Re-considering bKAGRA EOM layout

May 2017
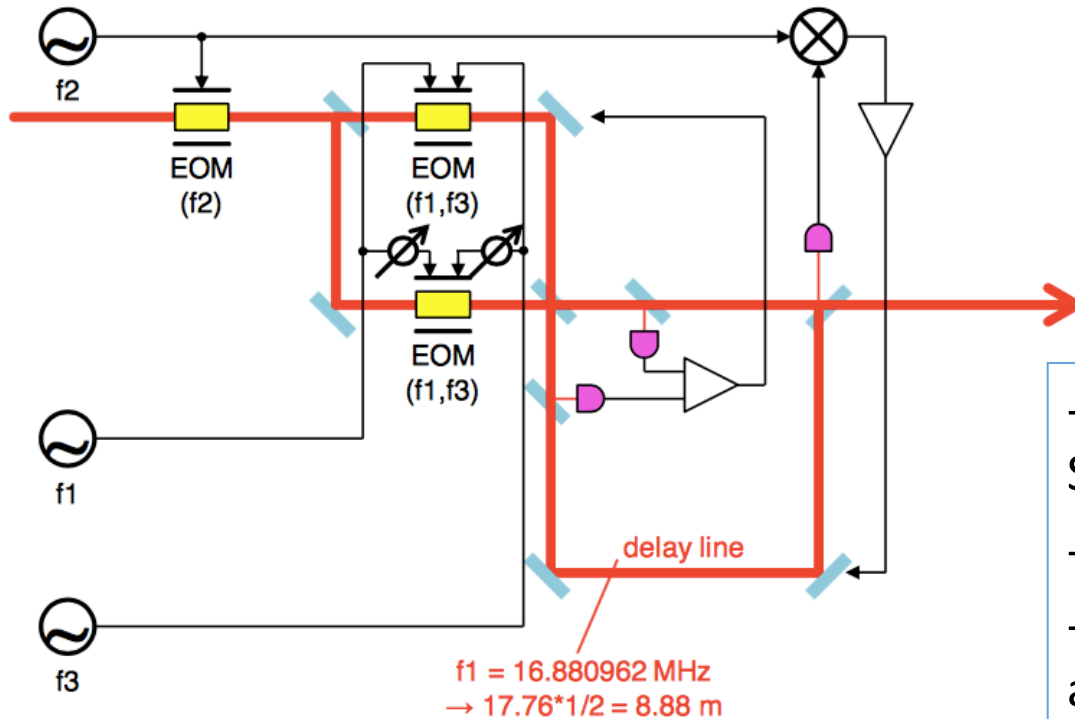
Yutaro Enomoto

default plan

default plan

JGW-D1503189-v3

Layout 3

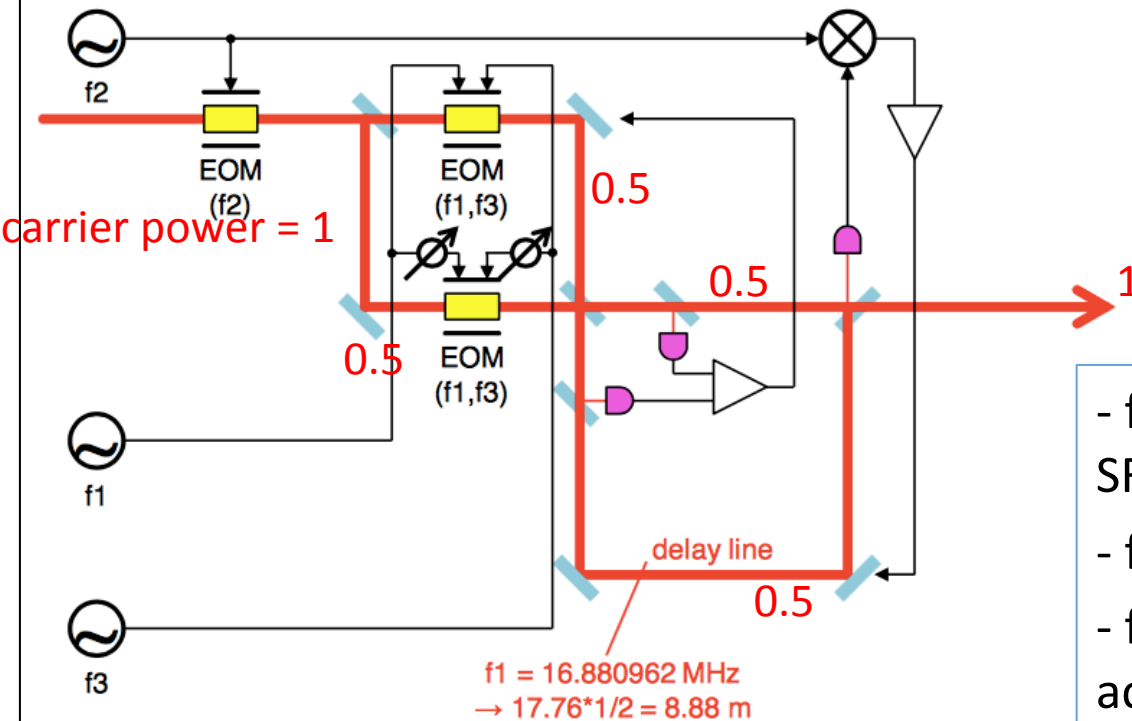- Simpler, but loses some f3 AM

oscillator
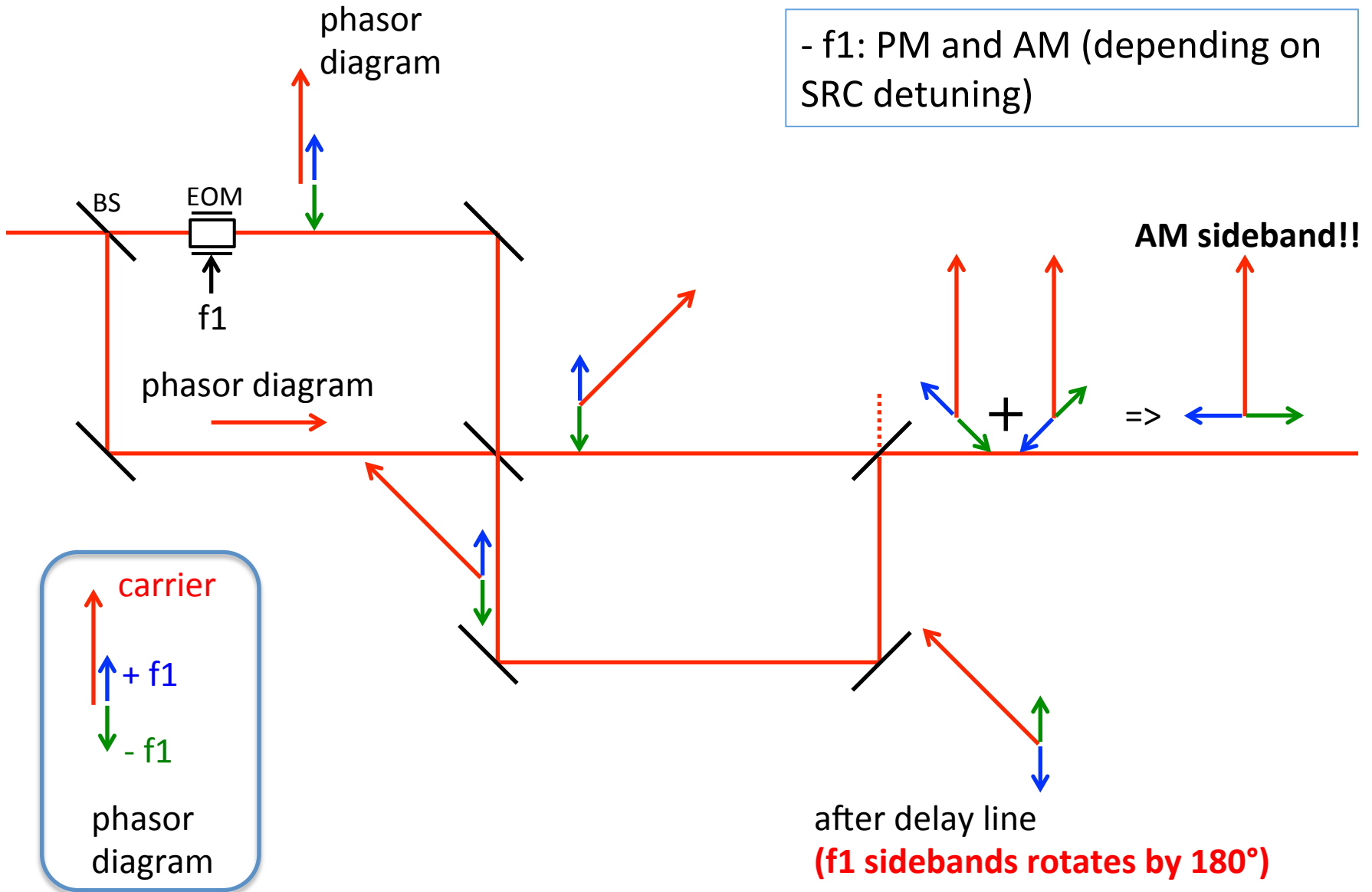mixer
phase shifter

- f1: PM and AM (depending on SRC detuning)
- f2: PM only
- f3: AM only (used only for lock acquisition phase)

carrier power = 1

EOM (f2)

EOM (f1,f3)

EOM (f1,f3)

0.5

0.5

0.5

0.5

1

delay line

f1 = 16.880962 MHz
→ 17.76*1/2 = 8.88 m

f2

f1

f3

