Offset locking with transmitted light

Osamu Miyakawa, Daisuke Tatsumi

July 11, 2009

1 Parameters

Table 1: Important parameters of the interferometer.

T_{PRM}	0.23
T_{FM}	0.008
T_{EM}	10 ppm
Arm finesse	777
G_{arm}	$495 = 777 \times 2/\pi$
G_{PRC}	11
full power inside cavity	200 kW

2 Power budget

2.1 Transmitted power after the full lock

$$200 \text{ kW} \times 10 \text{ ppm} = 2 \text{ W} \quad (\sim 6 \text{ W})$$

However it is really difficult to have 10 ppm transmittance accurately, so the safety factor by 3 should be assumed at least.

2.2 Transmitted power just after the lock acquisition

Intra-cavity power, when the cavity is locked, is limited by an ability of lock acquistion with a disturbance of the radiation pressure pushing mirrors. This stored power was estimated by the e2e time domain simulation with Advanced LIGO parameters, but not with LCGT parameters. Roughly speaking, the stored power will be $<$ 1kW, so transmitted power can be estimated as follows, 1kW $\times$ 10 ppm = 10 mW (30mW with the safety factor).

2.3 Offset locking

Currently the offset locking method is thought as one of the best candidates for lock acquisition of RSE. It puts an offset on the common mode of arms (CARM, or L+) when the 5 DOFs are locked initially, then the offset will be reduced, and the stored power will be increased along the reduction of the offset.

Ratio of power inside the cavity between lock acquisition and full lock for the offset locking will be

$$T_{\mathrm{PRM}}/G_{\mathrm{PRC}} = 0.23/11 \sim 1/50$$

in for the LCGT. This can be explained like this; the offset locking method assumes that the stored power inside the cavity for lock acquisition of 5 DOFs should be the same as the stored power inside the cavity with a misaligned power recycling mirror. The power transition from the lock acquisition of 5 DOFs to the full lock is the same as the single arm lock with misaligned PRM to full lock so that the ratio will be by a factor of T_{PRM} and by a factor of G_{PRC}.

So the power inside cavity will be 4 kW since the full power inside cavity will be 200 kW. Initial input power must be less than $75/4 \leq 18.75$ W to have less than 1 kW in the arm cavity when the cavity acquires lock with the offset on L+. If we take into account for the safety factor, it is better that the input power may be less than $75/25 = 5$ W which corresponds to the safety factor by ~ 6.

From above discussion, the initial input laser power into interferometer for the lock acquisition can be assumed as 5W (of 75W, 1/25). and the power on the high gain PD placed at the transmitted port with -20dB attenuation by BS and attenuator when the cavity is placed at an anti resonant point,

$$\begin{aligned}
& 1\ \mathrm{kW}\ /\mathrm{saftyfactor}\ /G_{\mathrm{arm}} \times T_{\mathrm{FM}}/4(\mathrm{antifactor}) \times 10\ \mathrm{ppm} \times 0.1\ (\mathrm{BS,\ attenuation}) \\
= & 1\ \mathrm{kW}/6/(777/\pi \times 2) \times 0.004\ /4 \times 10\ \mathrm{ppm}\ /10 \\
= & 0.35\ \mathrm{mW} \times 10\ \mathrm{ppm}\ /10 \\
= & 0.35\ \mathrm{nW}
\end{aligned}$$

To get good quality signals for lock acquisition at the point far from resonance using offset locking method we assume 100 times lower power than the power from the locking point. The transmitted power on the high gain PD for minimum useful signals will be

$$\begin{aligned}
& 10\ \mathrm{mW}\ /6\ (\mathrm{safety\ factor}) \times 0.1\ (\mathrm{BS,attenuator})\ /100\ (\mathrm{further\ locking\ point}) \\
= & 1.6\ \mathrm{uW}\ .
\end{aligned}$$

It corresponds ?? times farther point from locking point, and will be m from resonant point.

