LIGO

Advanced LIGO optical configuration investigated in 40meter prototype

LSC meeting at LLO

Mar. 22, 2005

O. Miyakawa, Caltech
and the 40m collaboration

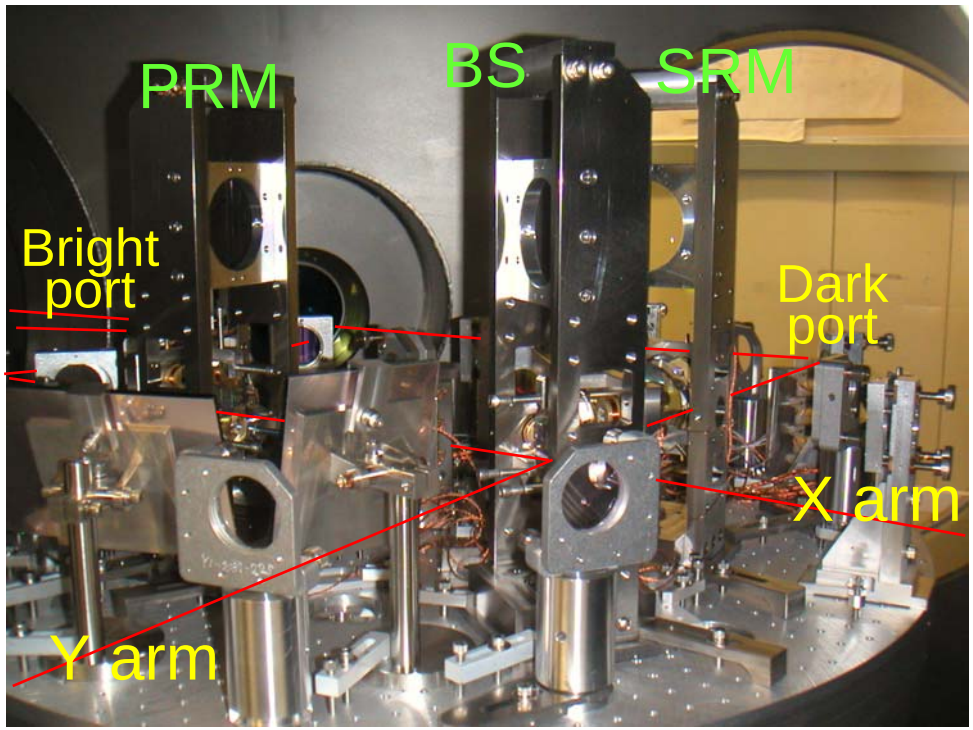
Caltech 40 meter prototype interferometer

Objectives

- Develop **lock acquisition procedure** of detuned Resonant Sideband Extraction (RSE) interferometer, as close as possible to Advanced LIGO optical design

- Characterize noise mechanisms
- Verify optical spring and optical resonance effects
- Develop DC readout scheme

  Next Rob's talk
- Extrapolate to AdLIGO via simulation
- etc.



Important Milestones

2003

Installation of Four TMs and BS***:done***

Lock of FP Michelson ***:done***

2004

Installation of Power Recycling Mirror (PRM) ,Signal Recycling Mirror (SRM) ***:done***

Installation Mach-Zehnder to eliminate sideband of sideband ***:done***

DRMI locked with carrier resonance using dither for Michelson DOF. ***:done***

DRMI locked with sideband resonance using Double Demodulation(DDM) ***:done***

Off-resonant lock of signal arm cavity with DRMI ***:done***

Off-resonant lock of both arm cavities with DRMI ***:done***

Full carrier resonant of single arm with DRMI ***:done***

2005

Full RSE ***:in progress***

Arm lock is really really difficult!

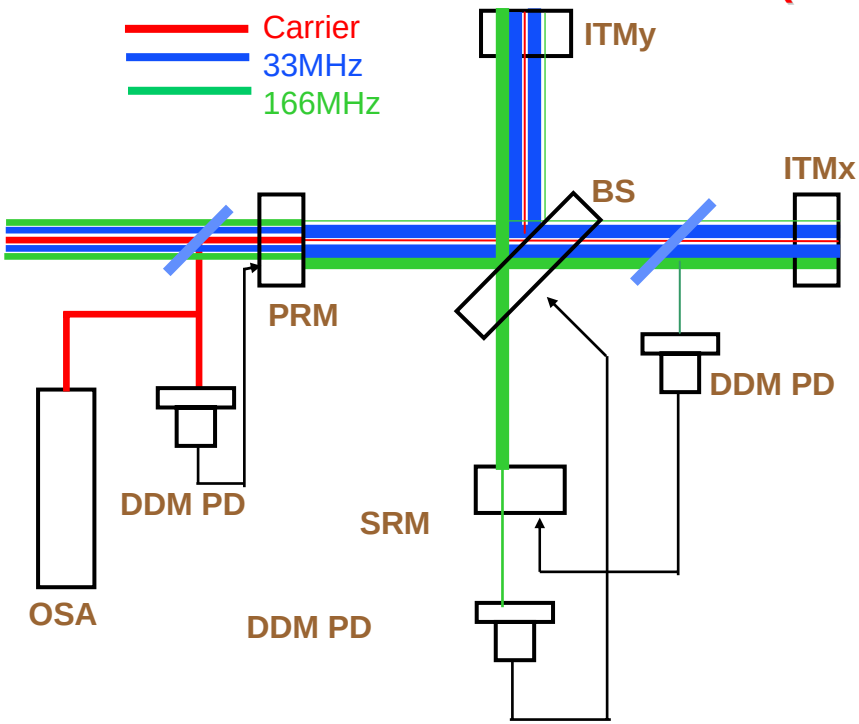
DRMI lock with Unbalanced sideband by detuned cavity

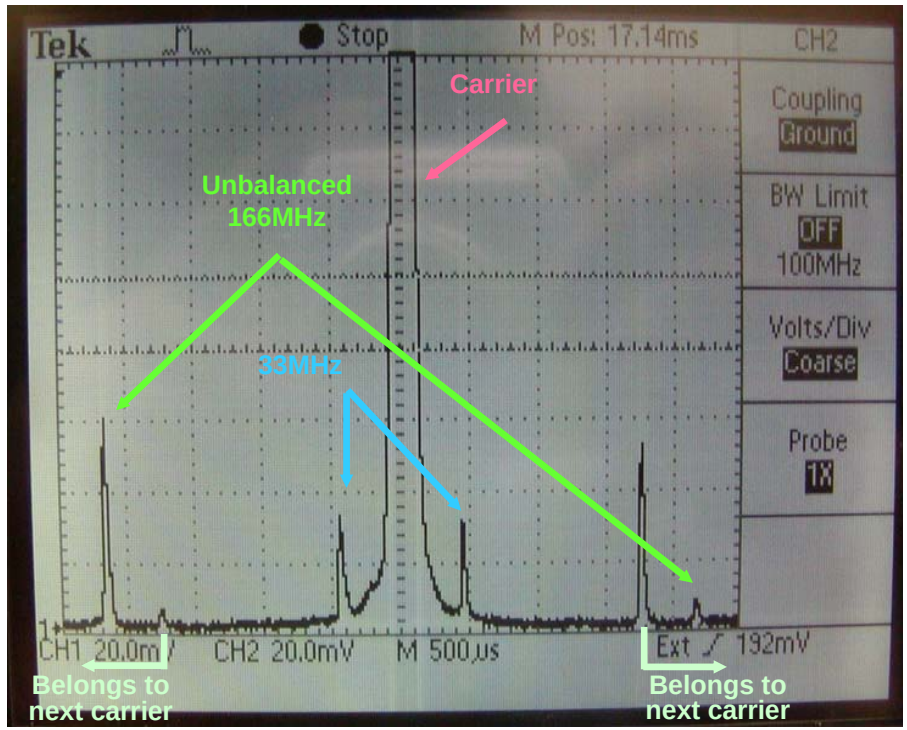
August 2004

- **DRMI locked with carrier resonance (like GEO configuration)**

November 2004

- **DRMI locked with sideband resonance (Carrier is anti resonant preparing for RSE.)**





