Low-Frequency Control Scheme for AdLIGO

Kentaro Somiya, Fumiko Kawazoe, and Osamu Miyakawa

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K.Somiya

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Motivation to change the control scheme

Default design is to use 9MHz and 180MHz

↓

But there are some possible difficulties in using 180MHz

1. L- detection is not a problem as we use DC readout
2. Double-demodulation signal will be noisy (⟶ Osamu’s talk)
3. Wave-front sensing signal is hard to get by 180MHz

Is there a good alternative?

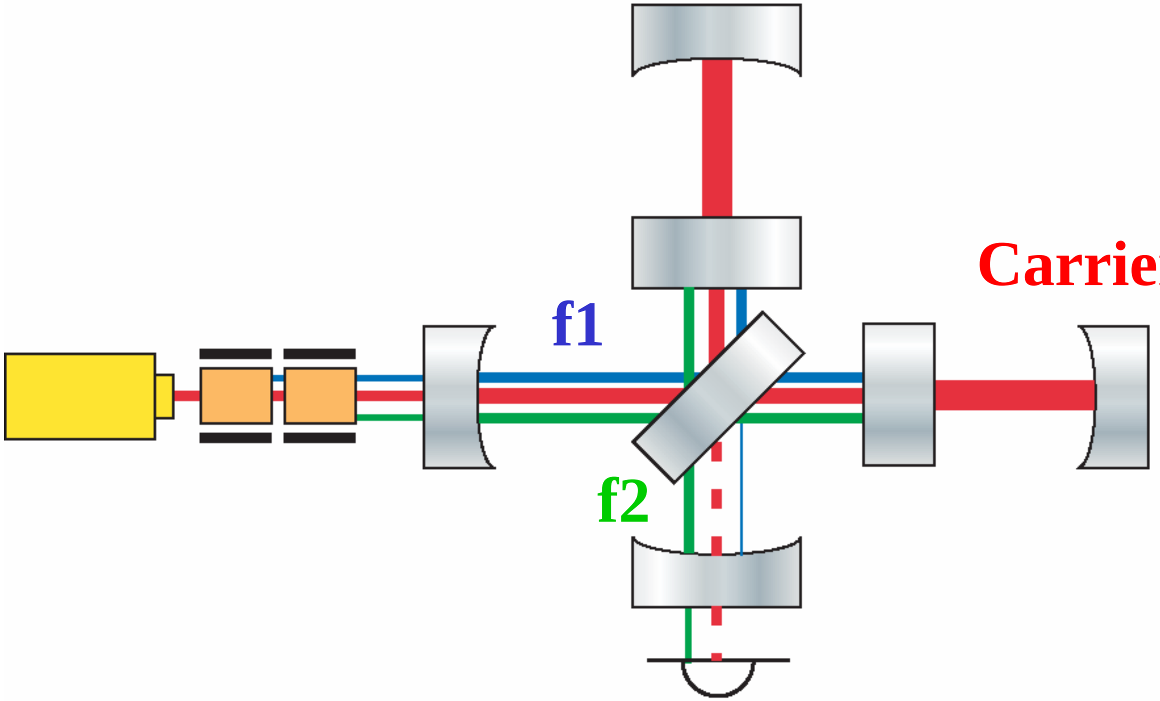
There have been many control models

	f1	f2	Asym.	By
AdLIGO	9	180	42cm	J.Mason?**
Glasgow 10m	12	120	63cm	B.Barr*
CIT tabletop	27	81	93cm	J.Mason
CIT 40m	33.2	166	45cm	to be AdLIGO
UFL tabletop	60	32	2.5m	G.Mueller
LCGT plan	150	25	3m	S.Sato**
Japan 4m	34	17	2.9m	O.Miyakawa*
Japan 4m	17	34	47cm	K.Somiya*
LF method	15	35	27cm	K.Somiya**

Not listed here are ANU, Hannover, Pol-RSE, etc.

