Progress Report on Optical Simulations for the 40m, Advanced LIGO (LIGO II), and future LIGO Configurations Using FFT.

California State University Dominguez Hills
Elementary Particles and Relativity Group

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LSC Meeting-8 at Baton Rouge, LA, advanced interferometer configurations (AIC) committee meeting.

by Ken Ganezer for CSUDH/ EPRG.

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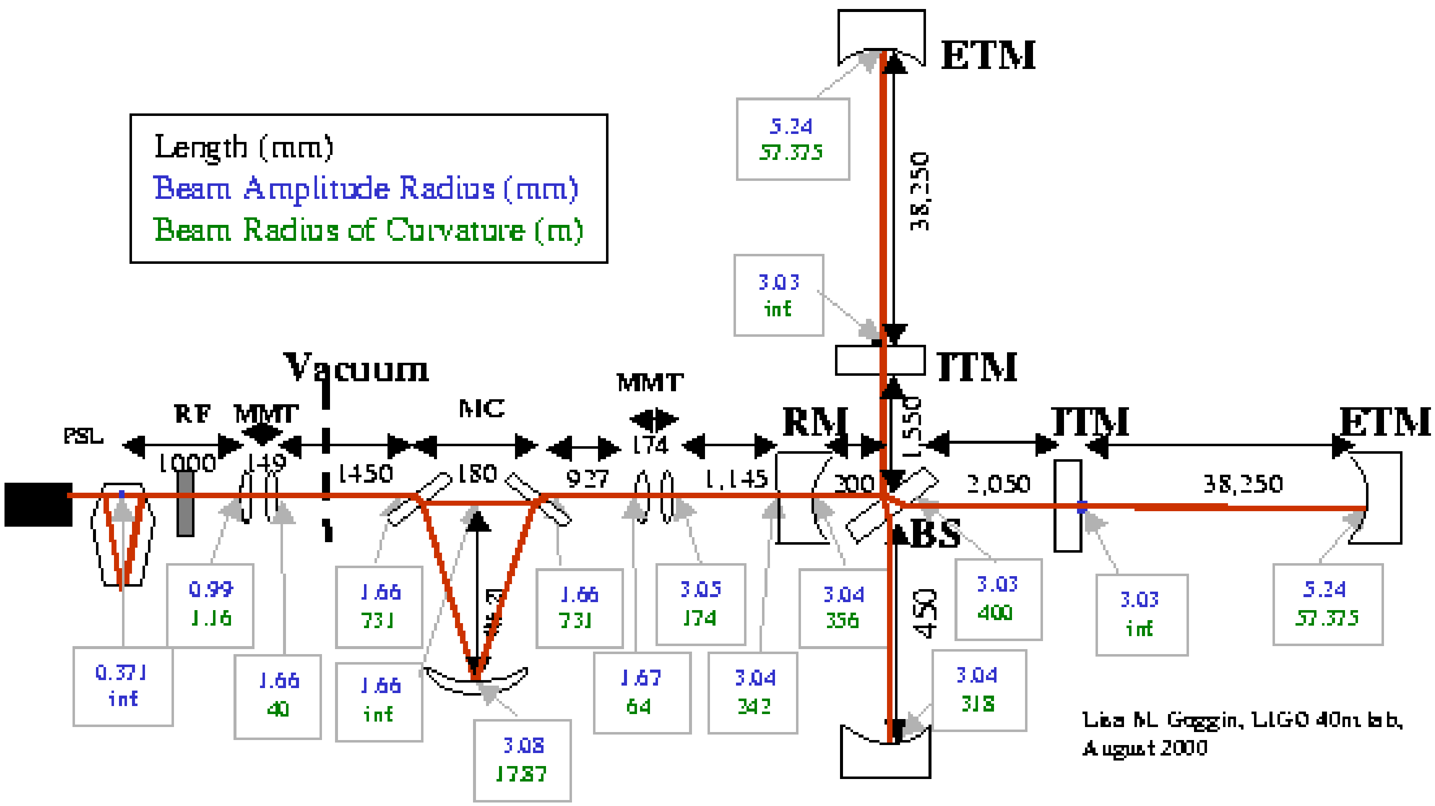
FFT