Lock acquisition

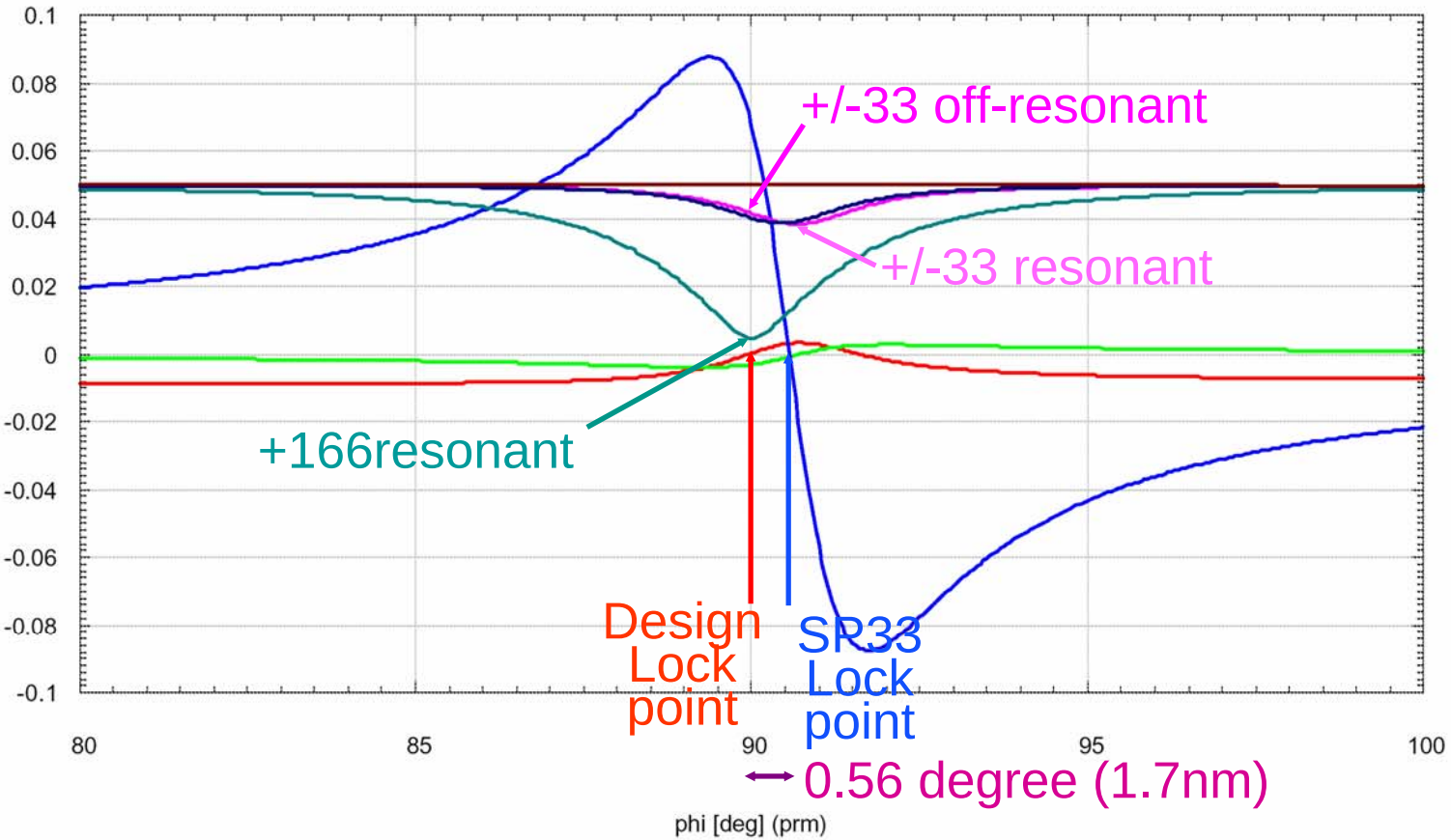
MICH : dither @ 1200 Hz
PRC : 33MHz@SP
SRC : DDM@PO

After lock:

→ DDM@AP
→ DDM@SP
→ DDM@PO

Typical lock acquisition time : ~10sec
Longest lock:2.5hour

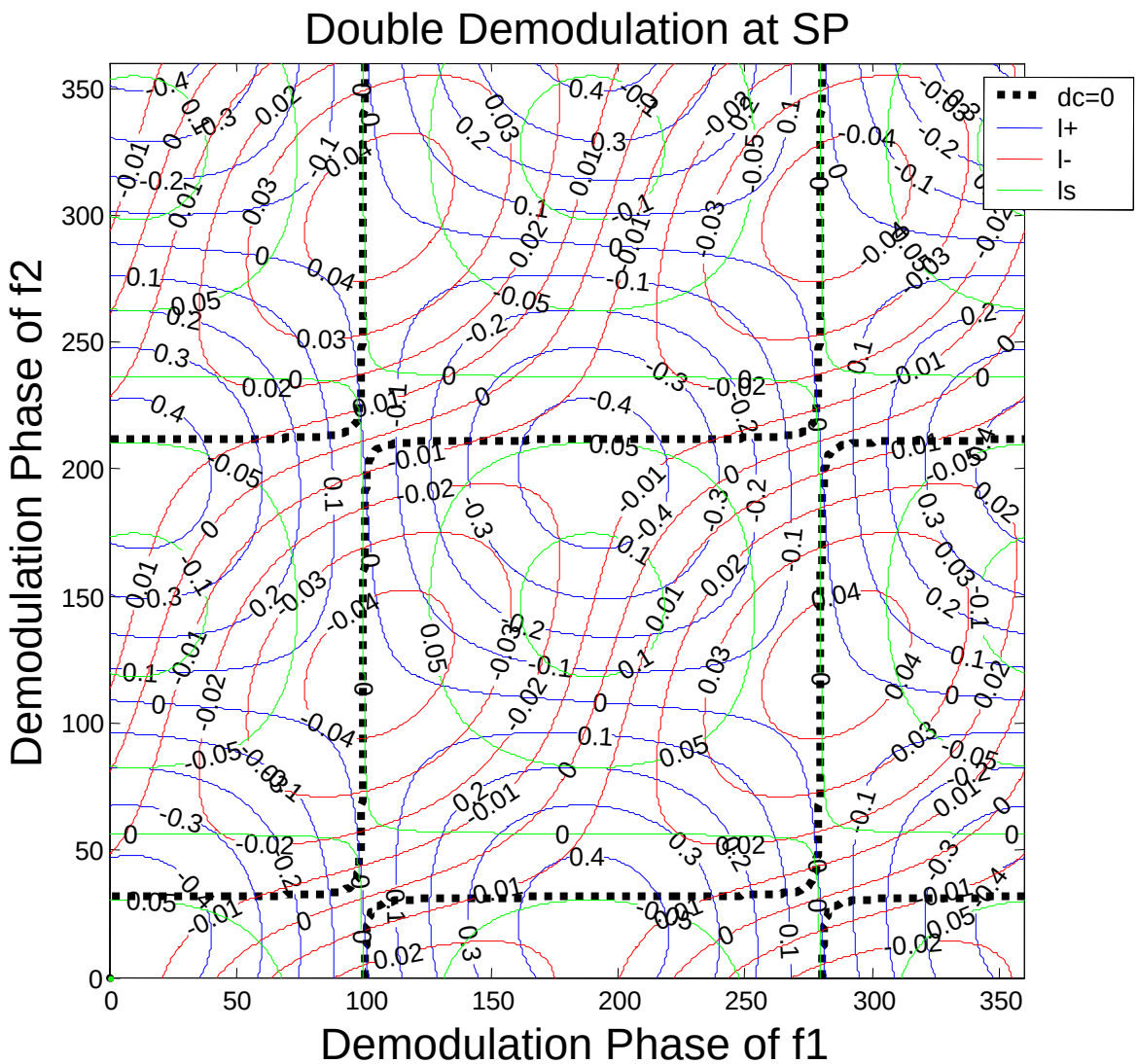
SP33,DDM,+/-33M,+/-166M@SP



40m Original design of SP DDM

+33 : off-resonant
-33 : off-resonant
+166: resonant
-166 : anti-resonant

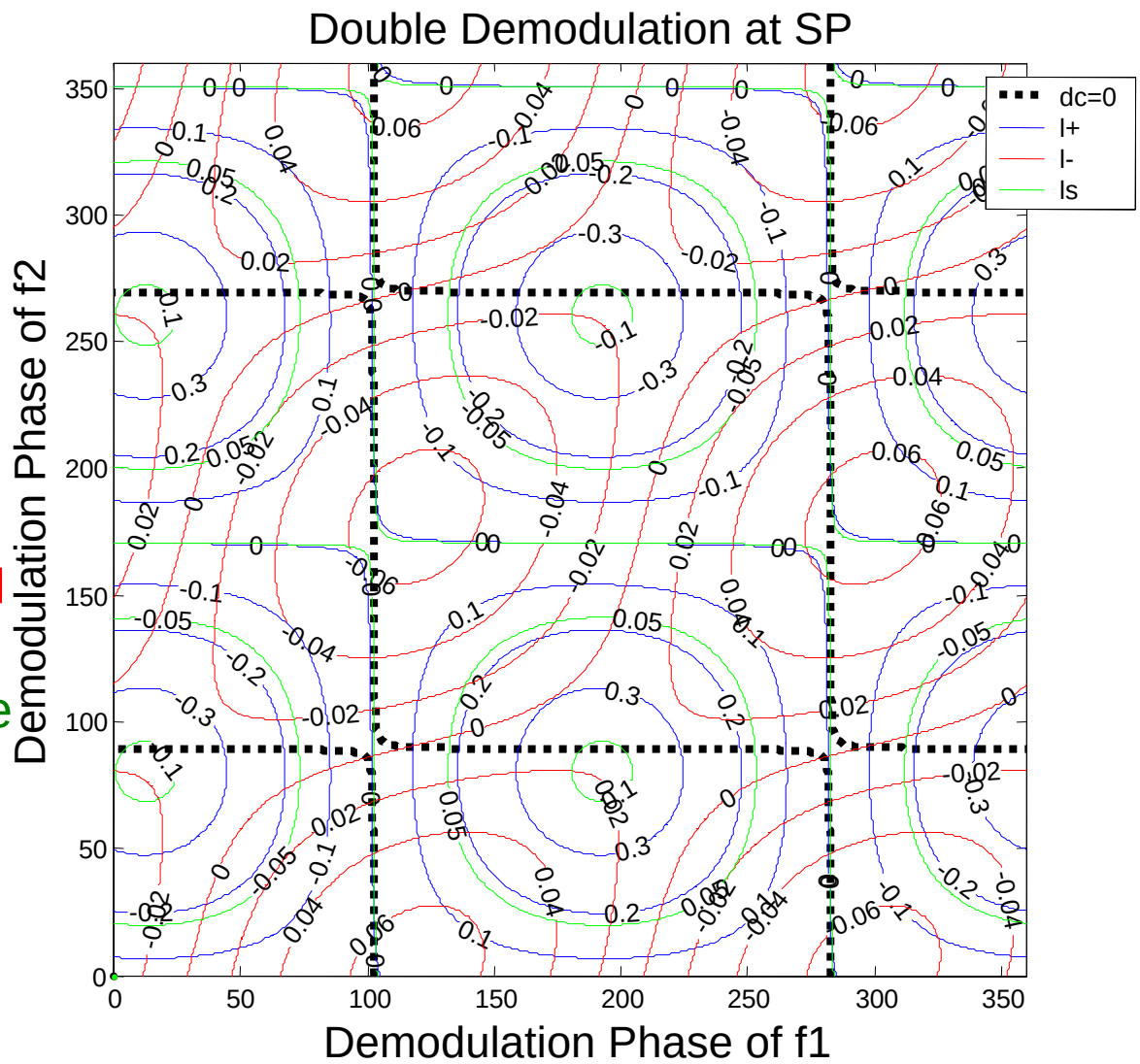
- I_+ and I_s plot separated
- Difficult to find PRM position without carrier



Offset I_+ +0.56 deg, I_s +0.56 deg

+33 : resonant
-33 : resonant
+166: resonant
-166 : anti-resonant

- I_+ and I_s plot overlapping
- DC line changed
- Easy to find PRM position using 33MHz resonance
- Like AdLIGO configuration
- Carrier would be off resonant



40m vs. Ad-LIGO

40m

Table 4: Length sensing signals. $\otimes$ means double demodulation.

Signal	L_+	L_-	l_+	l_-	l_s
SP, f_1	**15.2**	0.000	-0.062	0.064	-0.001
AP, f_2	0	**1.69**	0	0.002	0
SP, $f_2 - f_1$	-0.0003	0.0001	**0.214**	0.029	0.039
AP, $f_2 \otimes f_1$	0	0	0.0025	**-0.0034**	-0.0004
PO, $f_2 - f_1$	0.005	-0.004	1.000	-0.277	**-2.980**

x6
x1.5
x3

Table 5: Length sensing signals for Advanced LIGO. $\otimes$ means double demodulation. These numbers agree, up to an overall constant, with the table Peter Fritchel showed at the August 2000 LSC meeting (LIGO-G000225).

Ad-LIGO

Signal	L_+	L_-	l_+	l_-	l_s
SP, f_1	**1890**	0.00	-1.94	0.11	0.00
AP, f_2	0	**-1500**	0	-1.88	0
SP, $f_2 - f_1$	-0.11	-0.01	**19.5**	-0.11	8.66
AP, $f_2 \otimes f_1$	0.000	0.001	-0.031	**0.242**	0.005
PO, $f_2 - f_1$	-0.42	-0.01	8.84	5.81	**245**

x2
x8
x17

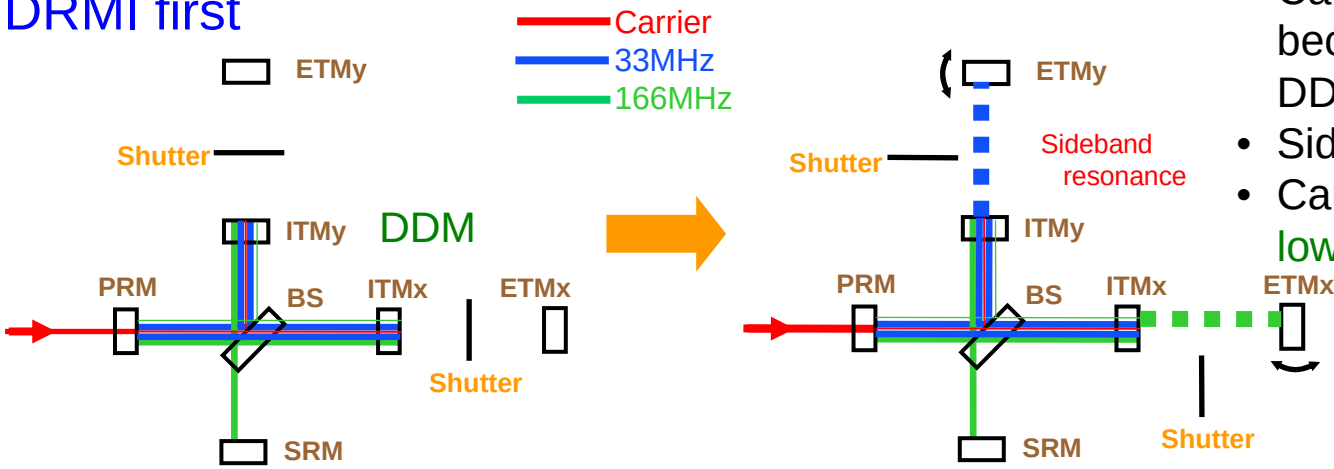
Struggling lock acquisition for Arms

Problems

1. Sideband resonance on arm cavities
2. Resonant point shift due to detuned SRC
3. 16kHz sampling rate is too slow for 40m.
4. Coupling between X arm and Y arm