*no PR, **no experiment

Basic concept is common in all the models

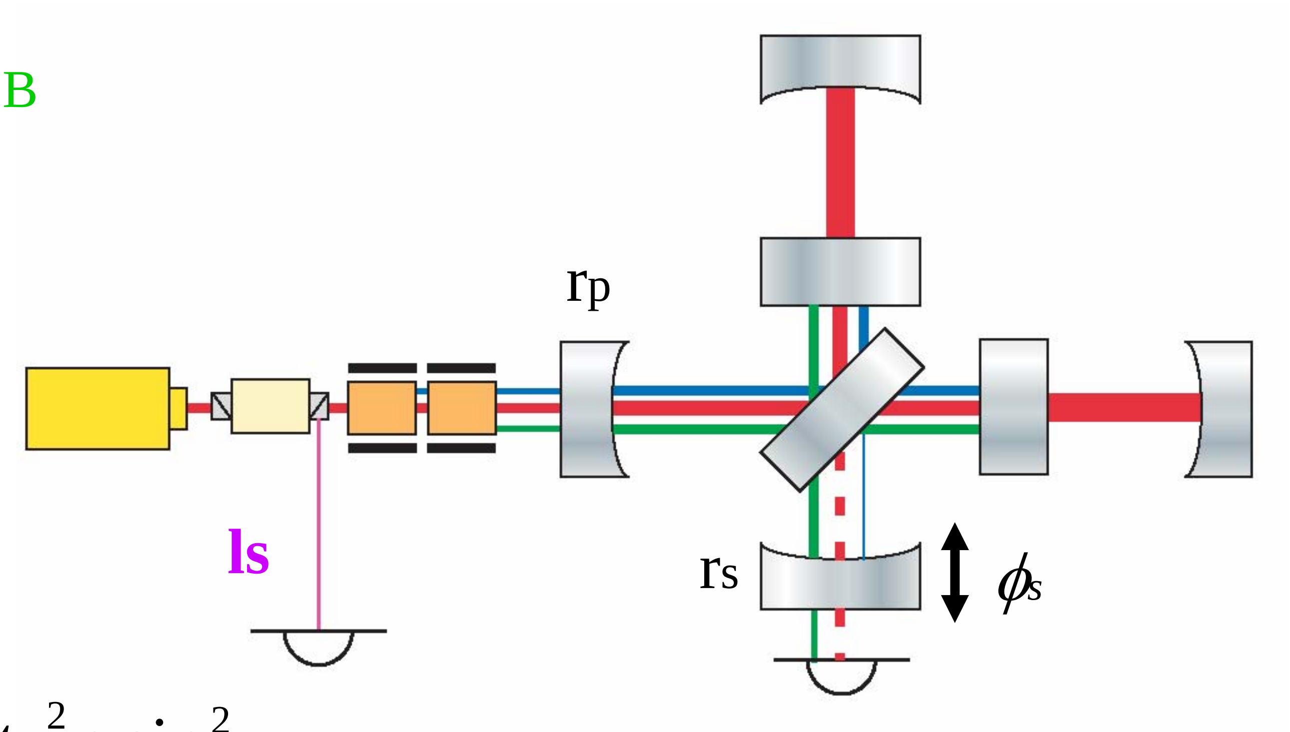


One of the SBs probes ls (SRM motion) as much as possible, and the other probes ls as little as possible to be the reference.

