Re-considering bKAGRA EOM layout

May 2017
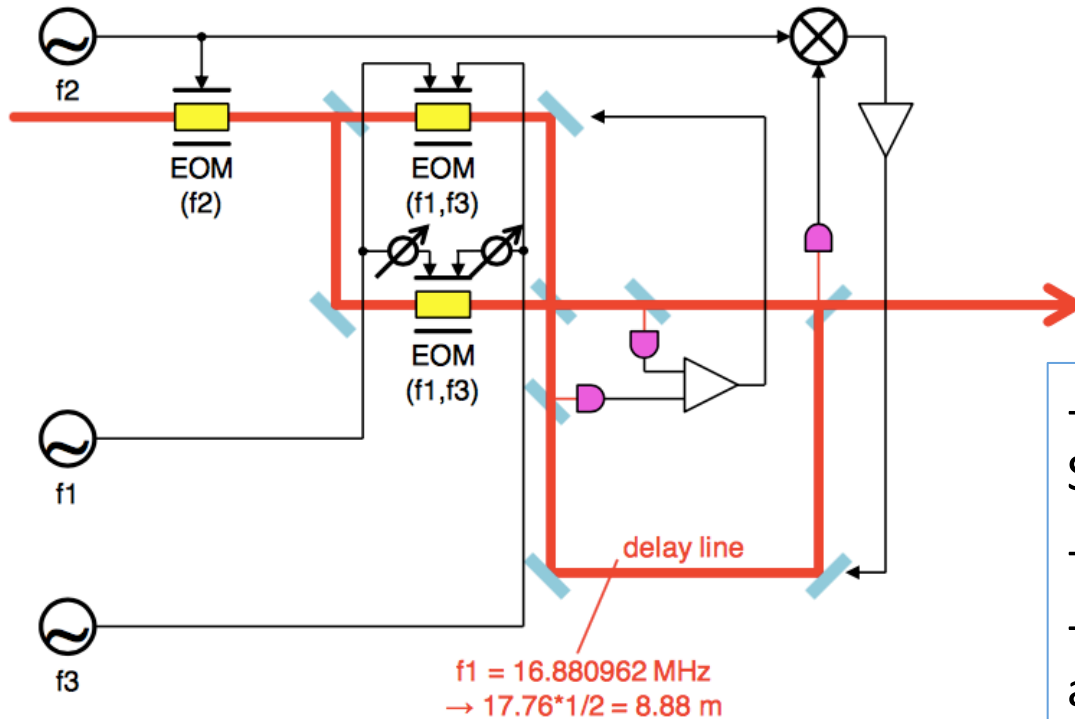
Yutaro Enomoto

default plan

JGW-D1503189-v3

Layout 3

- Simpler, but loses some f3 AM
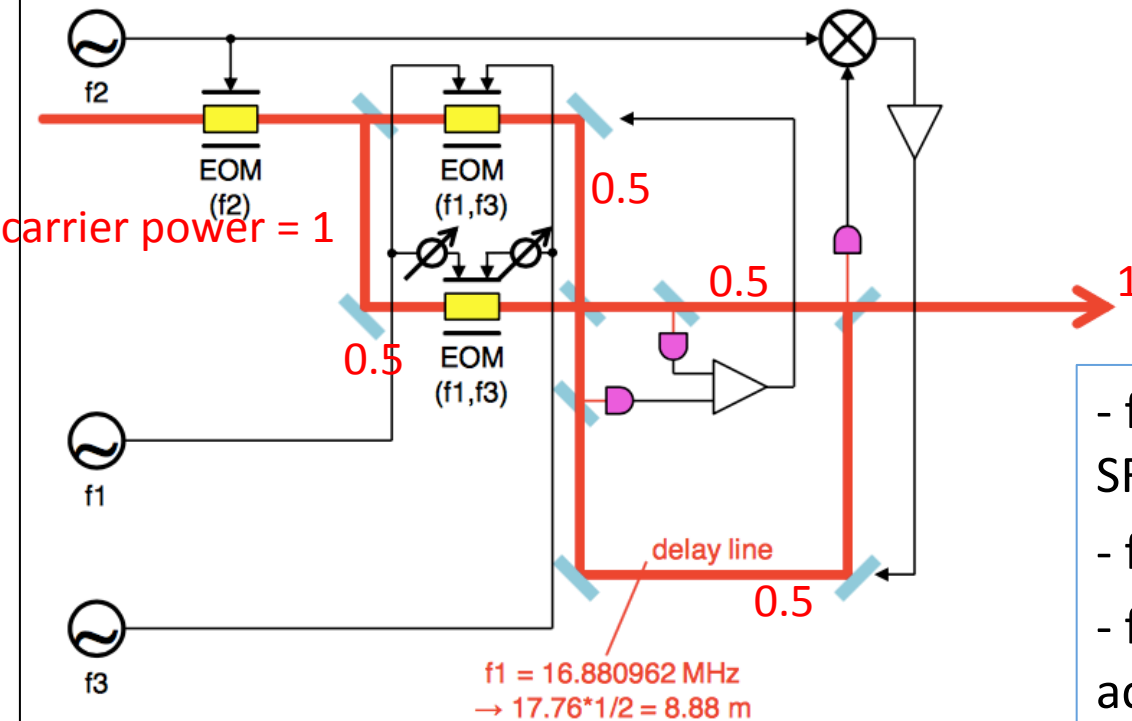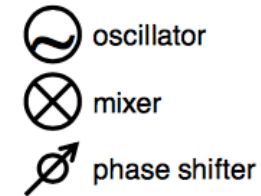
oscillator
mixer
phase shifter

f2

EOM
(f2)

EOM
(f1,f3)