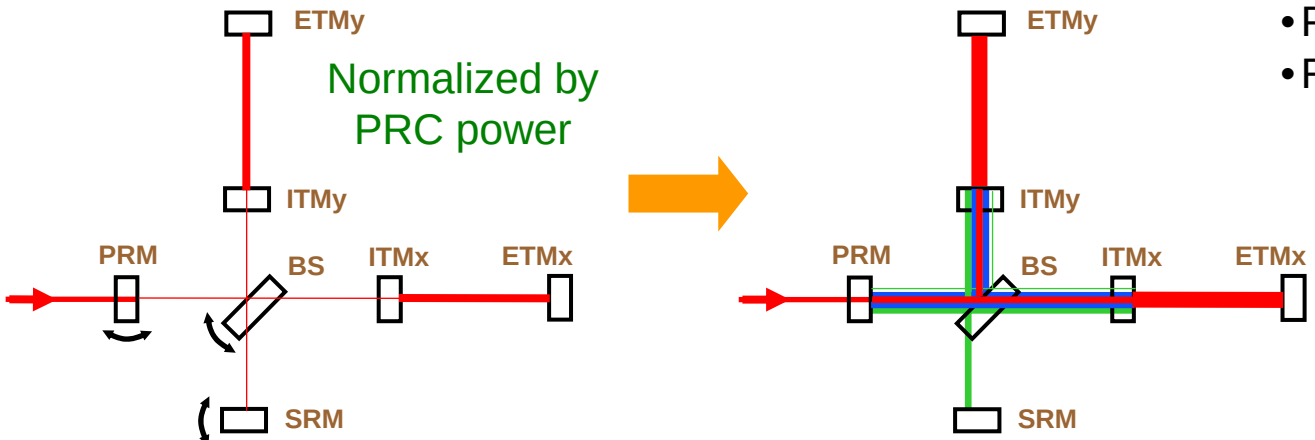
Which is first ? DRMI lock or Arms lock?

DRMI first



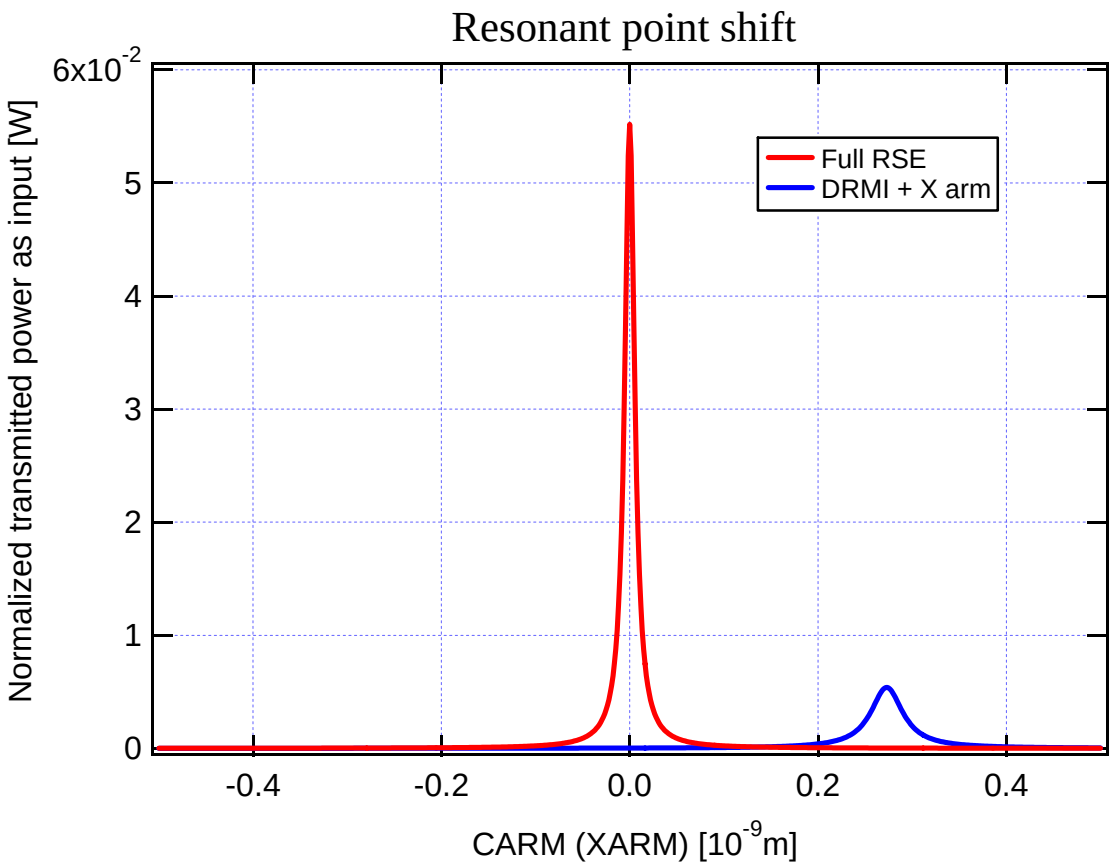
- Carrier flash does not matter because DRMI is locked by DDM (beat of sidebands).
- Sideband flash matters.
- Can keep locking ~10sec with lower gain.

Arms first



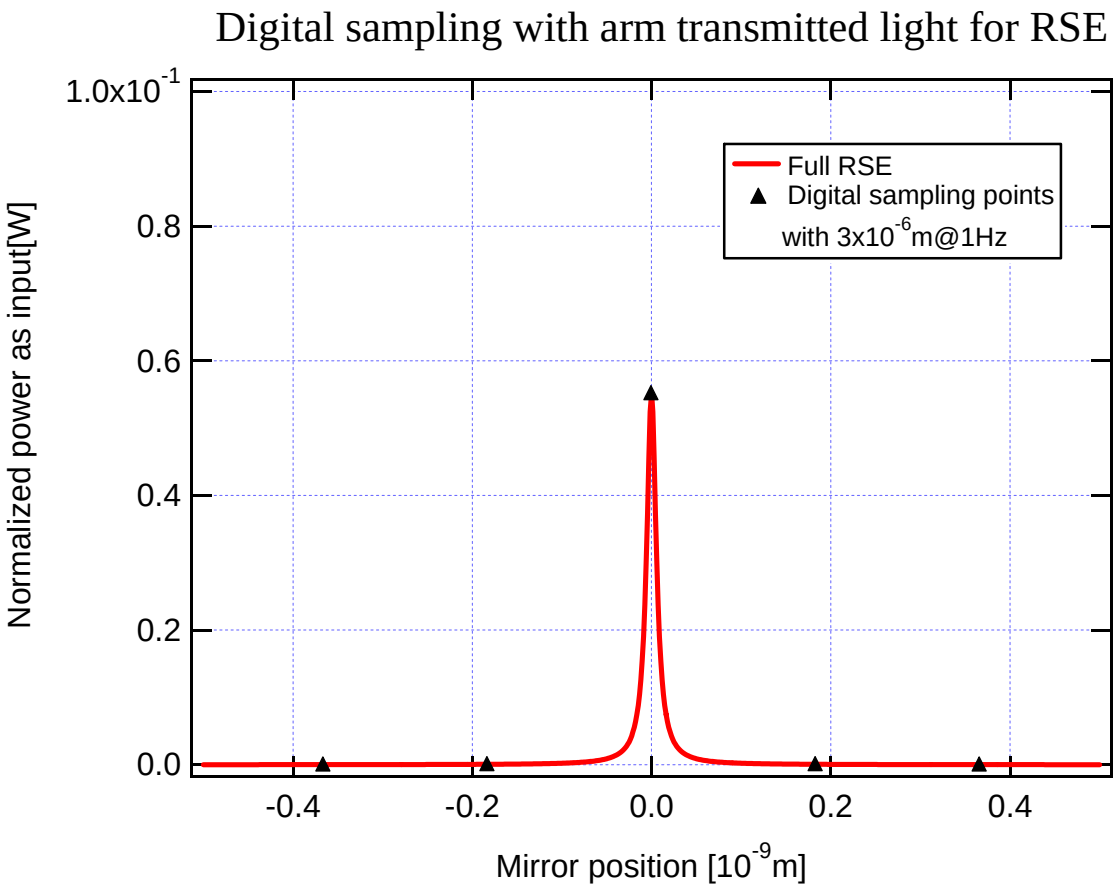
- PRFPMI : succeeded
- RSE : not succeeded!
  - »Because of resonant point shift due to detuned SRC