f1 : reso in PRC,   f2 : reso in PR-SRC

Asymmetry optimization to maximize ls on f2

$\alpha = \frac{\Delta l \omega_m}{c}$ for f2 SB

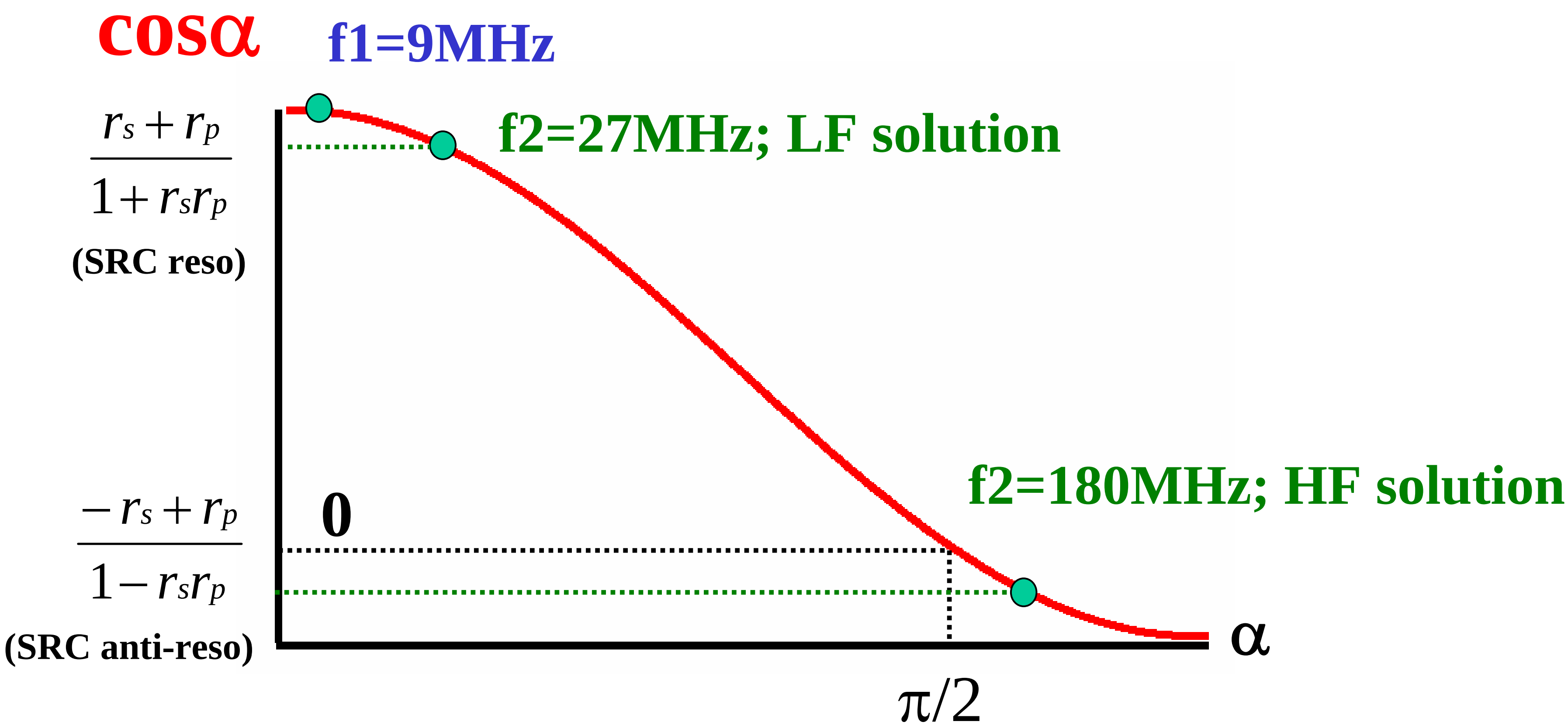


$$l_s \approx \phi_s \times \frac{i t_p^2 r_s \sin^2 \alpha}{\left(1 + r_p r_s - \left(r_p + r_s\right)\cos\alpha\right)^2}$$

