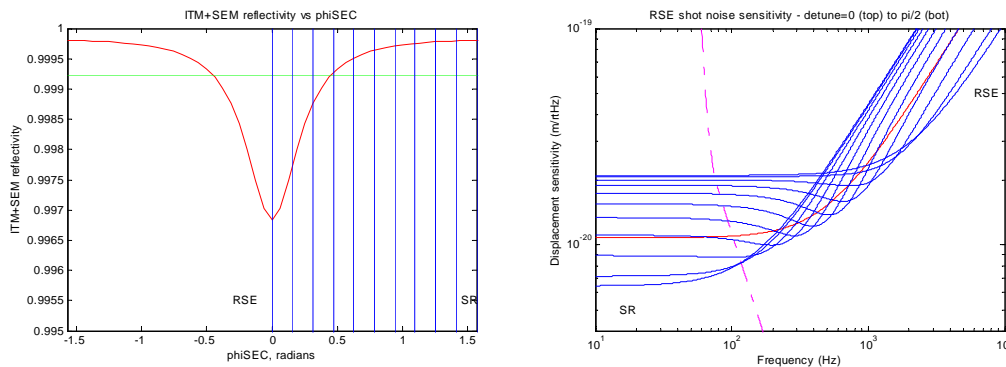


# Signal Recycling Cavity tune for 40m prototype of Advanced LIGO

AJW, 4/12/01

**Dual recycling:** One of the main purposes for dual recycling at Advanced LIGO is to manipulate the shot noise response of the interferometer, placing the peak of the sensitivity at lower (signal recycling, SR) or higher (RSE) frequency than the arm pole frequency. This is accomplished by changing the carrier tune in the signal recycling cavity (SRC)  $\phi_{\text{SRC}}$ , by making a microscopic (modulo  $\lambda = 1.064 \mu\text{m}$ ) shift in the signal mirror (SM) position.

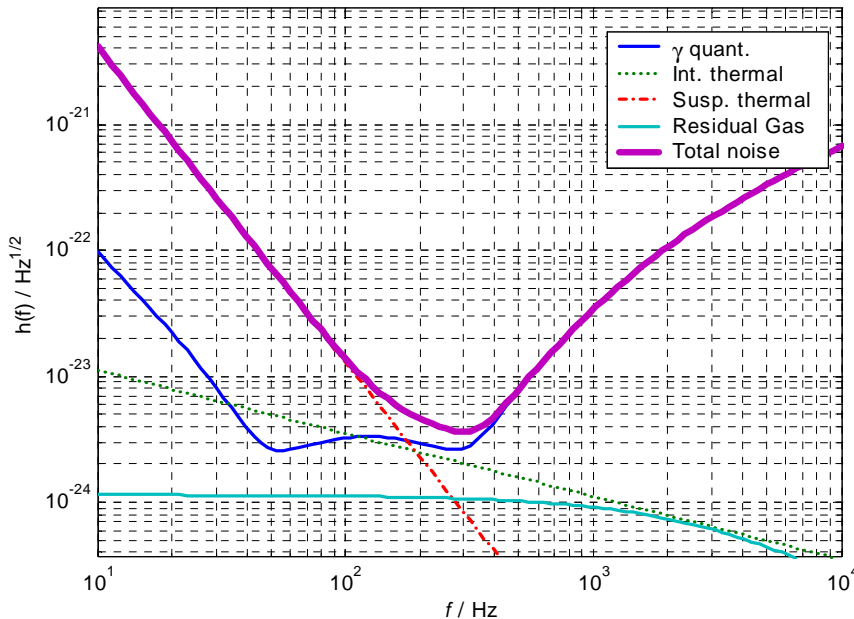
This is illustrated by the following pair of figures.



In the left figure, we plot the amplitude reflectivity of the compound mirror formed by the ITM plus SM, for different detunings. The horizontal line is the ITM reflectivity. The vertical lines indicate detunings  $\phi_{\text{SRC}}$  in radians which correspond to the shot noise curves in the right figure.