Resonant point shift



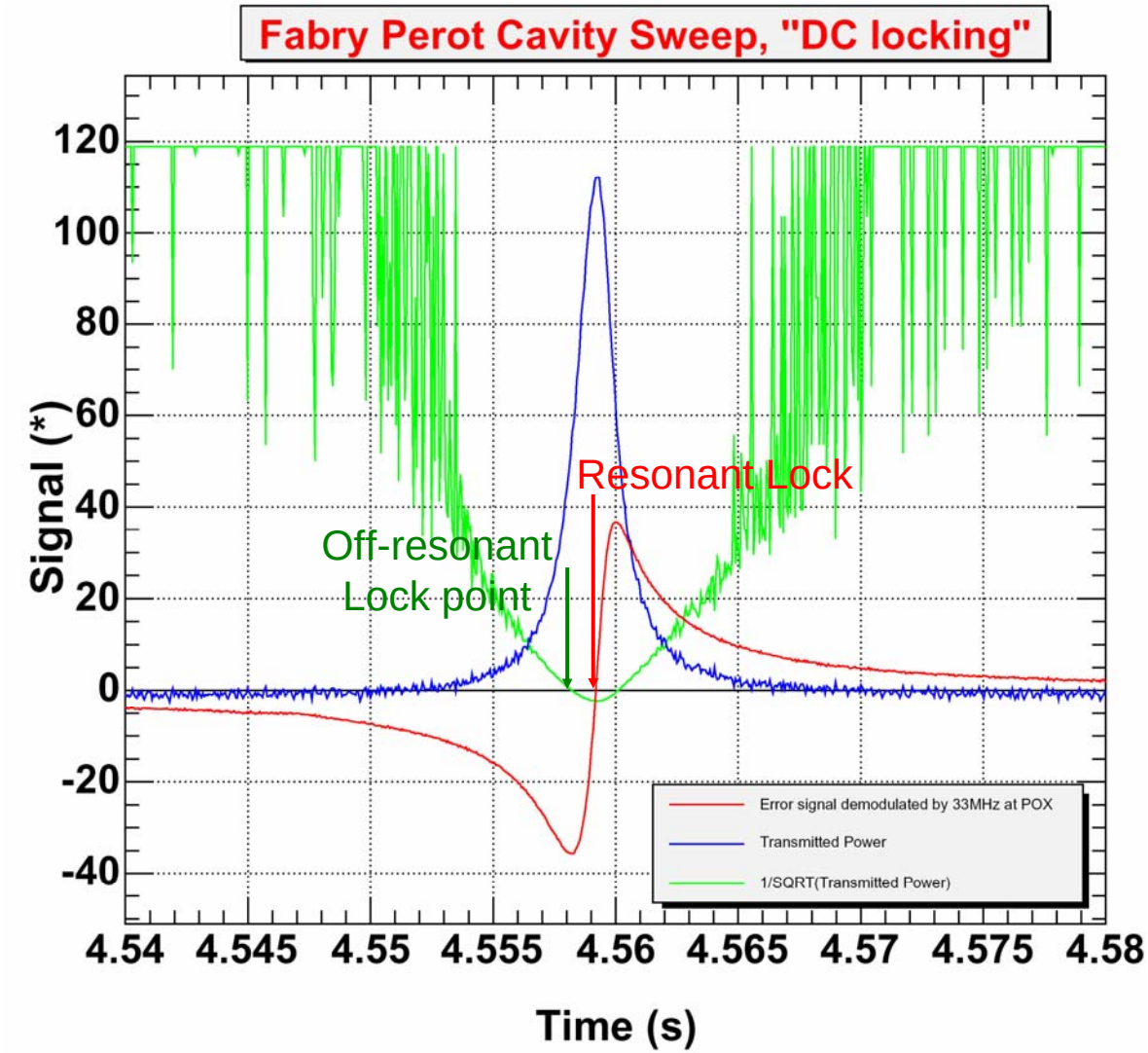
- Resonant point shifts in single arm lock because of carrier phase change in detuned SRC

Digital sampling for 40m RSE configuration



- Due to large seismic motion, 3×10^{-6}m at 1Hz assumed here
- Due to very high combined finesse of arm and PRC ~18000.
- Night is about 10 times better but still not enough.
- Needs wider linear error signal.
  - » Normalization technique to widen linear range
  - » Slower mirror motion

Off-resonant lock scheme for arm cavity



Error signal is produced by transmitted light as

$$\frac{1}{\sqrt{\text{Transmitted power}}} + \text{offset}$$

1. to avoid coupling through carrier in central part,

2. to widen linear range.

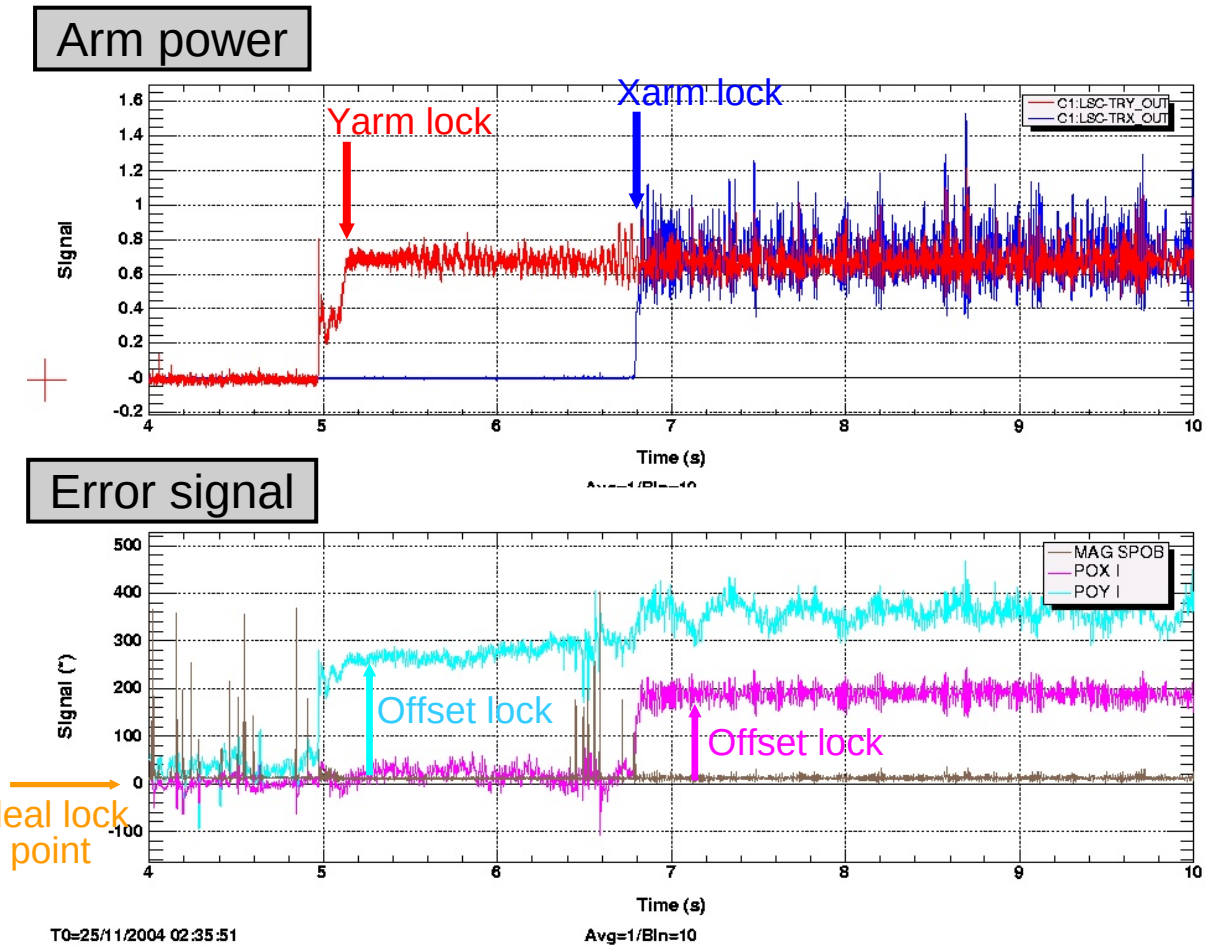
Off resonant Arm lock with DRMI

DRMI with single arm lock

- Not so difficult
- Last ~10 min
- Lock acquisition time ~1 min
- Switched to POX/POY signal normalized by transmitted light
- Full carrier was stored in each arm cavity separately.