EOM
(f1,f3)

f1

f3

delay line

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

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

1

default plan

JGW-D1503189-v3

Layout 3

- Simpler, but loses some f3 AM

oscillator
mixer
phase shifter

f2

EOM (f2)

carrier power = 1

EOM (f1,f3)

0.5

0.5

0.5

EOM (f1,f3)

1

f1

delay line

0.5

f3

f1 = 16.880962 MHz
→ 17.76*1/2 = 8.88 m
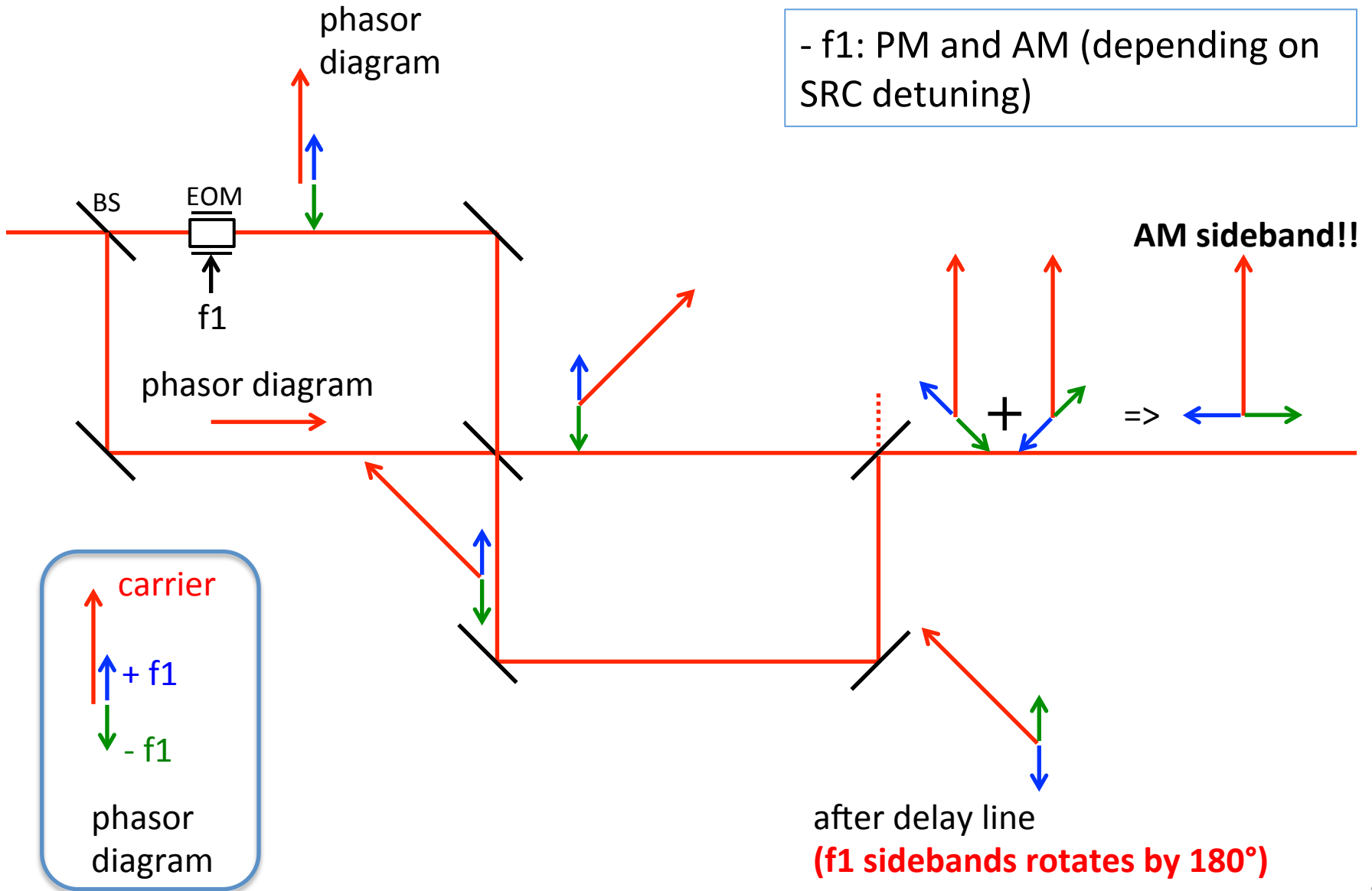
- f1: PM and AM (depending on SRC detuning)
- f2: PM only
- f3: AM only (used only for lock acquisition phase)