In the right figure, we plot the shot noise displacement sensitivity versus GW frequency, for different SRC tunings. The middle, red curve, with no dip, corresponds to the absence of a SM; the other blue curves are in the presence of a SM, with tunes corresponding to the vertical lines in the left figure. They range from the narrow-band,  $\phi_{\text{SRC}} = \pi/2$ , “signal recycling” SR limit (bottom-most curve on the left), to the widest-band,  $\phi_{\text{SRC}} = 0$  “resonant sideband extraction” RSE limit.

**DR at Advanced LIGO:** Initial LIGO has the arm pole frequency at 91 Hz, and the plan for Advanced LIGO is to place it at 15 Hz, then use RSE to move the peak frequency out to some hundreds of Hz (depending on the level of thermal noise), as illustrated in the following noise plot.



**Sense and control:** To sense and control the SM position, the Advanced LIGO scheme is to make  $\sim 180$  MHz sidebands be resonant in the SRC. This means that the total tune of the sidebands

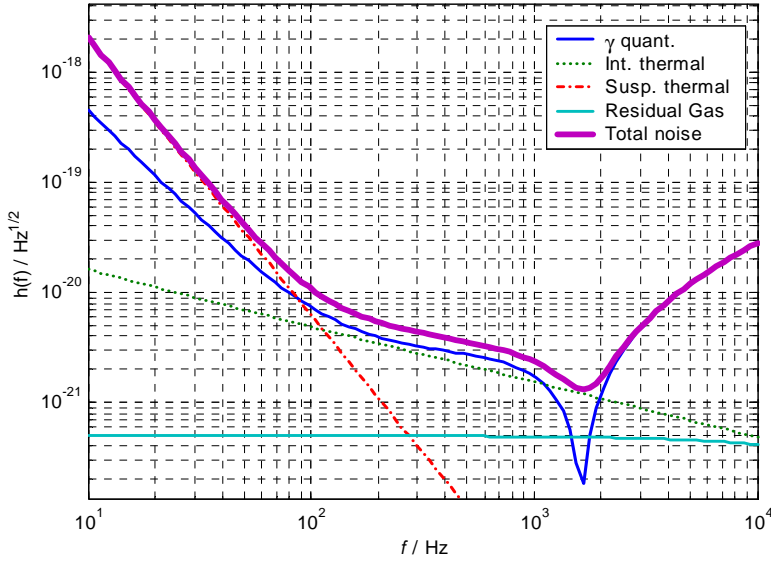
$\phi_{\text{SRC}} + \Delta\phi_{180}$  should  $= (2n+1)\pi$  for  $n$  integer. Changing  $\phi_{\text{SRC}}$  amounts to making a *macroscopic* shift in the length of the SRC (on the order of cm's) to make

$$\Delta\phi_{180} = (2n+1)\pi - \phi_{\text{SRC}} .$$

**40m Arm cavity:** For the 40m prototype, the arm pole frequency would be 100 times larger (1591 Hz), for the same  $T_{\text{ITM}}$ , ie, for the same arm cavity finesse. This is motivated by the naive belief that the controls fidelity between 40m and Advanced LIGO would best be served by having arm cavities of the same finesse, rather than similar pole frequencies and storage times. (To get the same storage times would require extremely high finesse arms at the 40m, making it very difficult to achieve and control resonance). I believe that the shorter storage times will result in more difficult, but achievable, lock acquisition, while the same arm finesse will result in in-lock behavior more closely resembling Advanced LIGO. *The impact of dual recycling on the controls bandwidth for Advanced LIGO and for the 40m is unknown to me, and I would be grateful for any wisdom on this subject!*