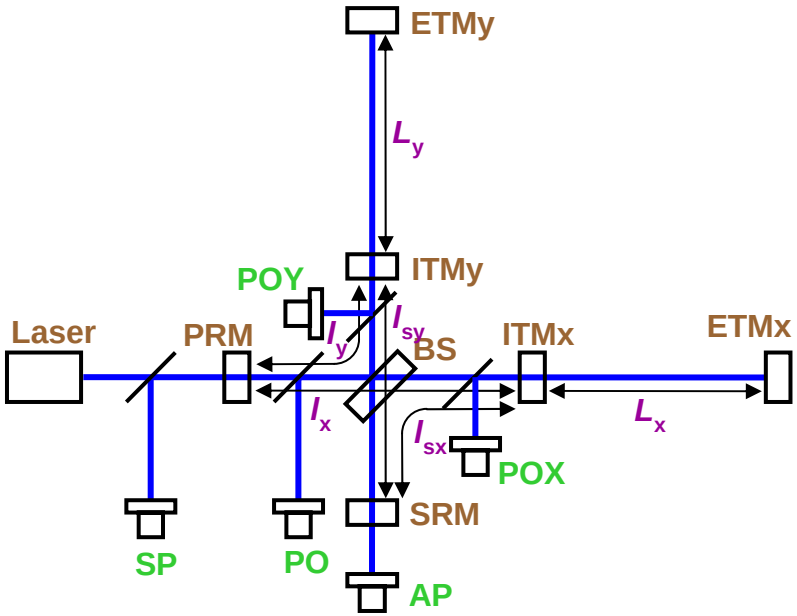
Both arms lock with DRMI

- Off-resonant carrier on arm cavities
- Last < 1 min
- Locked only 2 times



Coupling between L_x and L_y

Common of arms(CARM) : $L_+=(L_x+L_y)/2$
Differential of arms(DARM) : $L_-=L_x-L_y$
Power recycling cavity : $l_+=(l_x+l_y)/2$
Michelson : $l_-=l_x-l_y$
Signal recycling cavity : $l_s=(l_{sx}+l_{sy})/2$



CARM/DARM lock

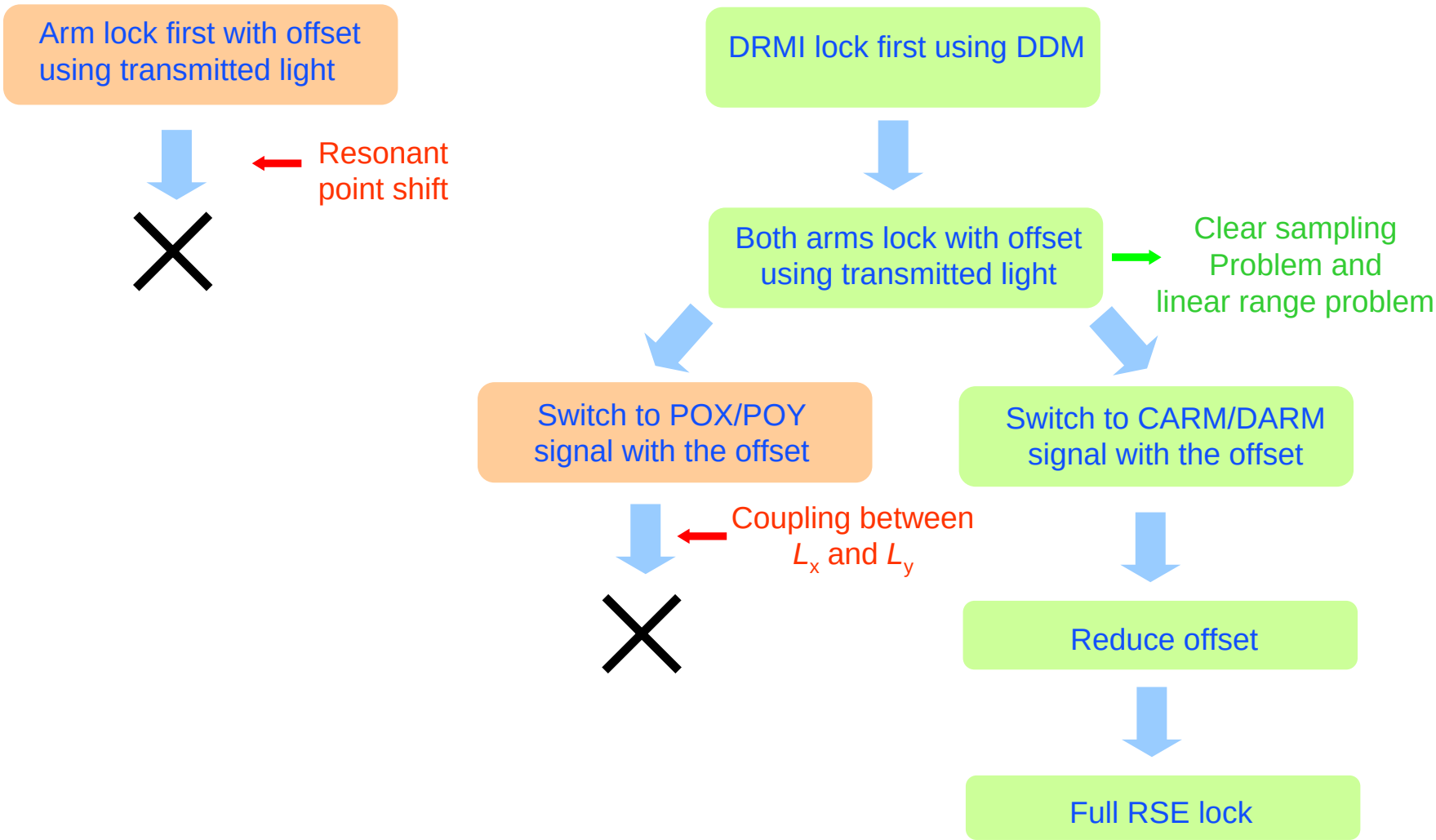
Port	Dem. Freq.	L_+	L_-	l_+	l_-	l_s
SP	f_1	1	-3.8E-9	-1.2E-3	-1.3E-6	-2.3E-6
AP	f_2	-4.8E-9	1	1.2E-8	1.3E-3	-1.7E-8
SP	$f_1 \times f_2$	-1.7E-3	-3.0E-4	1	-3.2E-2	-1.0E-1
AP	$f_1 \times f_2$	-6.2E-4	1.5E-3	7.5E-1	1	7.1E-2
PO	$f_1 \times f_2$	3.6E-3	2.7E-3	4.6E-1	-2.3E-2	1