Critical coupling of PR-SRC

ls is maximized when $\cos\alpha = \frac{r_s + r_p}{1 + r_s r_p}$

There are two solutions

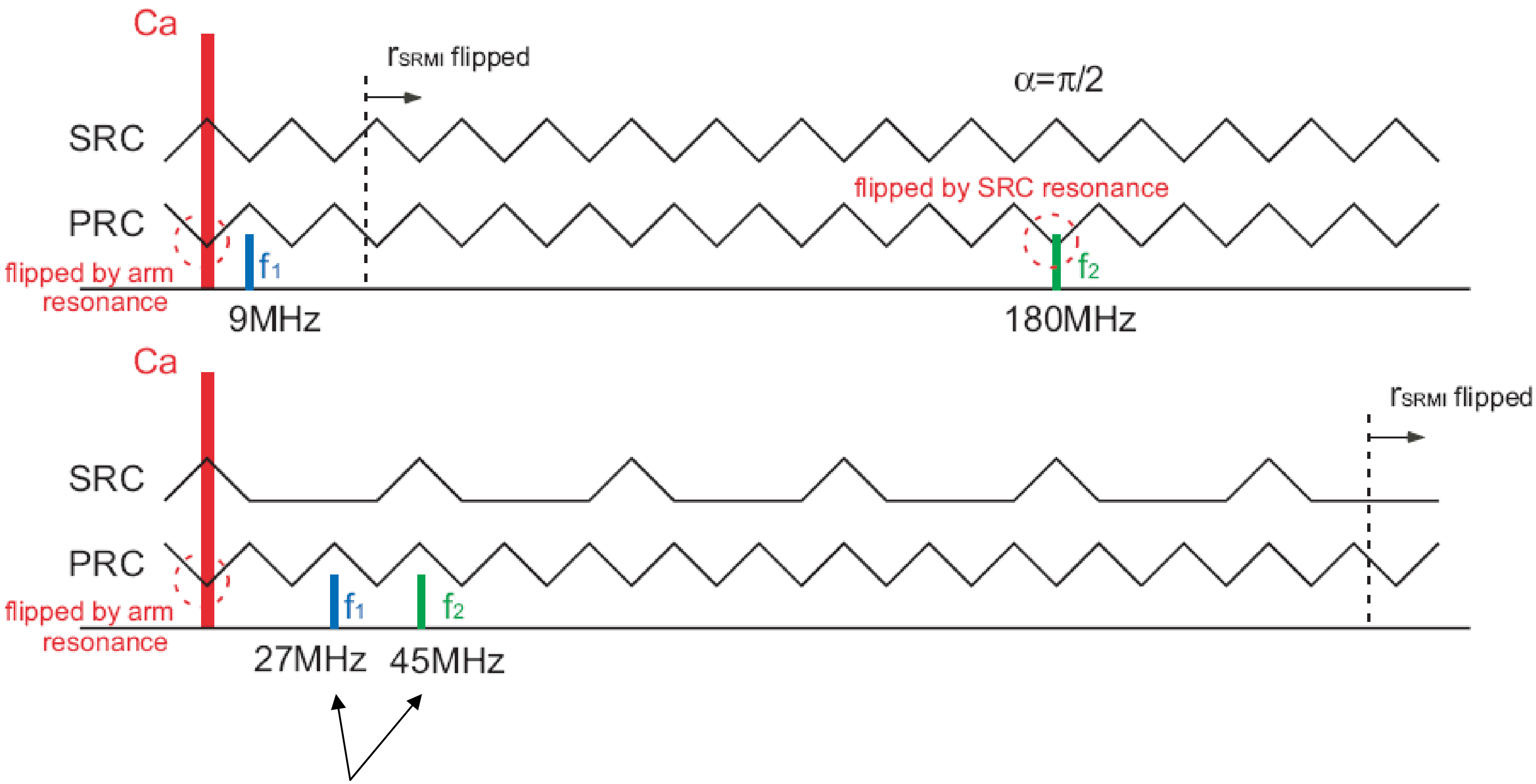


LF solution ⟶ Tested in Japan 4m w/o PR

HF solution ⟶ AdLIGO default control model

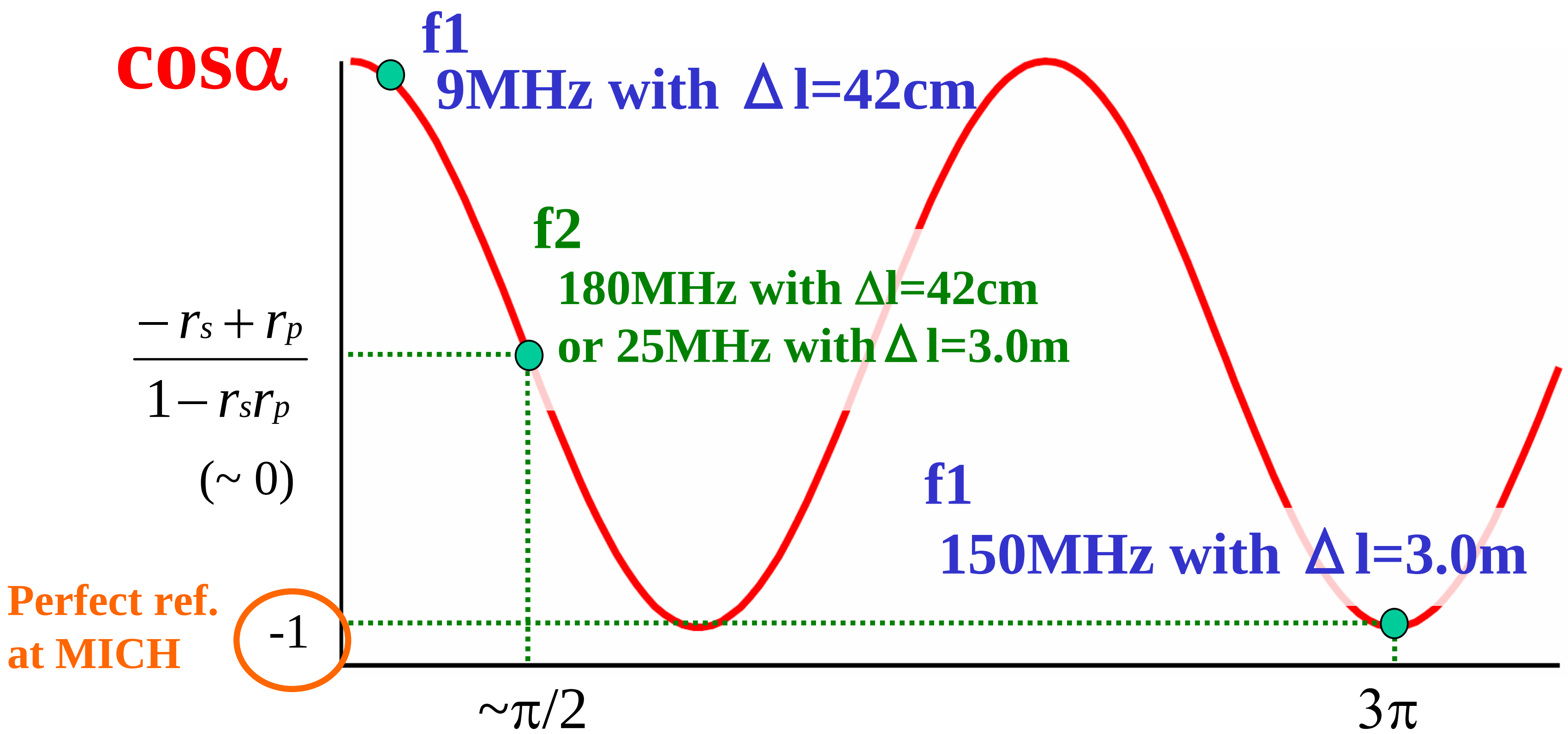
LF Common Multiple

Harmonics problem shall be avoided by the use of common multiple.



Common multiple of 9MHz
(FSR of PRC and MC are same as the default plan)

Asymmetry for f1 SB not to probe ls



α should be either very small (~0.1rad) or very big (~nπ).

Again we have two kinds of solution.