= 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

EOM

f1

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)
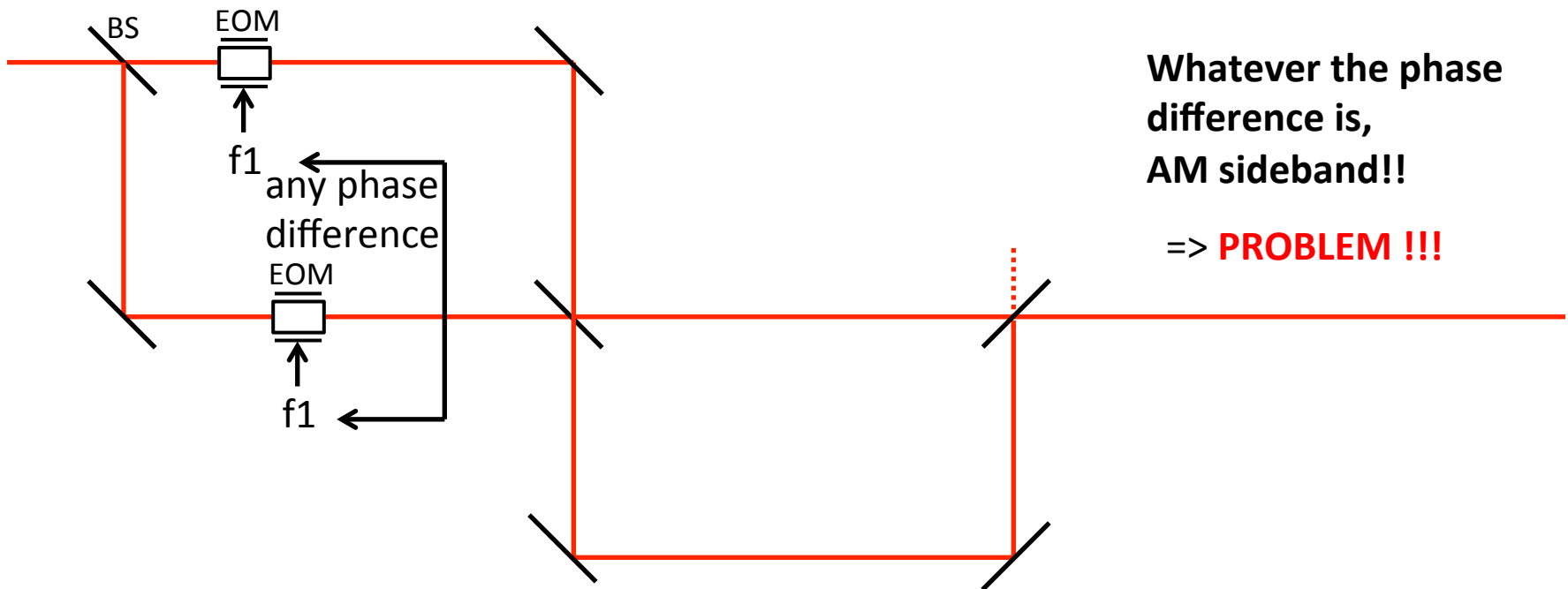
Whatever the phase difference is, AM sideband!!

=> **PROBLEM !!!**

after delay line
(f1 sidebands rotates by 180°)

alternative plan

JGW-D1503189-v3

Layout 3

oscillator
mixer
phase shifter

• Simpler, but loses some f3 AM

f2

EOM (f2)

EOM (f1,f3)

EOM (f1,f3)

f1

f3
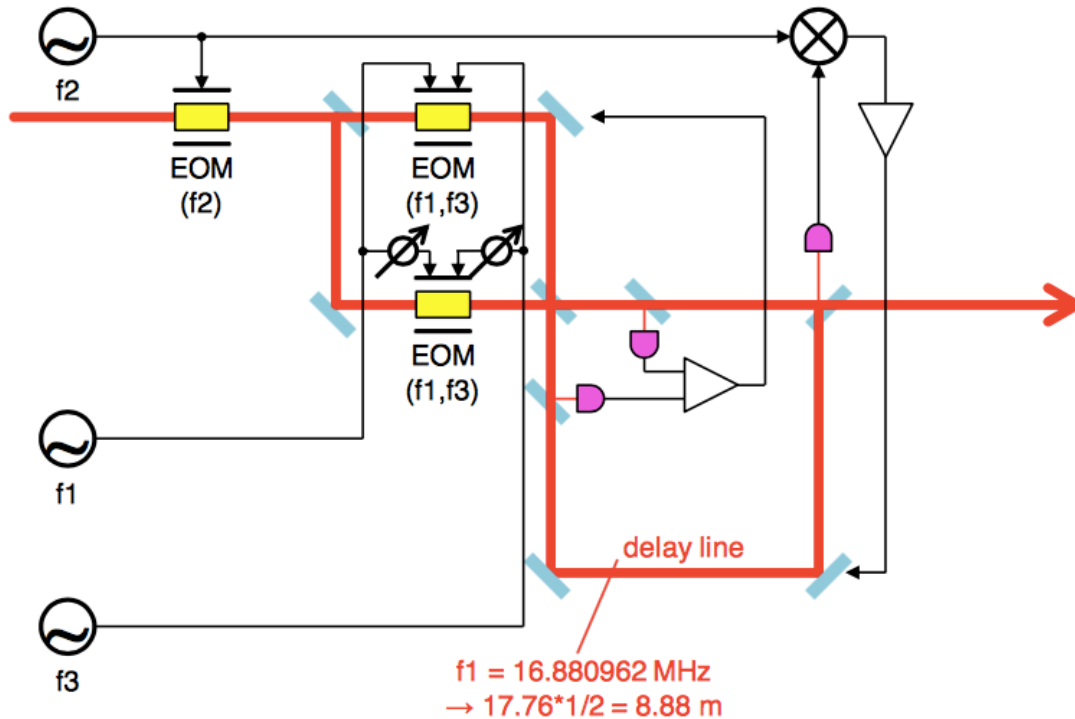
delay line

f1 = 16.880962 MHz
→ 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)