POX/POY lock

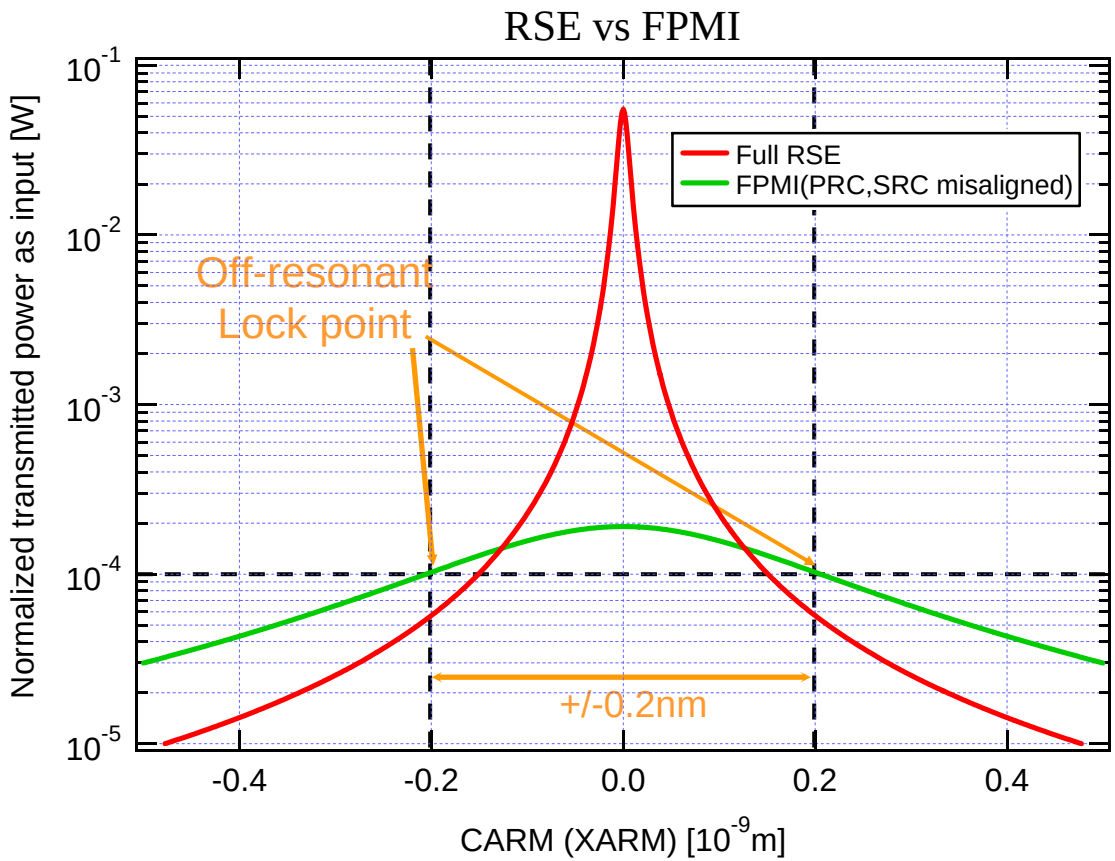
Port	Dem. Freq.	L_x	L_y	l_+	l_-	l_s
SP	f_1	1	9.4E-1	-1.2E-3	-1.3E-6	-2.3E-6
AP	f_2	9.4E-1	1	1.2E-8	1.3E-3	-1.7E-8
SP	$f_1 \times f_2$	-1.7E-3	-3.0E-4	1	-3.2E-2	-1.0E-1
AP	$f_1 \times f_2$	-6.2E-4	1.5E-3	7.5E-1	1	7.1E-2
PO	$f_1 \times f_2$	3.6E-3	2.7E-3	4.6E-1	-2.3E-2	1