⇨ **Control models can be categorized to 2x2=4 types**

4 types of control methods

Ref. Kokeyama et al (Amaldi6 Proceedings)

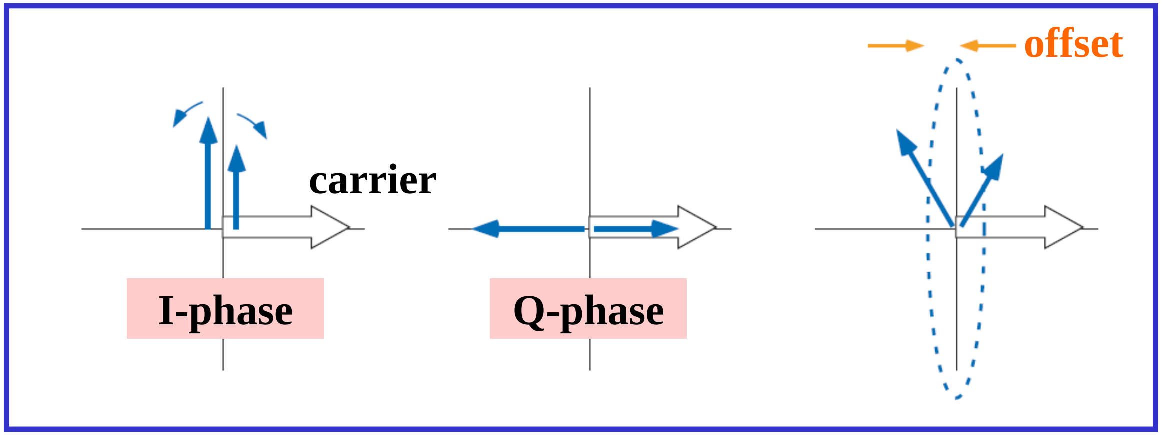
		f1(reso at PRC)	
		~0.1rad	π or 3π
f2(reso at PRSRC)	~π/2	**L-H (Caltech)** 9-90MHz, 84cm **Enough experience at 40m**	**H-H (Florida)** 180-81MHz, 84cm **No imbalance on 180MHz**
	0.036rad	**L-L (Japan)** 27-45MHz, 4cm **Low freq. & small asym.**	**H-L (hasn't been tried)** 390-9MHz, 38cm **No imbalance, small asym.**

I think the LF-multiple is most hopeful,
but we should be careful of practical problems