6

alternative plan

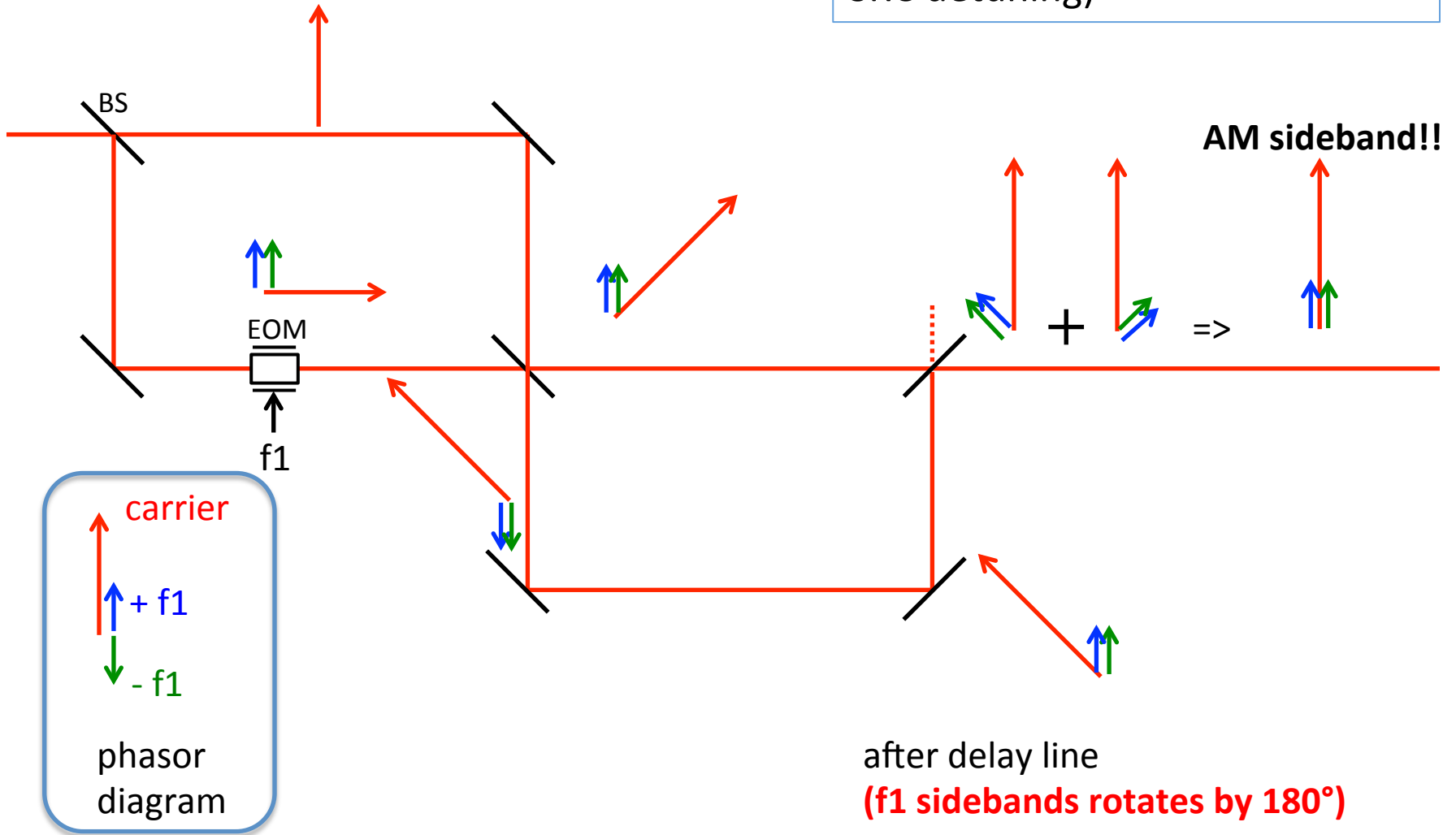$$A + m(e^{i\omega_m t} - e^{-i\omega_m t})$$

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)
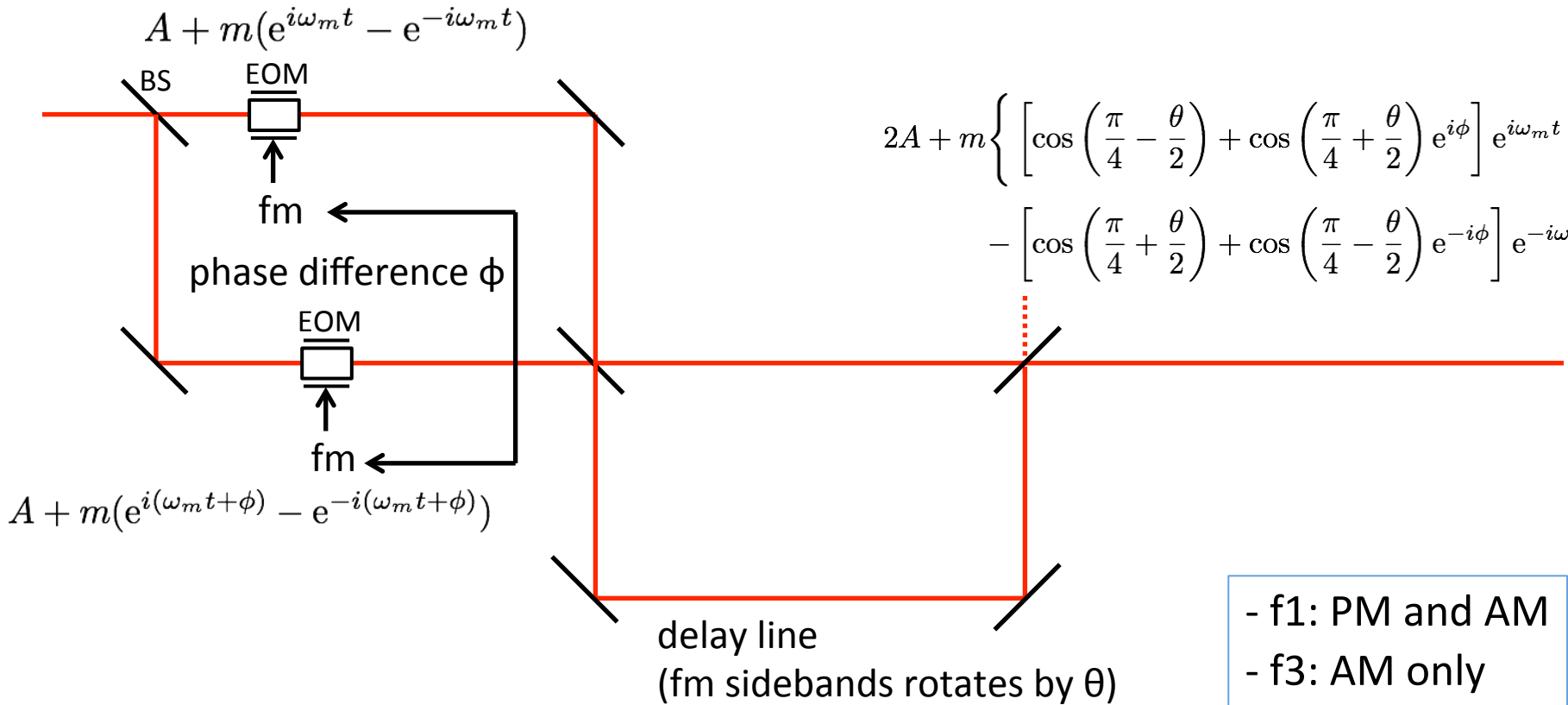
- f1: PM and AM
- f3: AM only