- Coupling is 94% when carrier is resonant.
  - » Off-resonant lock for arms

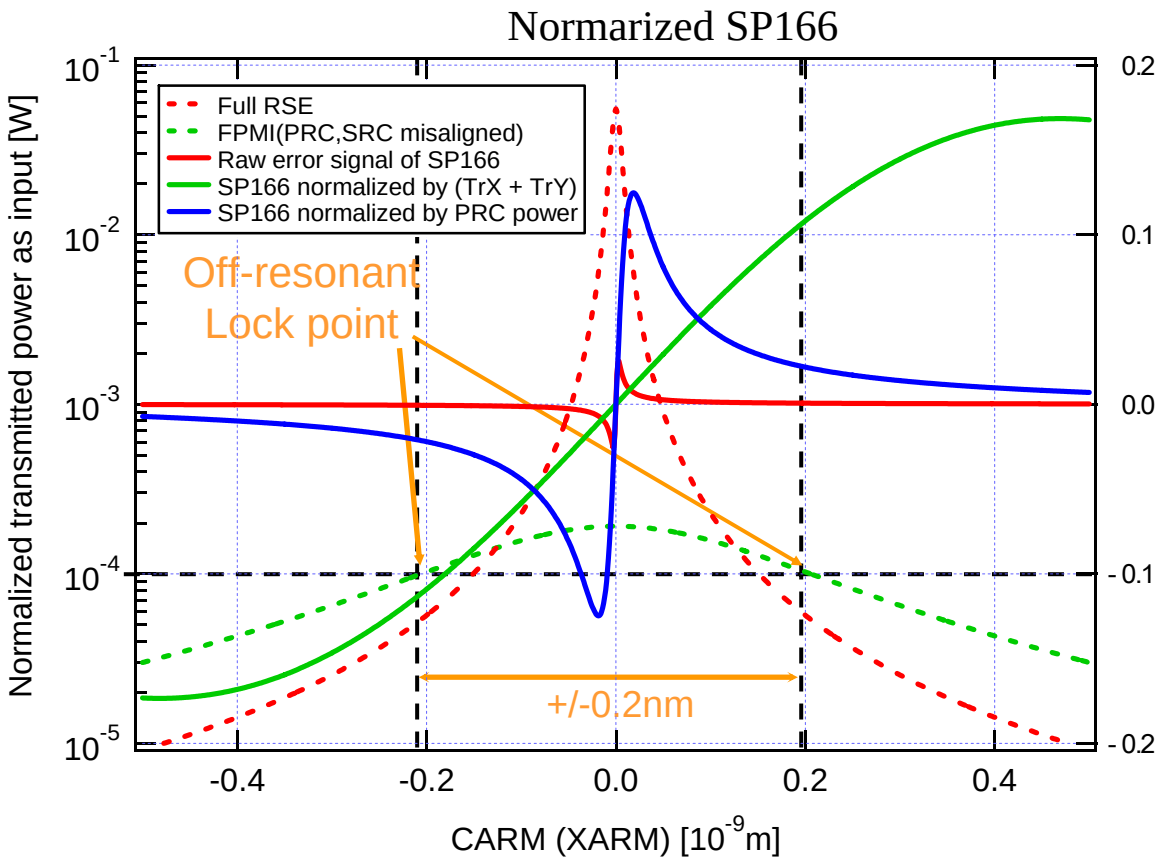
The way to RSE



Way from off-resonant lock to com/diff lock



Normalized SP166 for CARM



Dem.phase accuracy

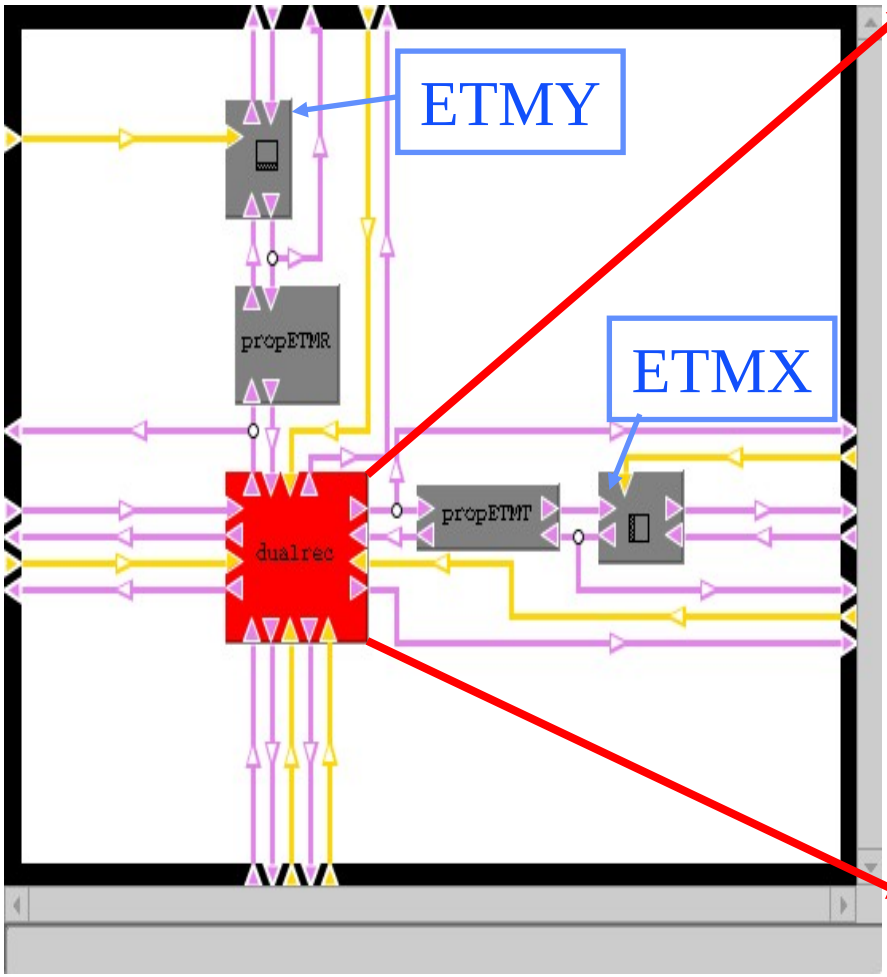
~10degre for 166MHz

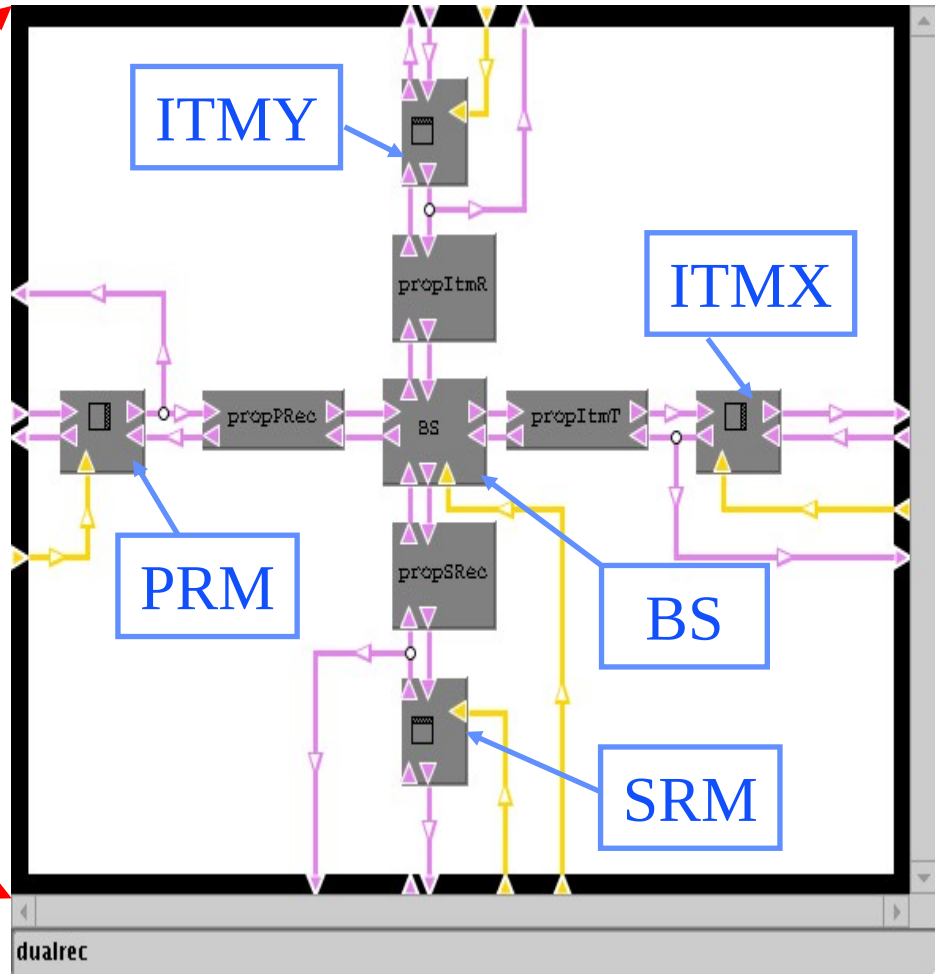
~0.1degree for 33MHz

e2e SIMULATION: 4Om/AdvLIGO package optical configuration

IFO with Arms

IFO Central part

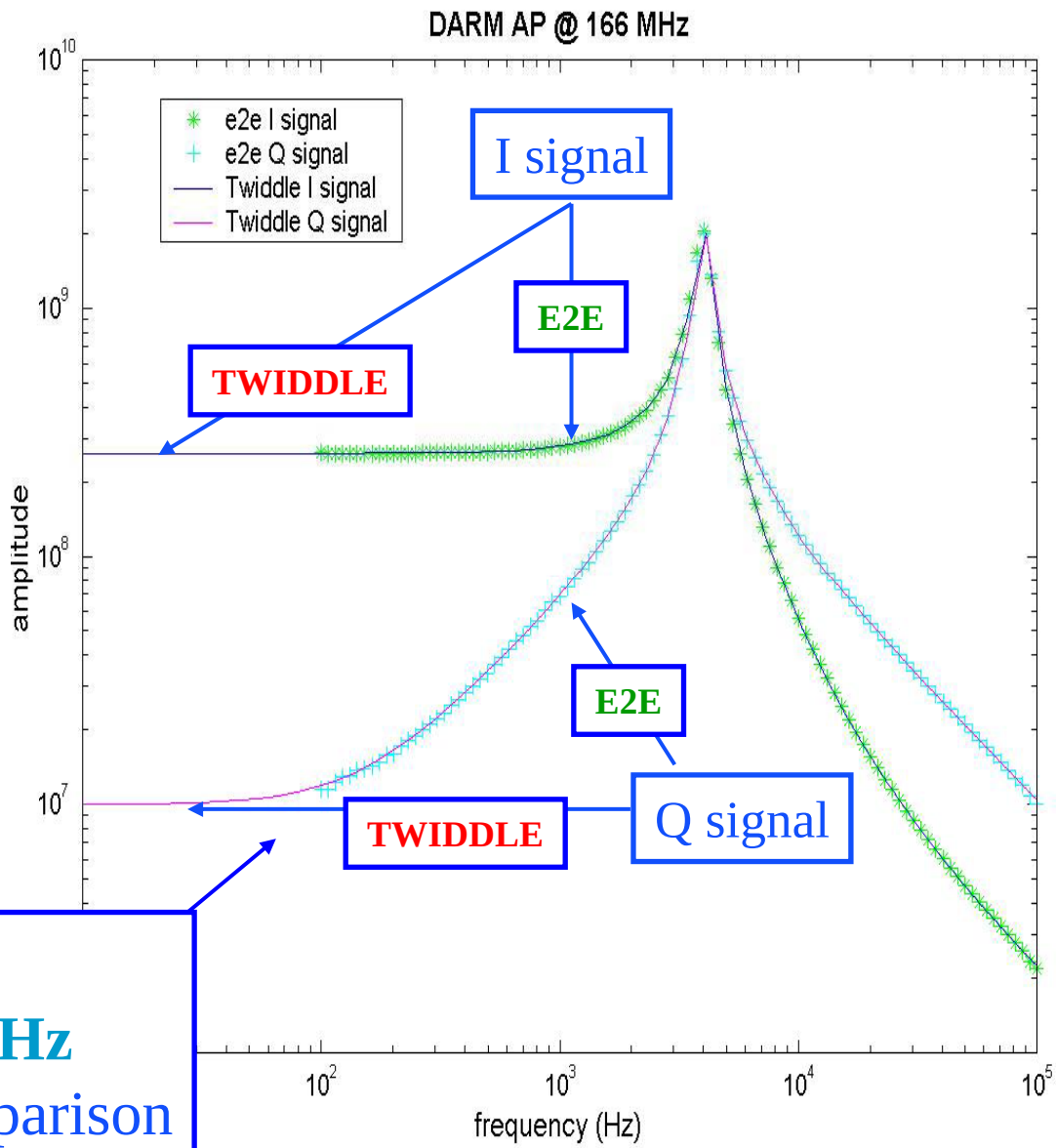




e2e SIMULATION: 4Om/AdvLIGO package

• E2E validation of DC fields comparing with TWIDDLE results: good agreement !

• E2E transfer functions simulations (and comparison with TWIDDLE ones) of DOF at SP, AP and PO shaking the end mirrors with *white noise* at different demodulation frequencies : (33,133,166,199) MHz



Example:
DARM @ **AP 166 MHz**
TWIDDLE and E2E comparison