= Let us focus on f1 =

phasor diagram

- f1: PM and AM (depending on SRC detuning)

BS   EOM

f1

phasor diagram

AM sideband!!

+   =>

carrier

+ f1

- f1

phasor diagram

after delay line
(f1 sidebands rotates by 180°)

= Let us focus on f1 =

- f1: PM and AM (depending on SRC detuning)

BS

AM sideband!!

EOM

f1

$+$ =>

carrier

$+ f1$

$- f1$

phasor
diagram

after delay line
(f1 sidebands rotates by 180°)

= Let us focus on f1 =

- f1: PM and AM (depending on SRC detuning)
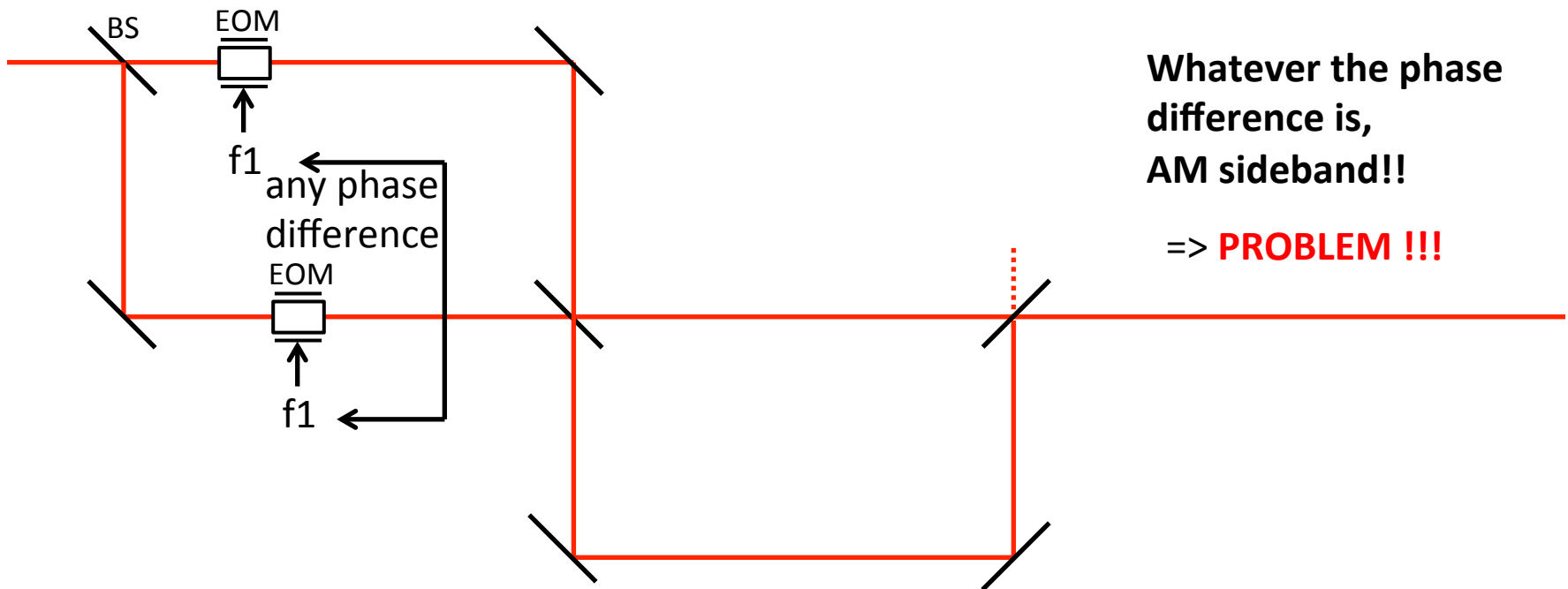
Whatever the phase difference is, AM sideband!!