- **The (Iterative) Relaxation code that models the steady-state electric fields in a LIGO interferometer that was used by Brett Bochner to show that rms deformations of less than 1 nm were needed for LIGO-I optical components and was developed by Brett and several others.**
- **Uses Fast-Fourier Transforms to propagate fields, thus the name.**

Figure-1. (compiled by Lisa Goggin, Caltech Sumer 2000 SURF student). **A schematic of the upgraded Caltech 40m IFO. The distances between various optical elements are given.** This figure also contains the beam amplitude radius and the radius of curvature for all optical elements



MPI Version of Dual Recycling FFT Now Running on CACR HP-V Class Cluster With and Without Zernike Polynomial (Z(n,l)) Deformations

- **Results that are consistent with Analytical Calculations for 40m configuration; for 1 Watt carrier excitation power ~ 5400 W in both FP arms, 14 W in power recycling cavity (PRC) and at symmetric port, 0 W in Signal Recycling Cavity (SRC) for no Schnupp Asymmetry (SA).**
- **For Currently planned SA similar results except ~ .28 W in SRC.**
- **We also get results for LIGO II that are consistent with previous work of Bochner (will check carefully).**

Imperfect Optics Using Zernike Polynomials

- **Z(5,1) deformations one ITM for 40m with and without SA for amplitude 1064nm/300 deformations.**
- **Obtain an FP contrast defect (CD) of 1.7 x 10^{-4}. Coincidentally, Bochner obtained a CD of 1.36 x 10^{-4} for similar deformations of amplitude 514nm/300 and LIGO-I.**
- **With these deformations we obtain ~ 10^{-3} W of non TEM_{00} (higher mode) light in SRC for no SA and 8 x 10^{-2} W for planned 40m SA.**
- **Bochner checked LIGO-I Zernike results with a perturbation theory (analytical 2nd order) calculation of Saha and Weiss (1995). Could do similar check for LIGO-II?**

Some Other Issues Concerning DR FFT

- **MPI DR FFT is fast. It takes about 5 minutes of run-time for a 4 node run on CACR V-class with imperfect optics for no SA. V-Class has 128 nodes , 16 or 32 can be reasonably requested. Including SA increases computation time by a factor of 4 and number of iterations in relaxation scheme by a factor of more than 10.**

- **GW sideband power calculations currently assume a h=1; to get realistic (non-huge) powers must assume h~ 10^{-21} or smaller since P~ h^2 . Otherwise GW sideband calculations seem fine.**

- **Optimization of SA is apparently not yet in DR FFT although it is undertaken in the single (power) recycling version of FFT. The latter has an MPI version written by F. Jenet and run by E. d'Ambrosio and W. Kells.**

Issues for MPI DR FFT Continued

- **We have a Mathematica notebook to plot Zernike polynomials, E-fields, and to determine parameters for removing FFT artifacts (apodization).**

- **All eour scalar and MPI for the single and dual recycling cases should be checked and a shell script (makefile or Imakefile) written that will let user choose which to compile and run. Input file needs some additions and output should include a graphic of the interferometer**.