alternative plan

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

BS   EOM

fm

phase difference φ

EOM

fm

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

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

$$\left. - \left[\cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right)e^{-i\phi}\right]e^{-i\omega_m t} \right\}$$
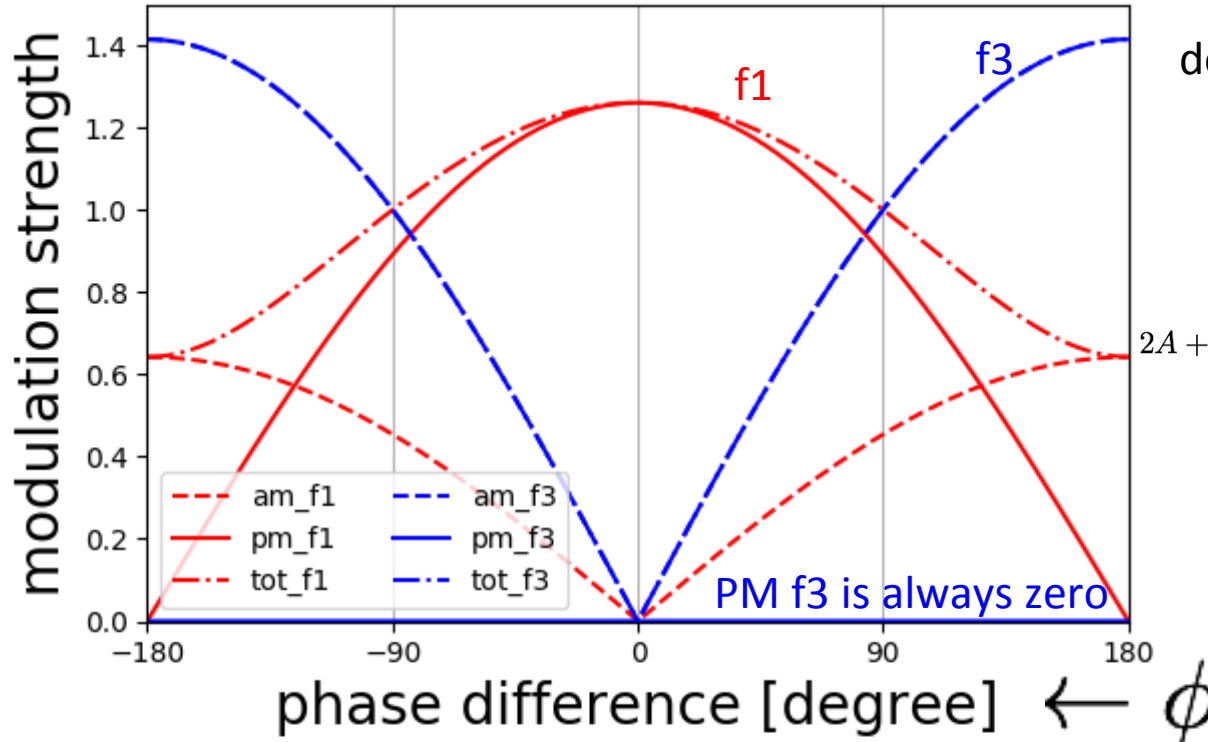
delay line
(fm sidebands rotates by θ)