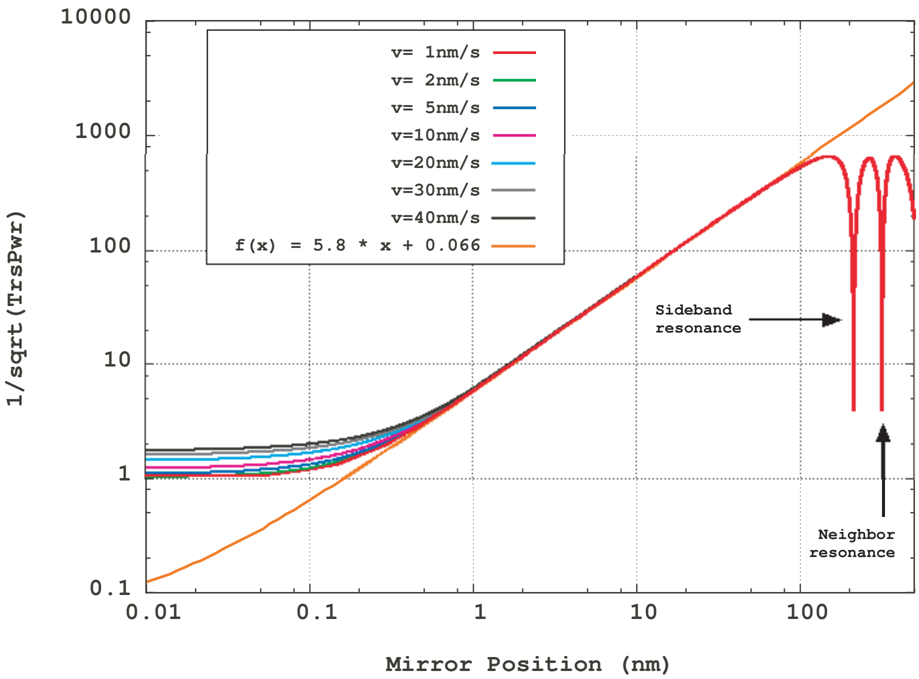

Figure 1: Transmitted light, 1/sqrt(T) + offset vs Cavity microscopic length

2.4 Power budget summary

Table 2: Power budget

	Anti lock	Min. useful signal	Lock acquisition	L+ resonant	full power
Input power	5W	5W	5W	5W	75W
Intra cavity	350uW	1.6W	160W	8kW	200kW
High gain PD	350pW	1.6uW	160uW	8mW	200mW
Low gain PD	3.5pW	16nW	1.6uW	80uW	2mW
Factor	x4500	x100	x50	x25	max

3 Requirement for noise level of high gain PD

3.1 Maximum power on the high gain PD

We assume that the high gain PD is used for 10 times higher power than locking power,

$$10 \times 160\ \mu\text{W} = 1.5\ \text{mW}\ (\ 5\text{mW})$$

3.2 Dynamic Range and Noise level

We can estimate a dynamic range for the high gain PD from above discussion as

$$1.5\ \text{mW}/\ 1.6\ \mu\text{W} > 10^3$$

We assume the maximum output voltage as 0.1 Volts. This low output voltage is due to slew rate or something.

Requirement for rms noise level will be

$$0.1/10^3 = 100\ \mu\text{Vrms}\ ,$$

with the assumption of 10 kHz bandwidth since transmitted signals used for locking will be sampled with 16 kHz, so a requirement of the output noise spectrum of the high gain PD is 1 $\mu\text{V}/\sqrt{\text{Hz}}$.

4 An example of table layout for the transmitted port

Figure 1. Table layout of transmitted port .

2 inch lense-¿ — —-¿ 10— —-¿ 50— —-¿ 10— —-¿ 10— —-¿ Beam dumper (max:400mW)

Pointing light from BS table -¿ 2inch lens -¿ QPD(DC)