=> **PROBLEM !!!**

after delay line
(f1 sidebands rotates by 180°)

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alternative plan

JGW-D1503189-v3

Layout 3

- Simpler, but loses some f3 AM

oscillator

mixer

phase shifter

f2

EOM
(f2)

EOM
(f1,f3)

EOM
(f1,f3)

f1

f3
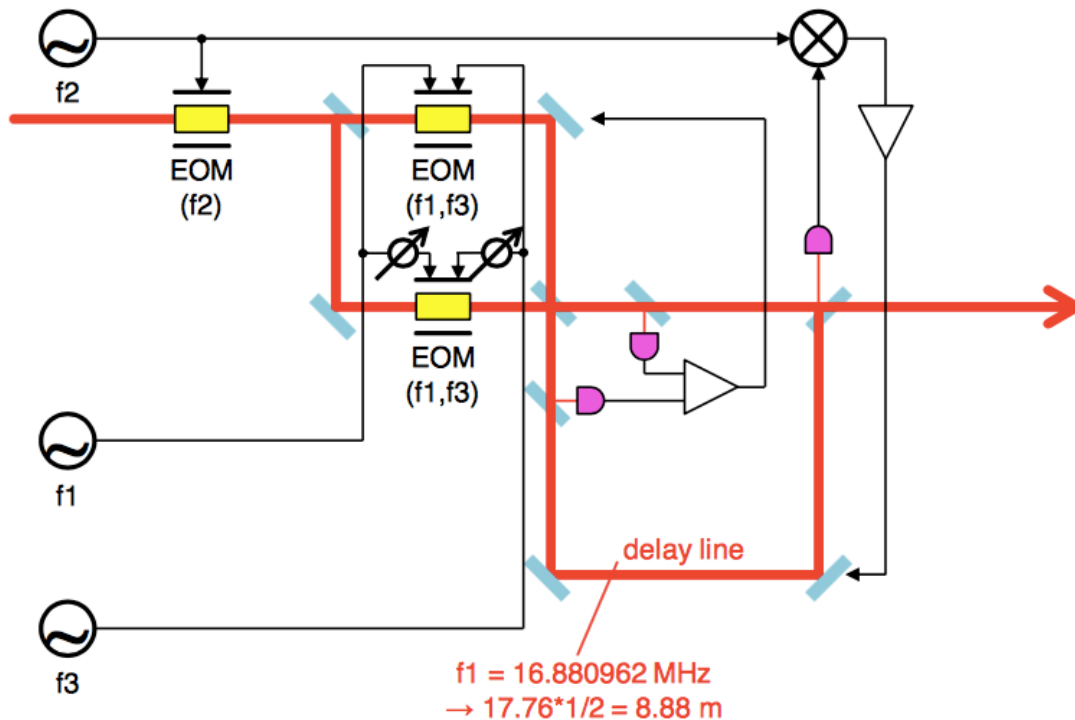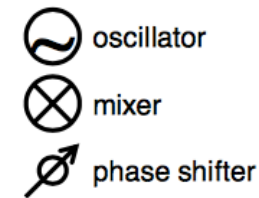
delay line

$f1 = 16.880962$ MHz
$\rightarrow 17.76*1/2 = 8.88$ m

=> change to 2.66 m

- f1: PM and AM (depending on SRC detuning)

- f2: PM only

- f3: AM only (used only for lock acquisition phase)