- **Are current MPI DR codes using FFTW?**

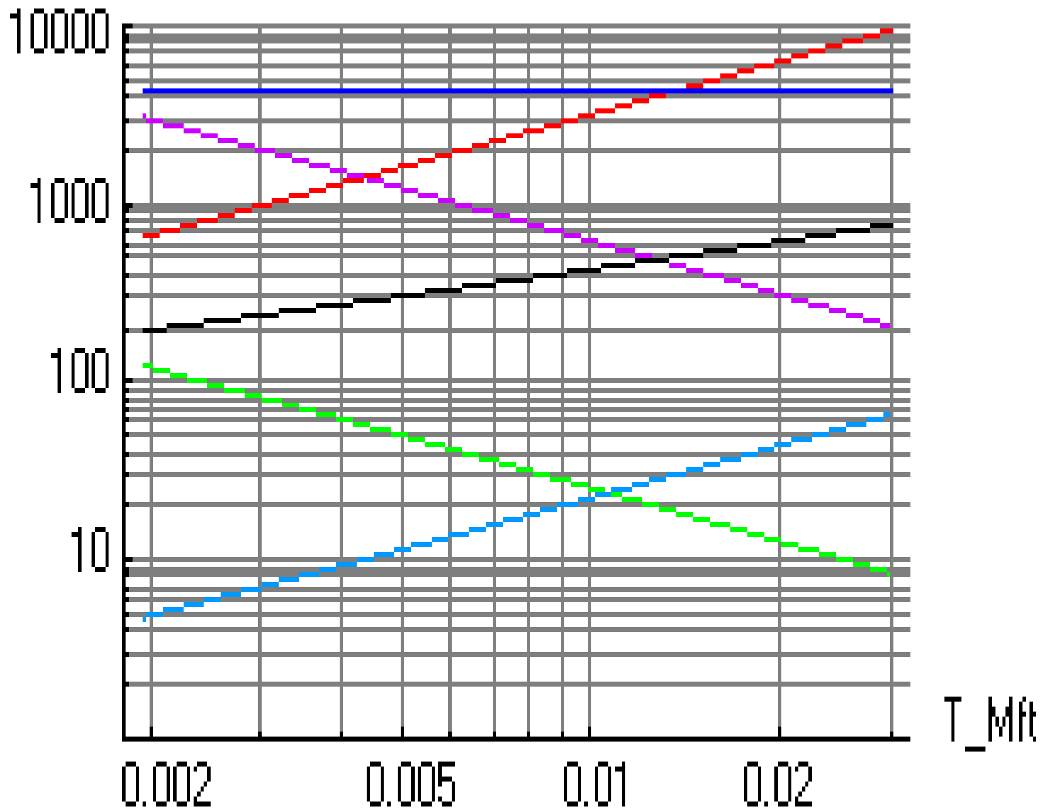
- **Is there a way to improve and optimize the way the work is divided up among nodes? We are currently using Bochner's scheme .**

Some Future Plans for MPI DR FFT

- The following calculations for the 40m and for Advanced LIGO and future (cryogenic?) LIGO.
- Careful study of effects of imperfect optics varying deformations of ETMs, ITMs, RM, and SM separately and together. Use Zernike deformations and possibly real mirror maps.
- Study of misalignments (tilts).
- Study thermal expansion and thermo-elasticity.
- Study the following as a function of T_{ITM}; finesse, storage time, cavity pole, power gain in FP arms and PRC, reflectivity of recycling mirror, higher modes, GW and Modulation sidebands, contrast defect and arm power decrease, Signal noise and strain sensitivity (DC), possibly SA and modulation depth; for imperfect optics.
- RSE (broadband and narrow band) including h sensitivity.

Future Plans for MPI DR FFT Continued

- Alan W has suggested that the choice of T_{SM} be revisited for LIGO II to optimize the dip in the shot noise curve.
- Simulations for sapphire optics.
- Changes in the 40m and advanced LIGO (LIGO II) as they occur.
- Simulations for future LIGO?
- Suggestions are Welcome.