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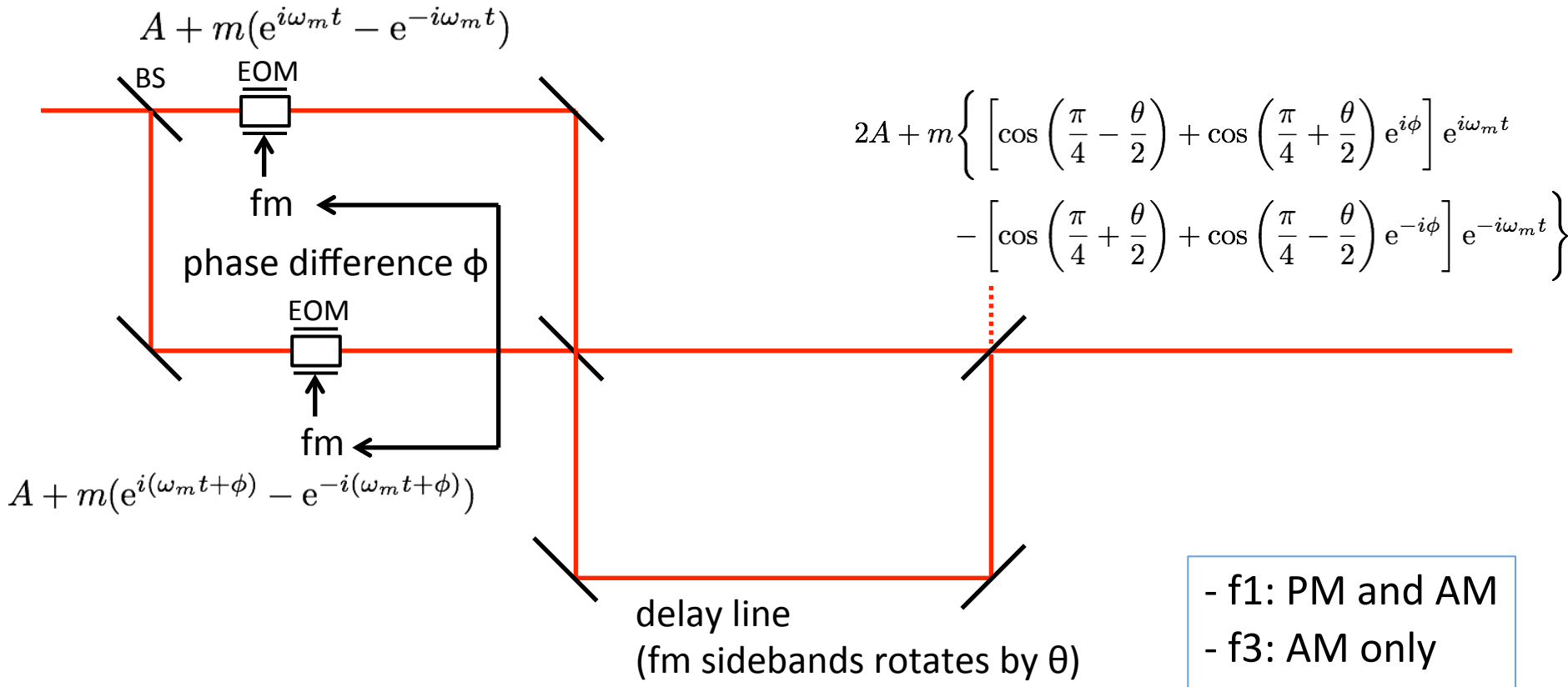
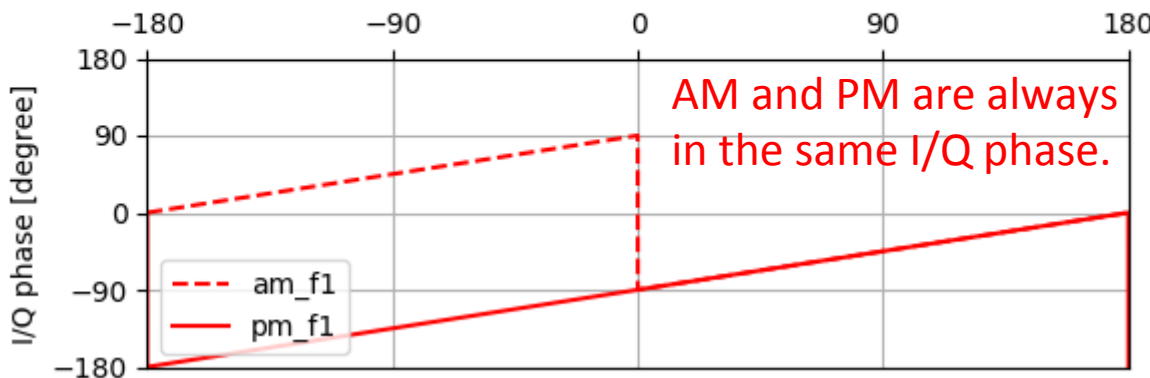delay line 2.66 m --> $\theta(f_1) = 54°$ --> combination of PM and AM (next page)