alternative plan

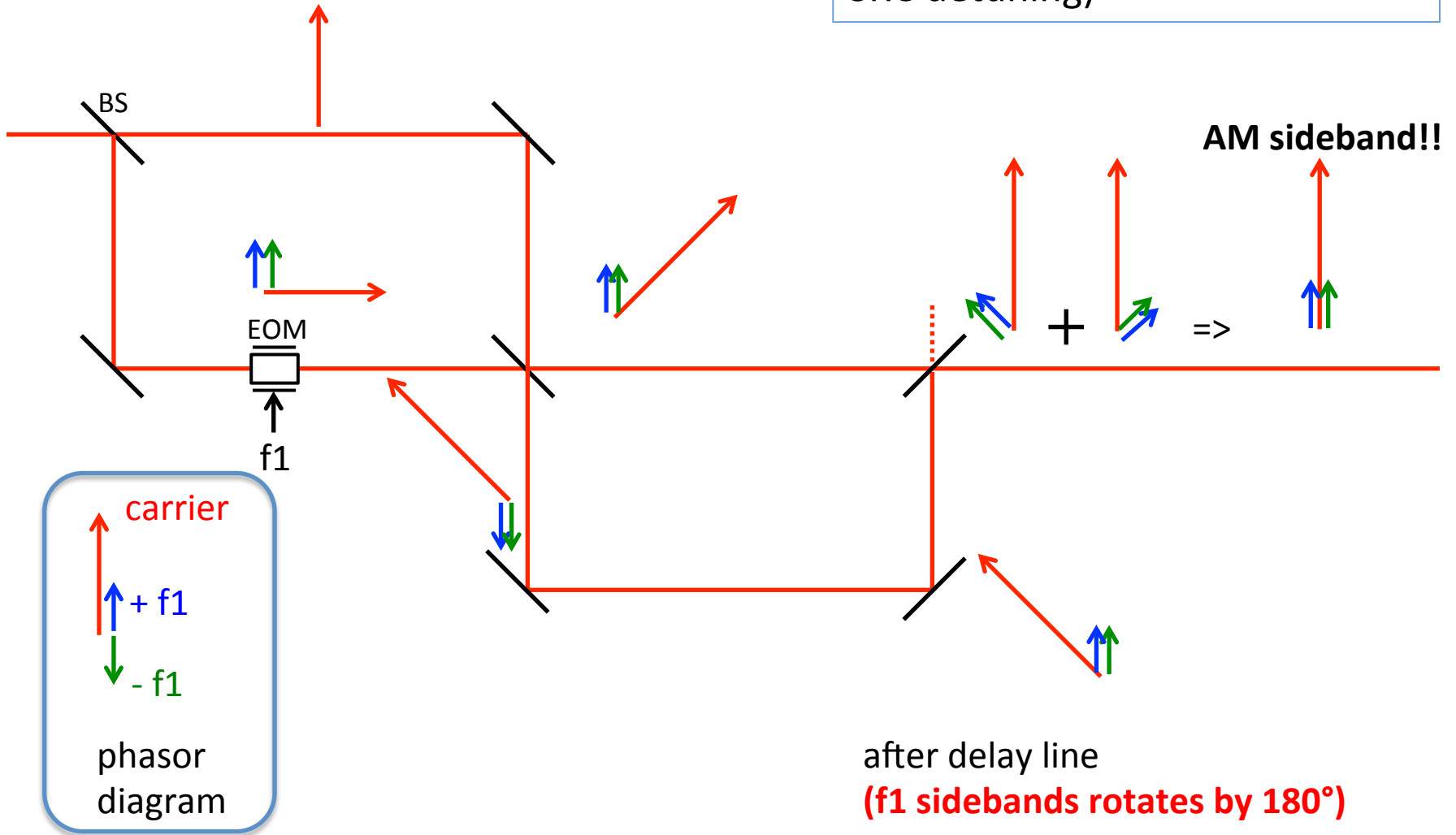$$A + m(e^{i\omega_m t} - e^{-i\omega_m t})$$

BS   EOM

fm

phase difference φ

EOM

fm

$$A + m(e^{i(\omega_m t + \phi)} - e^{-i(\omega_m t + \phi)})$$

delay line
(fm sidebands rotates by θ)

$$2A + m\left\{ \left[\cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) e^{i\phi} \right] e^{i\omega_m t} \right.$$
$$\left. - \left[\cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) e^{-i\phi} \right] e^{-i\omega_m t} \right\}$$
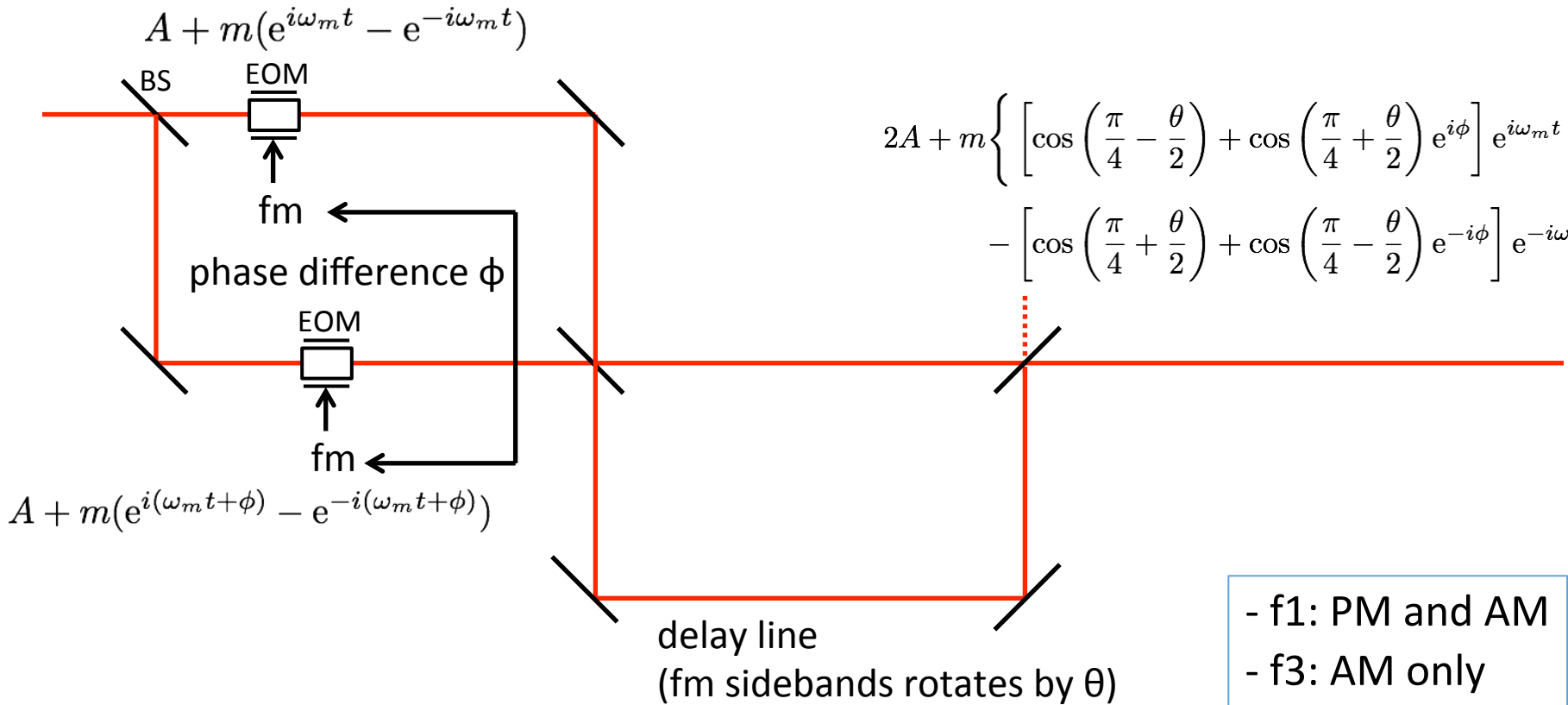
- f1: PM and AM
- f3: AM only