Offset problem

Single demodulation in FPMI

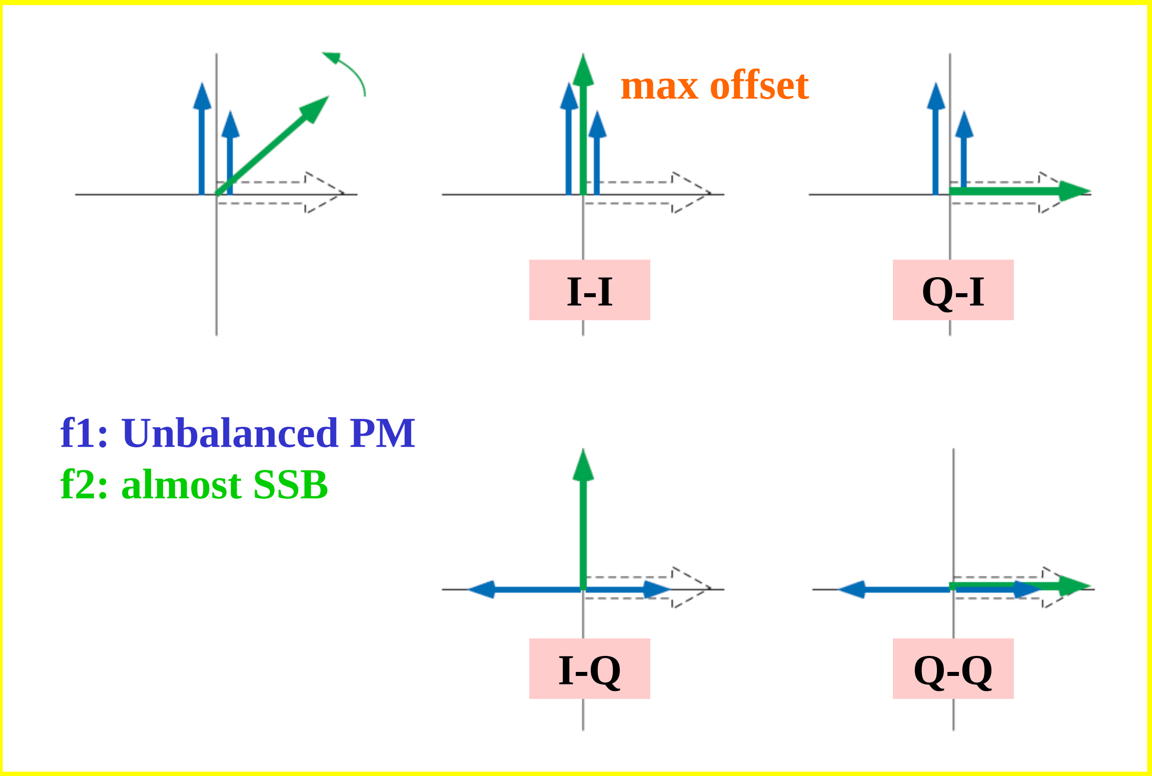
Offset appears due to imbalance between U/L SB.
The max. value of the offset can limit the power at PDs.