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

alternative plan

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

$\theta(f_3) = 180°$

f1

f3

PM f3 is always zero

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

$$\left. - \left[\cos\left(\frac{\pi}{4} + \frac{\theta}{2}\right) + \cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right) e^{-i\phi}\right] e^{-i\omega_m t}\right\}$$
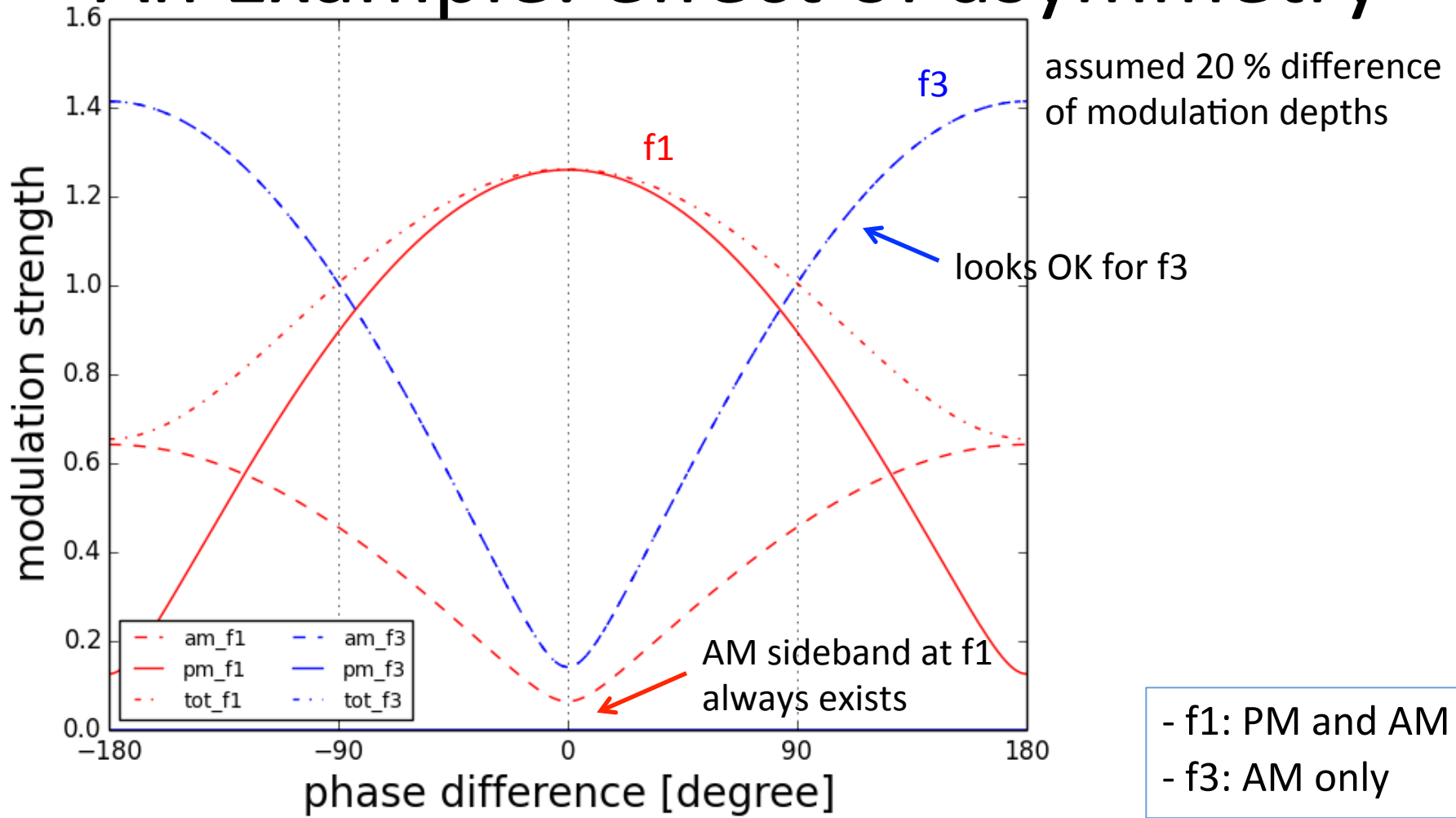
AM and PM are always in the same I/Q phase.