alternative plan

$$A + m(e^{i\omega_m t} - e^{-i\omega_m t})$$

BS   EOM

fm

phase difference φ

EOM

fm

$$A + m(e^{i(\omega_m t+\phi)} - e^{-i(\omega_m t+\phi)})$$

$$2A + m\left\{ \left[\cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) e^{i\phi} \right] e^{i\omega_m t} \right.$$

$$\left. - \left[\cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) e^{-i\phi} \right] e^{-i\omega_m t} \right\}$$

delay line
(fm sidebands rotates by θ)
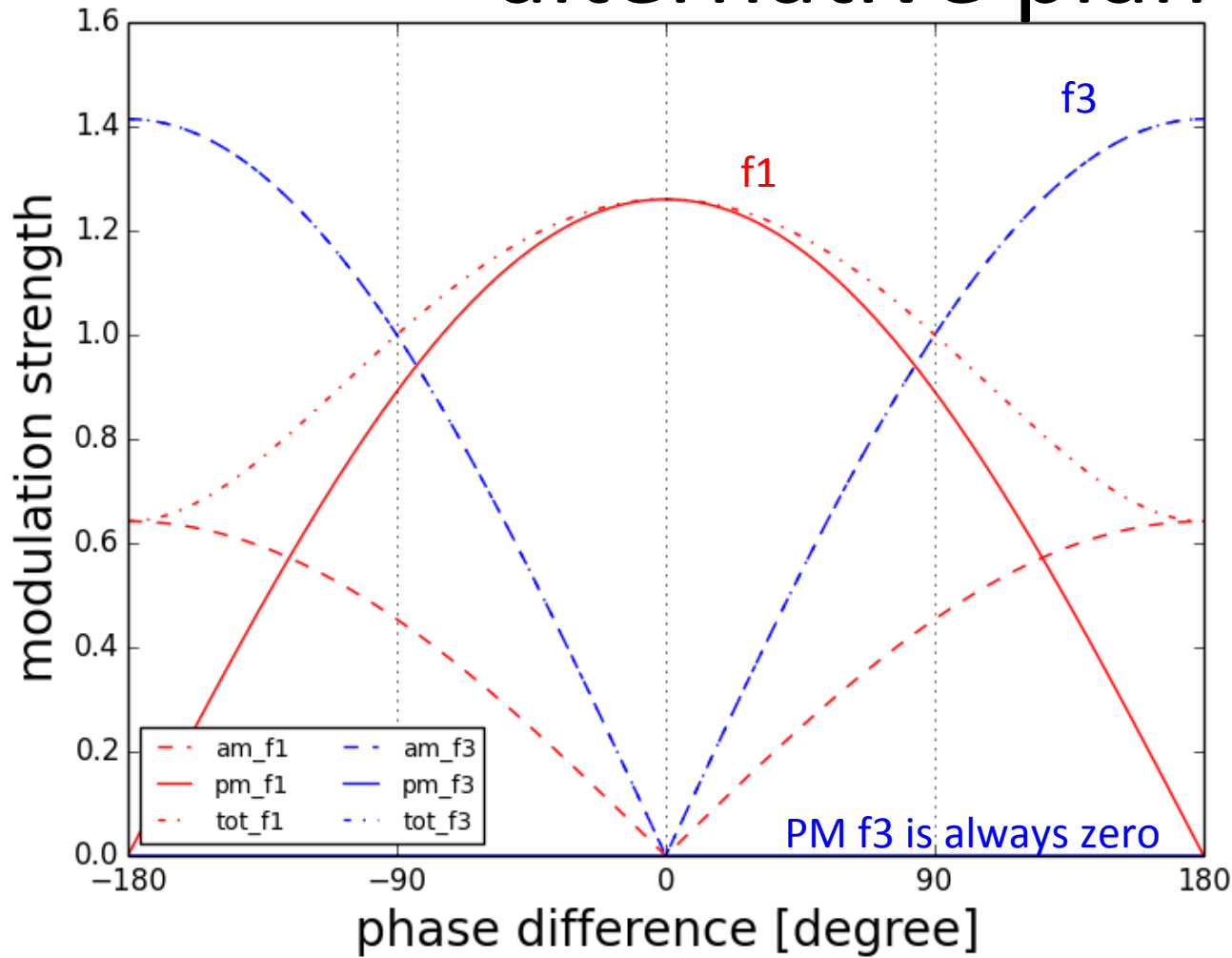
- f1: PM and AM
- f3: AM only
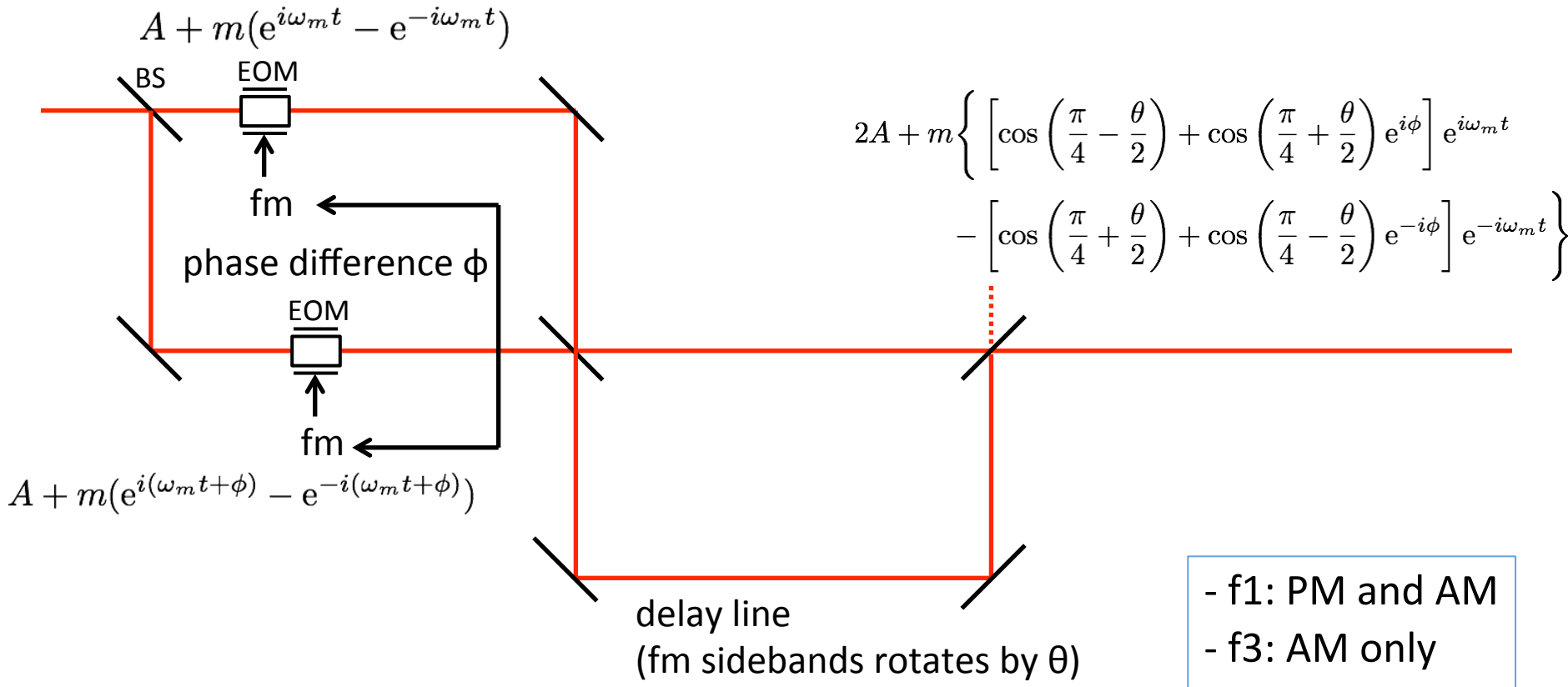
delay line 2.66 m --> $\theta(f_1) = 54°$ --> combination of PM and AM (next page)