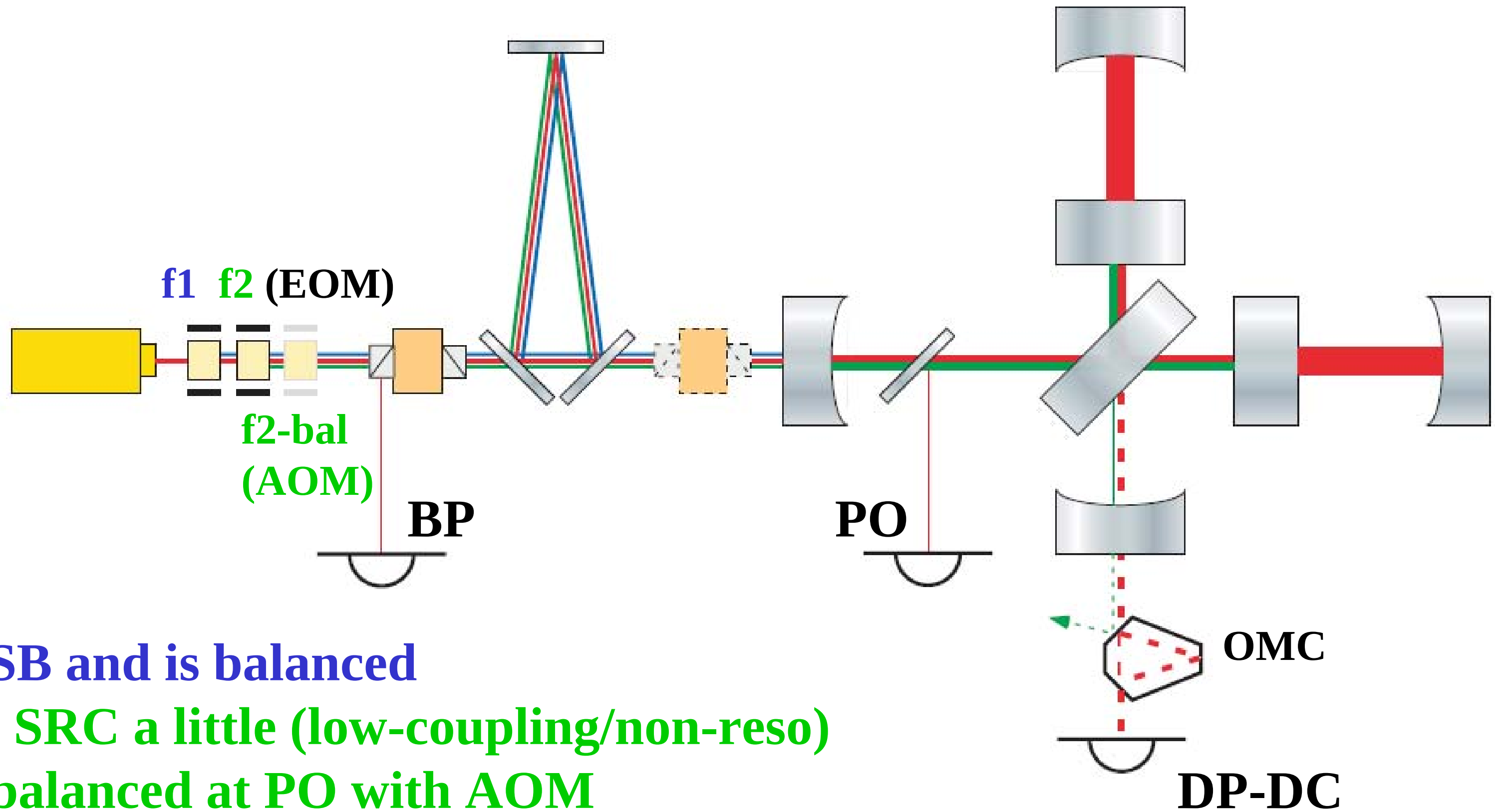
Also there can be common phase-shift of SB.

Double demodulation in DRSE

f2 is significantly unbalanced by influence of the detuning, and f1 is unbalanced due to its leaking through the SRC.
Offset is unavoidable if there are both f1 and f2; and is huge!