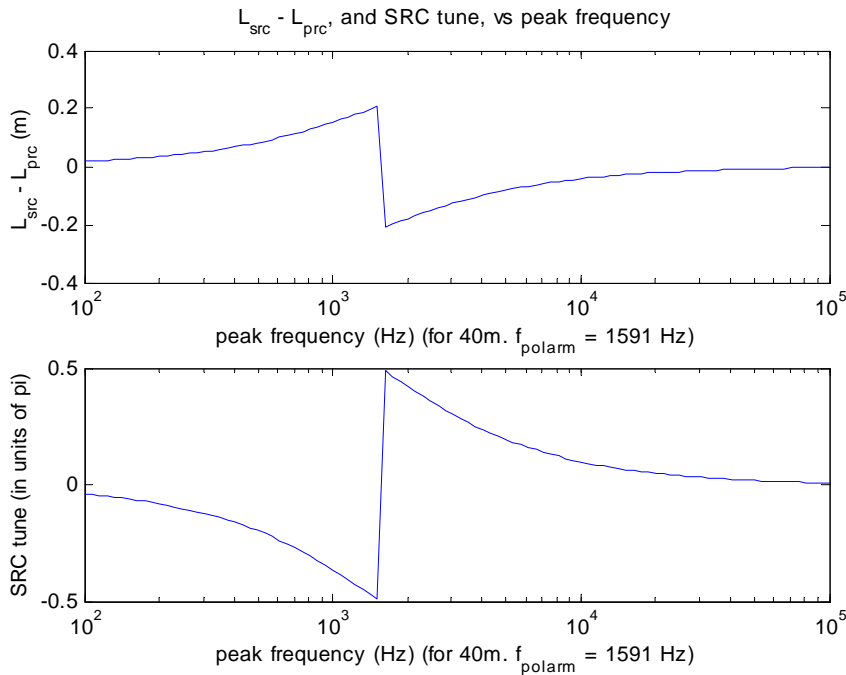
**40m Signal cavity:** The plan was to use SR to bring the peak sensitivity to lower frequencies, say, 1500 Hz. From the controls perspective, it doesn't matter whether one is in the SR or RSE regime (according to Ken Strain; and I see no reason to doubt the statement). The (very weak) motivations for moving in the SR direction were (a) perceived ease of making the length of the SRC such that both the power recycling mirror PM and the signal mirror SM both fit in the BS chamber; (b) putting the peak frequency closer to the peak frequency of Advanced LIGO (for no good reason that I could think

of), (c) avoiding the ADC Nyquist frequency of 8192 Hz. This results in the 40m shot noise curve shown below.

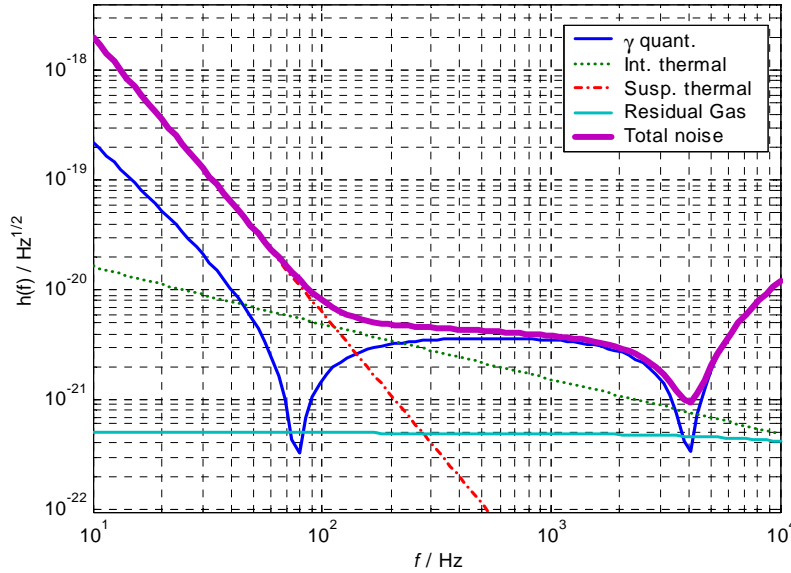


**40m signal cavity, alternative:** However, for higher fidelity, it may be desirable to also operate in the RSE regime (as suggested by David Shoemaker), operating with a peak sensitivity *larger* than the arm pole frequency of 1591 Hz.

The dependence of the tune  $\phi_{\text{SRC}}$ , and the SRC length (or the difference  $L_{\text{SRC}} - L_{\text{PRC}}$ ), on the desired peak sensitivity frequency, is shown in the following curves. (The “wrap-around” at 1591 Hz is artificial).



We are thus considering changing the plan in that way, and operating with a peak sensitivity at around 4000 Hz; still far from the Nyquist frequency. The resulting shot noise curve is shown in the next figure.



**Cavity lengths at the 40m:** This requires only that we rearrange the power recycling mirror and signal recycling mirror positions in the BS chamber. It's pretty crowded in there! But Mike Smith says it can be done.



**We welcome opinions on this subject!**