$\theta(f_3) = 180°$ --> AM only (φ=180° is preferable)

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alternative plan

PM f3 is always zero
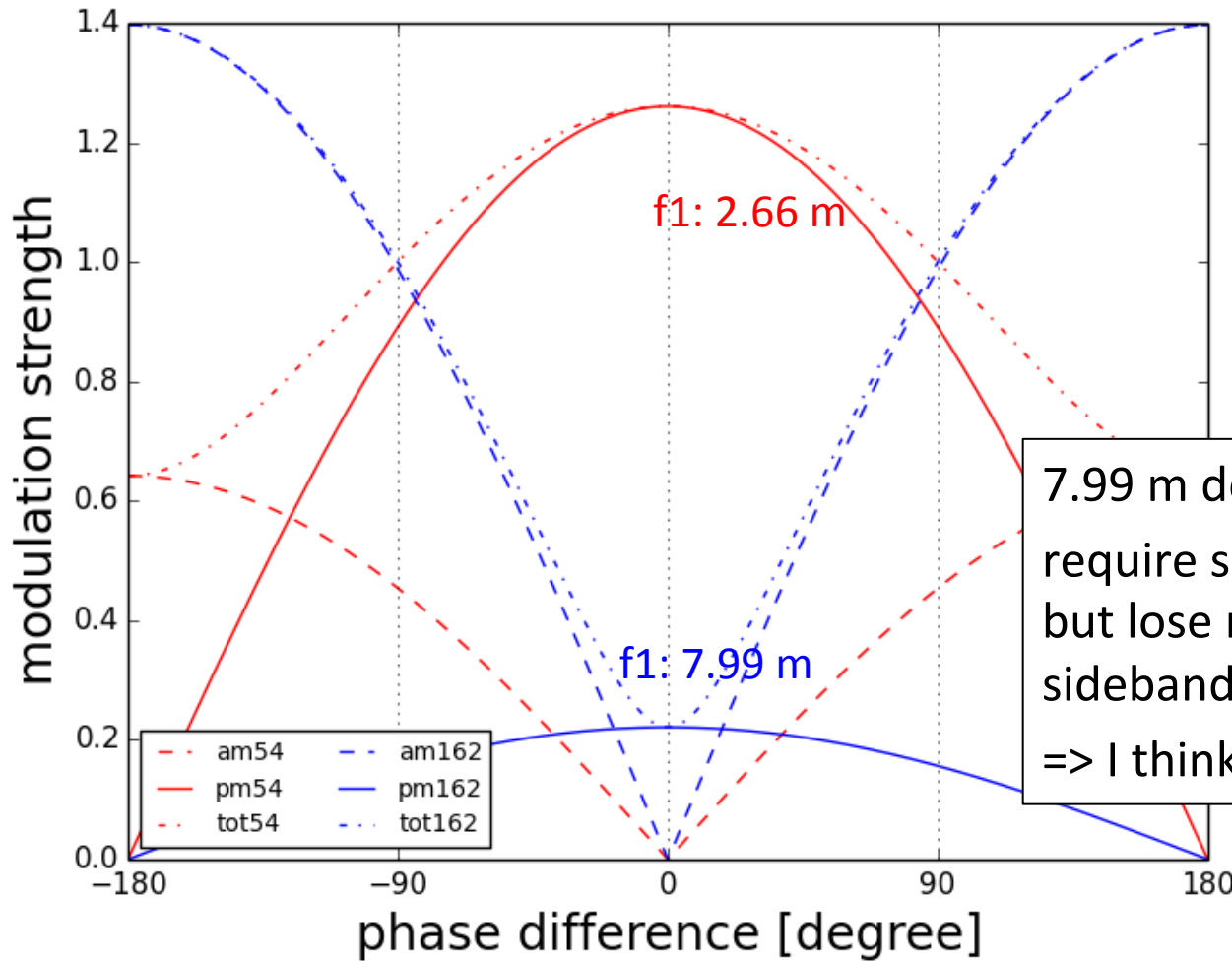
- f1: PM and AM
- f3: AM only

delay line 2.66 m --> $\theta(f_1) = 54°$

$\theta(f_3) = 180°$

$$2A + m\left\{ \left[\cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) e^{i\phi} \right] e^{i\omega_m t} \right.$$

$$\left. - \left[\cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) e^{-i\phi} \right] e^{-i\omega_m t} \right\}$$