- f1: PM and AM
- f3: AM only

9

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

looks OK for f3

AM sideband at f1 always exists

- f1: PM and AM
- f3: AM only

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

$\theta(f_3) = 180°$

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

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

11

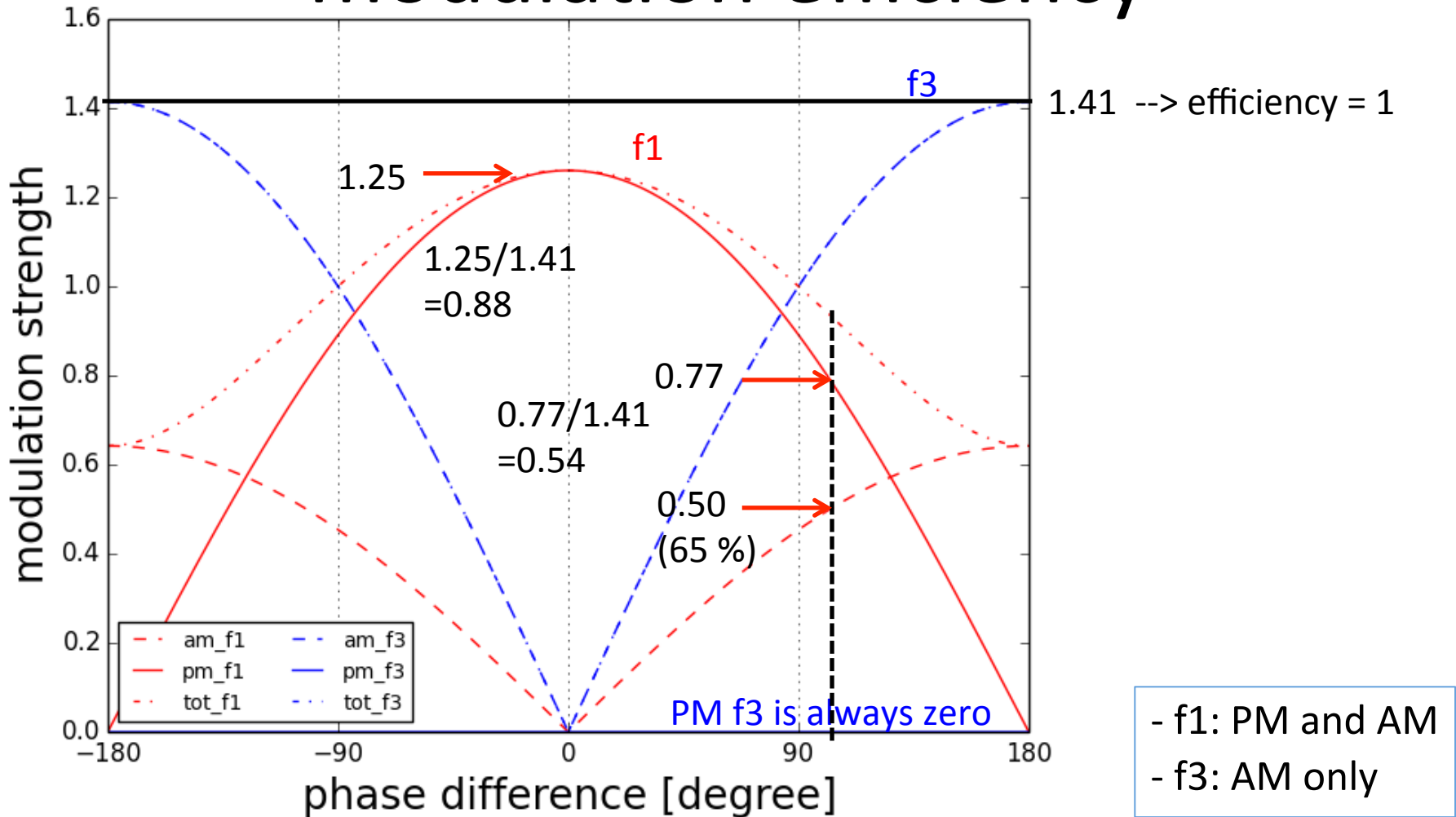# transmissivity of f2 and fimc

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

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

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

(assuming delay line length = 2.66 m)

modulation efficiency

1.41 --> efficiency = 1

f3

1.25

f1

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

Legend:
- am_f1 (red dash-dot)   am_f3 (blue dash)
- pm_f1 (red solid)   pm_f3 (blue solid)
- tot_f1 (red dotted)   tot_f3 (blue dotted)

Axes: modulation strength (y), phase difference [degree] (x)

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

$\theta(f_3) = 180°$

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

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

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

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?

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 ?

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?

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 ?

loses much power

could be a problem??

2.66 m vs. 7.99 m
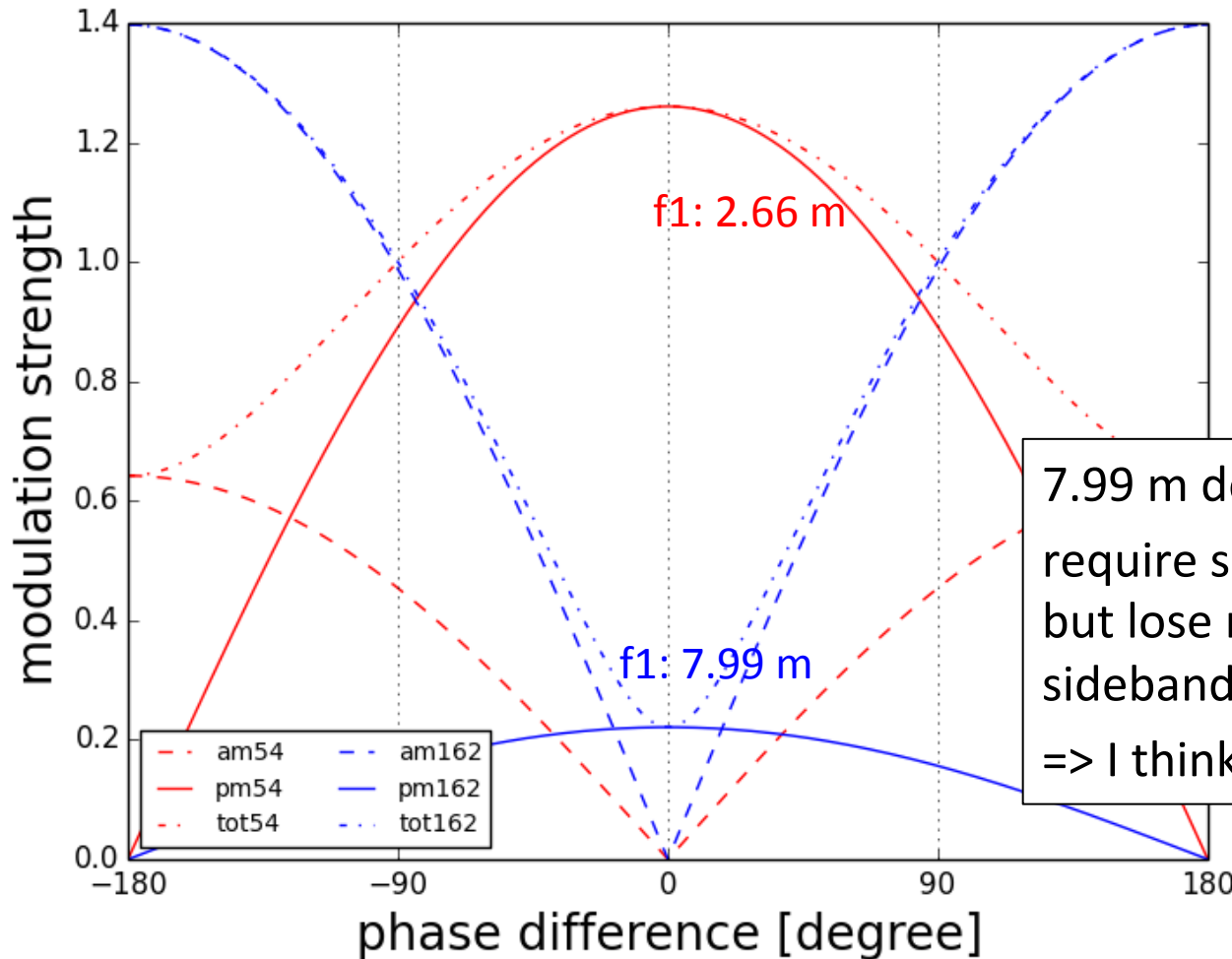
7.99 m delay line is also OK.

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 --> $\theta(f_1) = 162°$

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

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