One possibility is not to use DDM



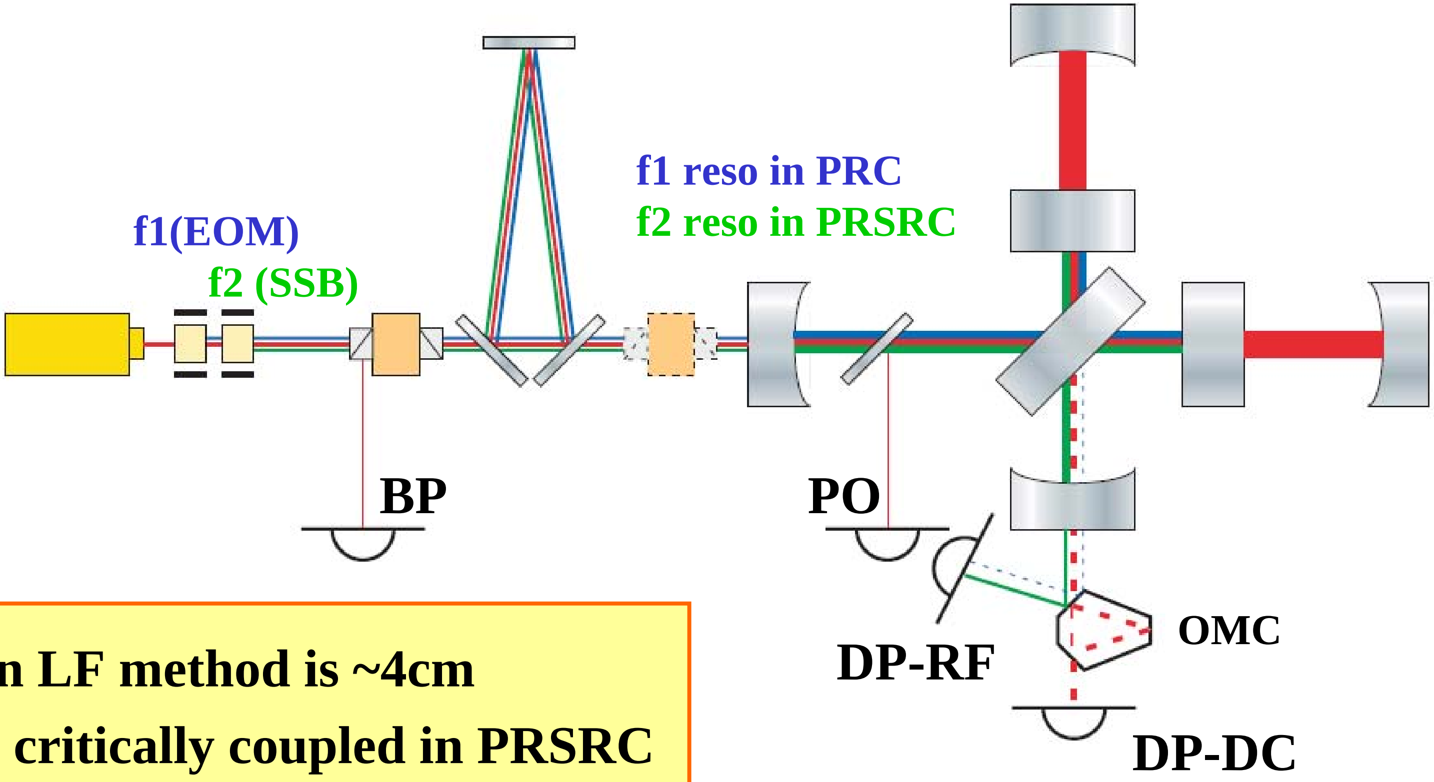
- f1 is non-reso SB and is balanced
- f2 transmits to SRC a little (low-coupling/non-reso)
- f2 can also be balanced at PO with AOM

- L- is taken from DP-DC
- L+, l+, l-, and ls may be taken from PO-f2-I/Q and BP-f1/f2-I/Q

- But I think l- feedback noise will be much bigger and may limit the sensitivity.

Even if we use DDM,

Offset can be removed with CC-SSB of LF scheme



- Asymmetry in LF method is ~4cm
- f2 is SSB and critically coupled in PRSRC

→ **At BP are balanced f1 and carrier so that there's no offset.**
At DP-RF is only SSB f2 so that there's no offset too.

L- is taken from DP-DC, L+ and l+ are from BP/PO f1,
l- is from DP-RF-DDM, and ls is from BP-DDM.

My opinion (Summary)

LF-multiple is good in the sense that

- **frequencies of RF SBs are low**
- **it is applicable to AdLIGO without big changes**
- **the offset problem can be relaxed with SSB-f2.**

We need quantitative evaluation!

Appendices

Shot-noise-limited Feedback noise from l-, l+, ls

Example

	L+	L−	l+	l−	ls
L+	1	0.003	−0.002	0	0
L−	0	1	0	0.00125	0
l+	−0.004	0.005	1	0.064	0.376
l−	0.001	0.006	0.015	1	0.017
ls	0.003	0.009	0.289	−0.159	1

1st-order contribution:

Shot noise on l- detection moves mirrors in l-,
and 0.00125 of that appears in L-. **(The motion depends on the servo.)**

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1st-order contribution:

Shot noise on l- detection moves mirrors in l-, and 0.00125 of that appears in L-. **(The motion depends on the servo.)**

2nd-order contribution:

Shot noise on l+/ls detection moves mirrors in l+/ls, and 0.015 or 0.017 of them appears in l-, 0.00125 of which appears in L-. **(The motion depends on the servo.)**

Is it better to obtain l- from BP FDM?

Rough estimation of l- shot noise at each port:

DP-DDM

LO is f2

$$\ell_- \sim \frac{\sqrt{m_1^2 + m_2^2}}{m_1 m_2} \frac{1}{\cos\alpha(f1)} \frac{1}{\sin\alpha(f2)}$$

BP-FDM(f1)

LO is carrier

$$\ell_- \sim \frac{1}{m_1} \frac{1}{\sin\alpha(f1)}$$

← **bigger shot noise**
also vacuum from PO

BP-FDM(f2)

LO is carrier

$$\ell_- \sim \frac{1}{m_2} \frac{1}{\sin\alpha(f2)}$$

← **as small as DP-DDM**
but the same HF problem