2.66 m vs. 7.99 m

f1: 2.66 m

f1: 7.99 m

Legend:
- am54 (red dash-dot)
- pm54 (red solid)
- tot54 (red dotted)
- am162 (blue dashed)
- pm162 (blue solid)
- tot162 (blue dash-dot)

7.99 m delay line is also OK.

require smaller changes of design, but lose much more power of f1 sideband to create AM at f1

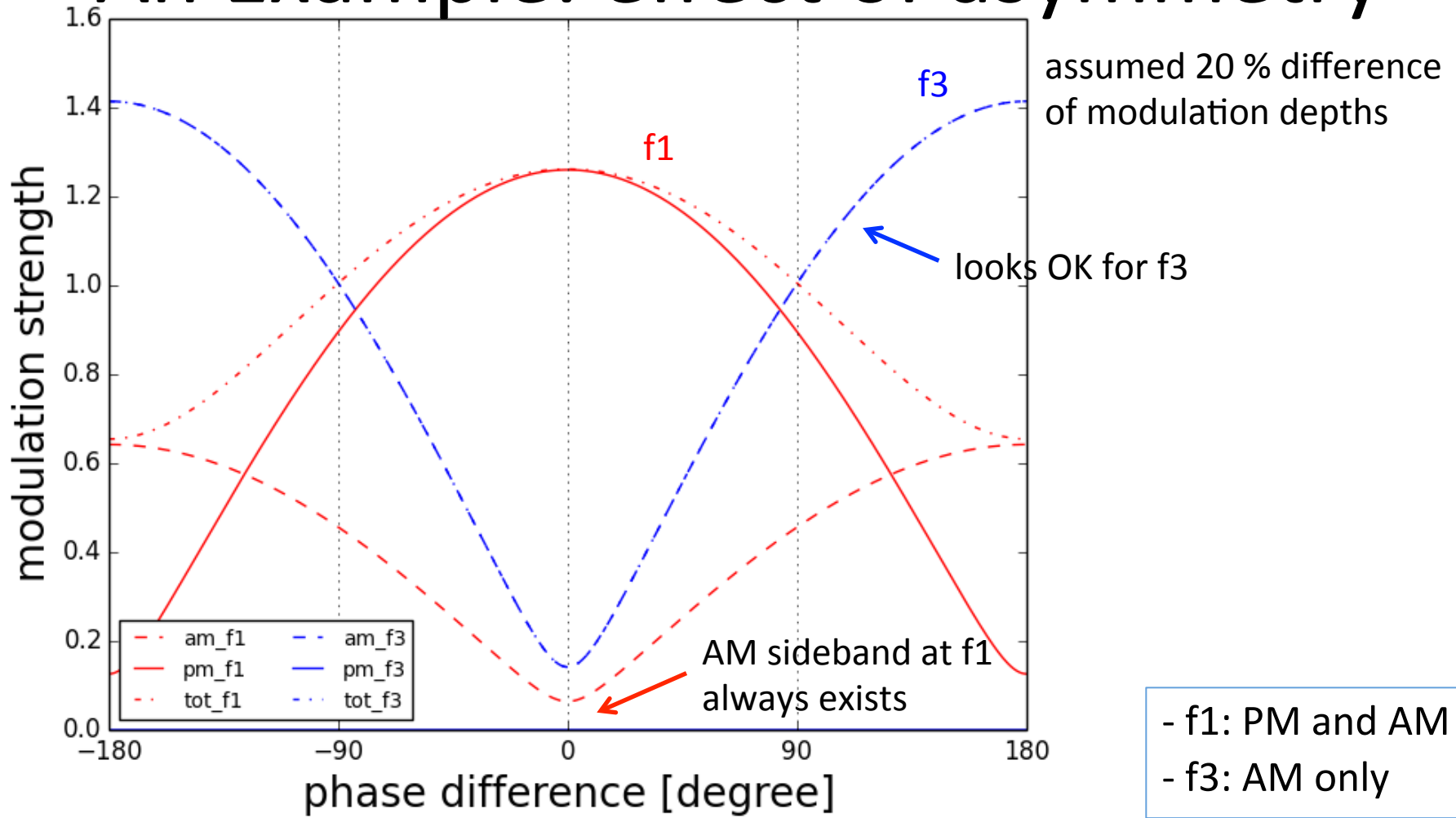=> I think 2.66 m is better.

- f1: PM and AM
- f3: AM only

delay line 2.66 m --> $\theta(f_1) = 54°$
delay line 7.99 m --> $\theta(f_1) = 162°$

$$2A + m\left\{ \left[\cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) e^{i\phi} \right] e^{i\omega_m t} \right.$$

$$\left. - \left[\cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) e^{-i\phi} \right] e^{-i\omega_m t} \right\}$$

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Remaining issues

-- Probably we need some control on the phase difference.

  - How can we the phase difference? Resonant EOM => phase of transfer function modulation/applied voltage can be different for two EOMs and can even be time dependent.

-- We need to consider the effect of asymmetries with respect to the requirement; modulation depths of two EOMs, non-perfect mid-fringe lock, non-perfect dark-fringe lock, etc..

-- and what else?