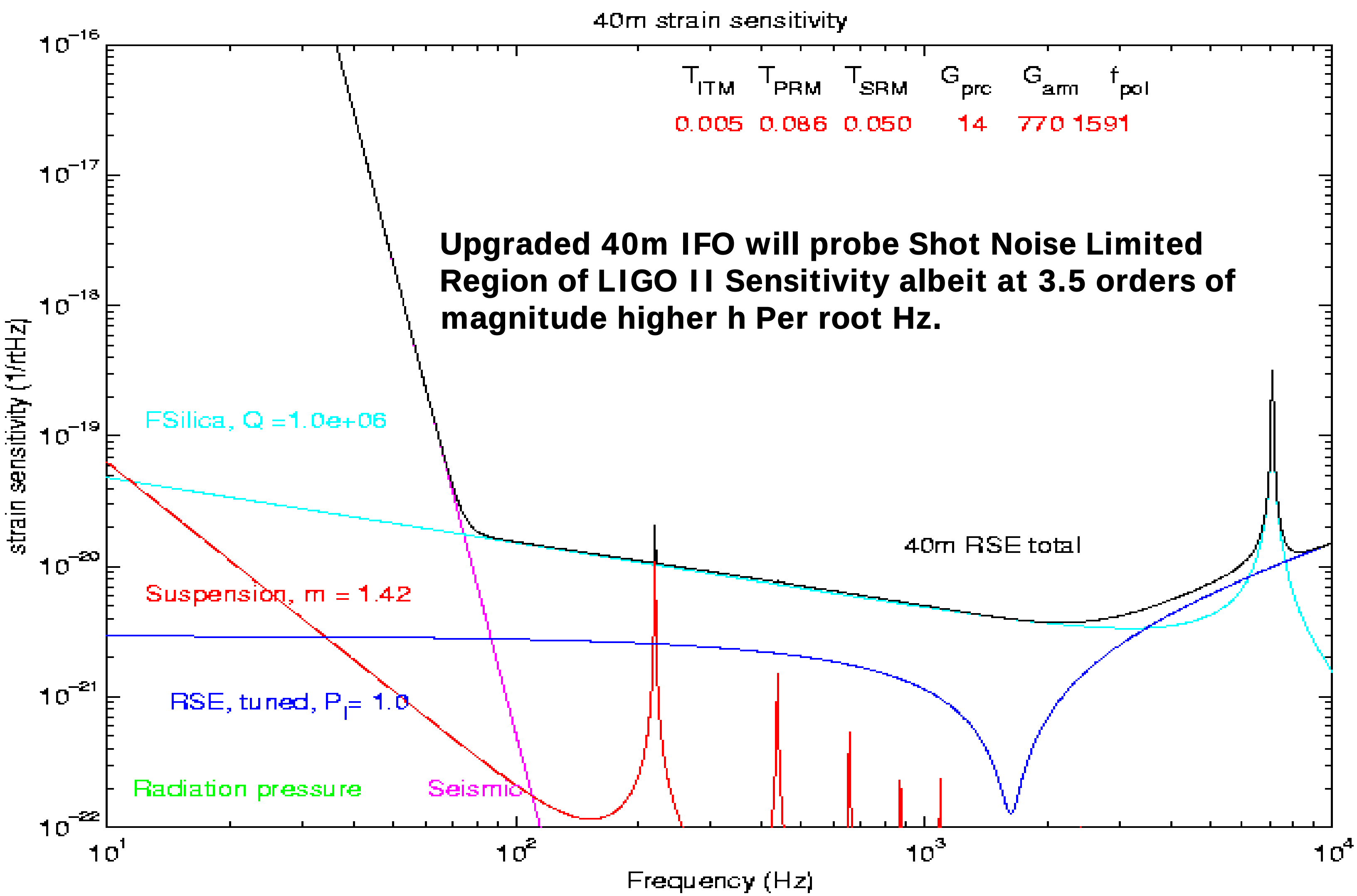
Graph of Transmittivity of ITM versus finesse, τ_{S}, f_{pole}, Arm-Carr00, PRC- Carr00, and h(f).

Abscissa has T_{itmI} horizontal axis has the following parameters With various units.

1. Finesse in **Purple**
2. τ_S = storage time in ms in **Green**.
3. Fpole-arm in Hz in **Red**.
4. Carrier TEM_{00} gain in in-line FP arm in **Dark Blue**.
5. Carrier TEM_{00} gain in PRC in **Bright Blue**
6. Strain sensitivity (h(f)) multiplied by 10^{-24} in **Black**.

Figure-3. Graphs of the Trasmittivity of the ITM versus various parameters for the 40m in a LIGO-I like configuration. These plots were obtained by the CSUDH group a full field simulation code called FFT. Any one of the plotted parameters can be used to determine the interferometer performance. Dual Recycling results will soon be available.

Figure-2 Noise Curves for the 40m IFO



Summary and Conclusions

- **We have formulated an MPI version of DR FFT and have applied it to the 40m and to imperfect optics modeled with a Zernike polynomial.**
- **There are many calculations that can be done with the new relatively fast code some of which have been planned for the near future.**
- **The FFT simulations have been a good way for us to learn some rudiments of interferometer physics and of parallel computing.**
- **Perhaps MPI DR FFT can be a "work-horse" tool for AIC.**
- **Much Thanks to Alan W. for help and collegiality.**