storage and archiving system hardware	1	0.8
Data acquisition and monitoring software	5	0.0
Facility control system design	1	0.5
Facility control system qual.	1	0.0
Communications system design	0.5	0.8
Communications system hardware/software	1	0.8
Documentation	3	0.0
TOTAL	47.5	

The job ahead of us is substantial, the numbers in the estimates even though they are guesses indicate, to me, that we are not in a position to contemplate much more than the barest essentials in the initial operations unless the number of people on the project, especially in engineering, can grow. The guess of three years after the initial facility becomes operational before anything but a single interferometer is in operation at both sites seems (unfortunately) reasonable. By my reckoning this does not allow much development of a second generation interferometer once the design of the initial interferometer is frozen. The development work could proceed in earnest in 1996 as more of the operational load becomes transferred to new people who have been trained.

SPECIFIC ISSUES CONCERNING THE INITIAL OPERATIONS

1) The initial development and search interferometer

I make the operation of a full length interferometer at each of the two sites the highest priority effort and the major goal of the initial operations. This is the most likely effort to give credible scientific returns.

I assume that the initial interferometer will be a system with sensitivity similar to that described at the NSF visting committee meeting last winter and in the letter to Ken Nordtvedt of the NSB. It will be predominantly a broadband system with sensitivity in the 100 Hz to a few kHz band with a burst sensitivity around $h \approx 10^{-21}$. A meaningful astrophysical sensitivity which would be important even if it gave a null result. The prime effort of the initial operations will be to get two interferometers, one at each site, working and running in coincidence. The data will be stored so that search for periodic sources at the galactic center and several other likely locations in our galaxy can be made along with the burst search. Unless new astrophysical information is discovered between now and then I see no reason to change our goal. The state of the other detectors in the world, bars and interferometers, does set a threshold only if their sensitivity is better than our goal. I give this a very small probability.

The philosophy of the initial receiver design should be that we have done as careful a job with engineering and testing those parts of the interferometer which do not require the additional length as possible. This is where the thoughtful mechanical and electronic design for reliability comes in. We should not be in a position where those components which we already know and understand are marginal in performance. The problems with the interferometer at the pre LIGO installation phase should become only those associated with the scaling to the larger length and smaller angles. I assume that we will want to devise tests that allow us to gain confidence in the scaling ahead of time. For example: that we will want to measure mirror figure and coating scattering and loss so as to predict the performance at 4 km, simulate the time constants for servo systems with the time scaling to the LIGO, measure the behaviour of pointing and postioning system at angles as small as those needed in the LIGO.

The capability to simulate and devise tests that relate to the scaling also influence the initial operations. I expect that most of the development work on new interferometer designs can really take place in the home facilities. The usefulness of the home facilities is bound to be enhanced by the degree to which information derived from initial operation in the facilities can actually be translated into parameters in the optics and lasers that are measurable in such tests. As we become more experienced, there really should not be mysteries in the technology. For example, a mirror figure error will translate into a specific scattering amplitude which can then be propagated through the known optical transfer function of the LIGO beam tubes, a laser beam wiggle will produce a known amount of fringe phase shift and so forth. The predictive capabilities of careful measurement coupled to modelling and simulation will pay large dividends in the operations and in the speed with which we can diagnose and iterate interferometer designs and increase sensitivity.

2) Other Interferometers

If prior experience with the prototypes is a guide, I expect that a large part of the initial operations will be dedicated to understanding the noise both Gaussian and non Gaussian in the interferometers. We will be in a better situation than we have been in the prototypes up to now. The facilities will be well instrumented and there will have been a substantial effort made in developing on line analysis software and other diagnostic and display tools so that it should be easier to diagnose the performance of the interferometer. The archiving of environmental data along with the interferometer signals and interferometer houskeeping information should make correlation and regression analyses a great deal less time consuming and more meaningful than is our current experience. With this resource we should be able to look into the non Gaussian tail of rare events and be able to determine their origin and thereby reduce the accidental coincidence rate between the interferometers at the two sites.

The operation of another interferometer, full length or fractional length, at the same site helps in the discrimination of the non Gaussian tail events. As Ron and Peter indicate fractional length interferometers may even help in discriminating whether non Gaussian tail events of large amplitude are gravitational waves by their correlation with the main interferometer, providing that other noise terms do not have the same amplitude ratio and that the signal to noise in the shorter interferometer is adequate to perform the correlation quantitatively. My preference is to understand the noise source and monitor it directly. This usually has a larger signal to noise in the correlation than to correlate two noisy channels and may lead to a direct cure. However, the noise may be due to fluctuations in a variable we are not monitoring or have not imagined. This is the strongest motivation to run a second interferometer at the same site especially during the initial diagnostic phase. If a choice must be made I make this a lower priority primarily since it complicates the initial interferometer, doubles the construction and installation effort and increases the data rate to gain information which has a good chance of being obtained by other methods (environmental monitoring system) explicitly put into the facility design.

The capability to simultaneously develop new interferometers while carrying out a search program is a valuable feature of the present conceptual design. I view it as important in the later part of phase A operations when we begin to have the time and manpower to improve on the search system. I don't imagine the capability being utilized until three years after the completion of the first facility. I expect that the major part of new interferometer development will take place in enhanced facilities at the home institutions. These facilities will become increasingly more effective as we know more about operations in the large facility and understand better the critical parameters in the interferometers that influence their performance in the large system. I assume the development instrumentation tanks of the large facility will be used primarily in final tests of a new interferometer prior to converting it to the search system.

3) The Second Site

The project becomes a great deal less interesting and also more risky if we do not have a second site, under our control, functioning in the initial operations. I feel so strongly about this because I don't believe we have a scientifically good leg to stand on to claim a measurement of gravitational wave bursts unless we have coincident events at two separated sites where the environmental noise is *shown* to be uncorrelated.

This viewpoint drives several factors in the initial operations. There should be as little delay as possible in bringing the second site on line. The initial interferometer build should be for two complete devices even though this entails the risk that the mistakes are duplicated. This may not be as devastating as it sounds since the individual risky components, I assume primarily the optics, will not be driving the project costs. Furthermore, the most time consuming part of testing is usually the setup and not the tests themselves. The early availability of the second site enhances the diagnostic studies of non Gaussian tails in the interferometer output in interesting ways. Not only does it let us get at noteworthy events which may be gravitational wave bursts right from the start, thereby guiding us to the most important noise sources or possibly a discovery; but also the second site provides another set of variables for the study. The same apparatus is being exposed to different environmental noise at different solar times at two places, this must help in being able to diagnose the troublesome large amplitude but low duty cycle noise. The analysis of the "stationary" noise processes that influence the interferometer performance is better carried out locally.

This vision of the role of the second site puts demands on the timing of data logging at the two sites and the ease of data transfer throughout the project. (The cost,noise,bandwidth and timing stability of direct communications links between the sites and home facilities is still a subject for conceptual design study). We will have to prove by direct measurements that the environmental monitoring signals at the two sites are indeed uncorrelated.

Assuming that we will continue to be manpower limited (but not idea limited); it is not necessary, in the initial operations, to have the two sites completely the same. In particular, there is some logic in having only one site with the capability for simultaneous search and development. I say this with some misgiving since I am sure there will be a time, most likely not in the initial phase, when we will want to try several different approaches to improving sensitivity or test specialized interferometer concepts. It may, however, be hard to argue the case for improved home facilities while at the same time argue for this dual capability at both sites.