An Example: effect of asymmetry

assumed 20 % difference of modulation depths

f3

f1

looks OK for f3

AM sideband at f1 always exists

- f1: PM and AM
- f3: AM only

delay line 2.66 m --> $\theta(f_1) = 54°$

$\theta(f_3) = 180°$

$$2A + m\left\{ \left[\cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) e^{i\phi} \right] e^{i\omega_m t} \right.$$

$$\left. - \left[\cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) e^{-i\phi} \right] e^{-i\omega_m t} \right\}$$

transmissivity of f2 and fimc

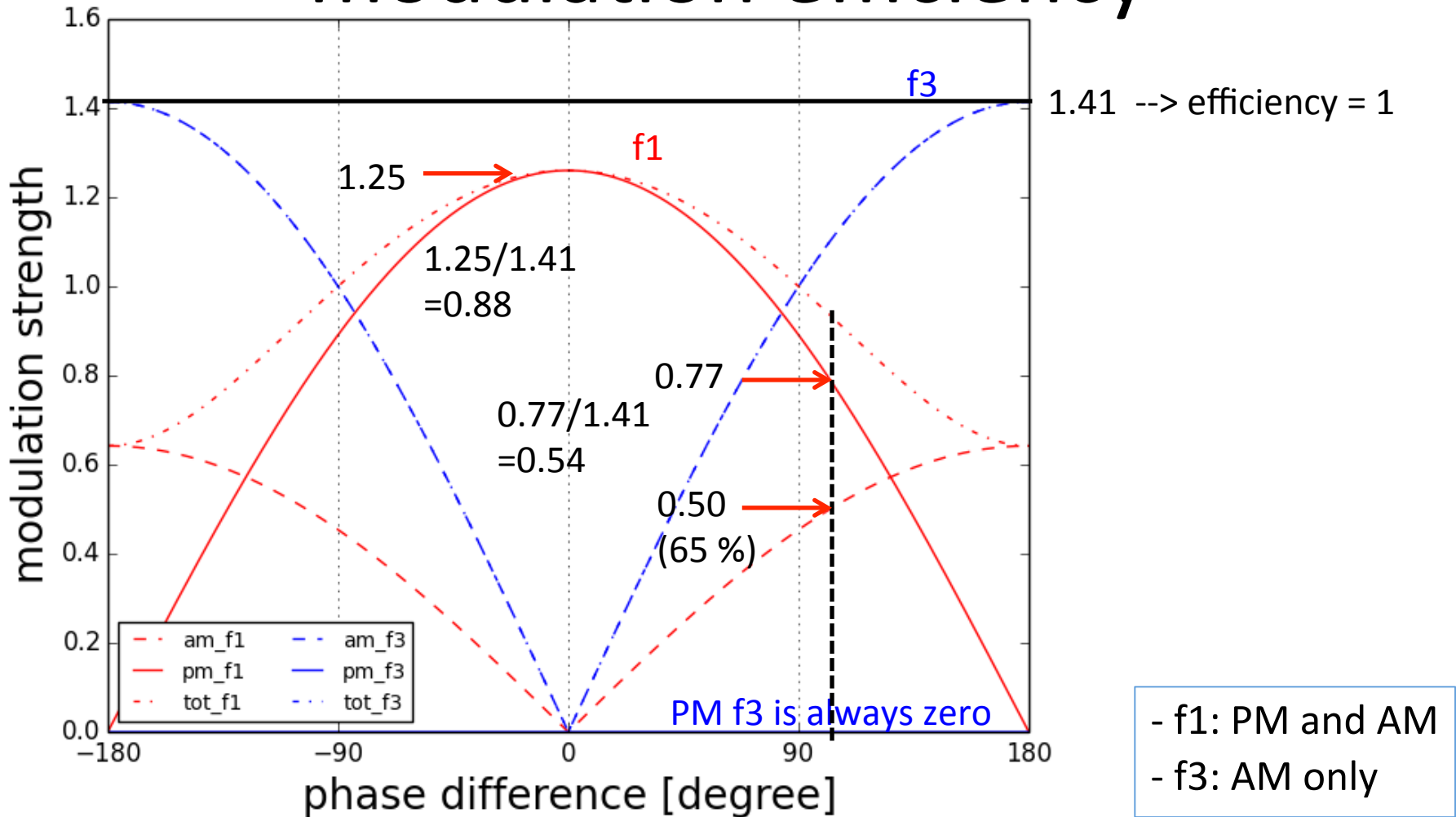amplitude transmissivity $= \left| \cos \theta / 2 \right|$

$$\theta(f_2) = 144° \quad \Rightarrow \quad 0.31$$

$$\theta(f_{\mathrm{imc}}) = 44° \quad \Rightarrow \quad 0.93$$

(assuming delay line length = 2.66 m)

modulation efficiency

1.41 --> efficiency = 1

f3

f1

1.25

1.25/1.41
=0.88

0.77

0.77/1.41
=0.54

0.50
(65 %)

PM f3 is always zero

- f1: PM and AM
- f3: AM only

delay line 2.66 m --> $\theta(f_1) = 54°$
$$\theta(f_3) = 180°$$

$$2A + m\left\{ \left[\cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) e^{i\phi} \right] e^{i\omega_m t} \right.$$

$$\left. - \left[\cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) e^{-i\phi} \right] e^{-i\omega_m t} \right\}$$

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sideband frequencies

Name	Frequency	Type	Mod. index
f1	16.880961MHz	PM	0.2rad (nominal 0.15)
f2	45.0159MHz	PM	0.1rad (nominal 0.05)
f3	56.2699MHz	AM	point of view0.05
2*f3	112.5398MHz	AM	less than ??
f1-AM	16.880961MHz	AM	65% of PM amplitude
fIMC	13.78 MHz	PM	0.025?

http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/MIFIOOInterfaces

(visited on May 22, 2017)

sideband frequencies

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f1	16.880961MHz	PM	0.2rad (nominal 0.15)
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2*f3	112.5398MHz	AM	less than ??
f1-AM	16.880961MHz	AM	65% of PM amplitude
fIMC	13.78 MHz	PM	0.025?

trans. efficiency <--	Mod. index @EOM
0.88	0.23rad (nominal 0.17)
0.31	0.32rad (nominal 0.16)
1	0.05
-	-
0.54	0.37 (nominal 0.28)
0.93	0.027 ?