Squeeze Amplitude Filters

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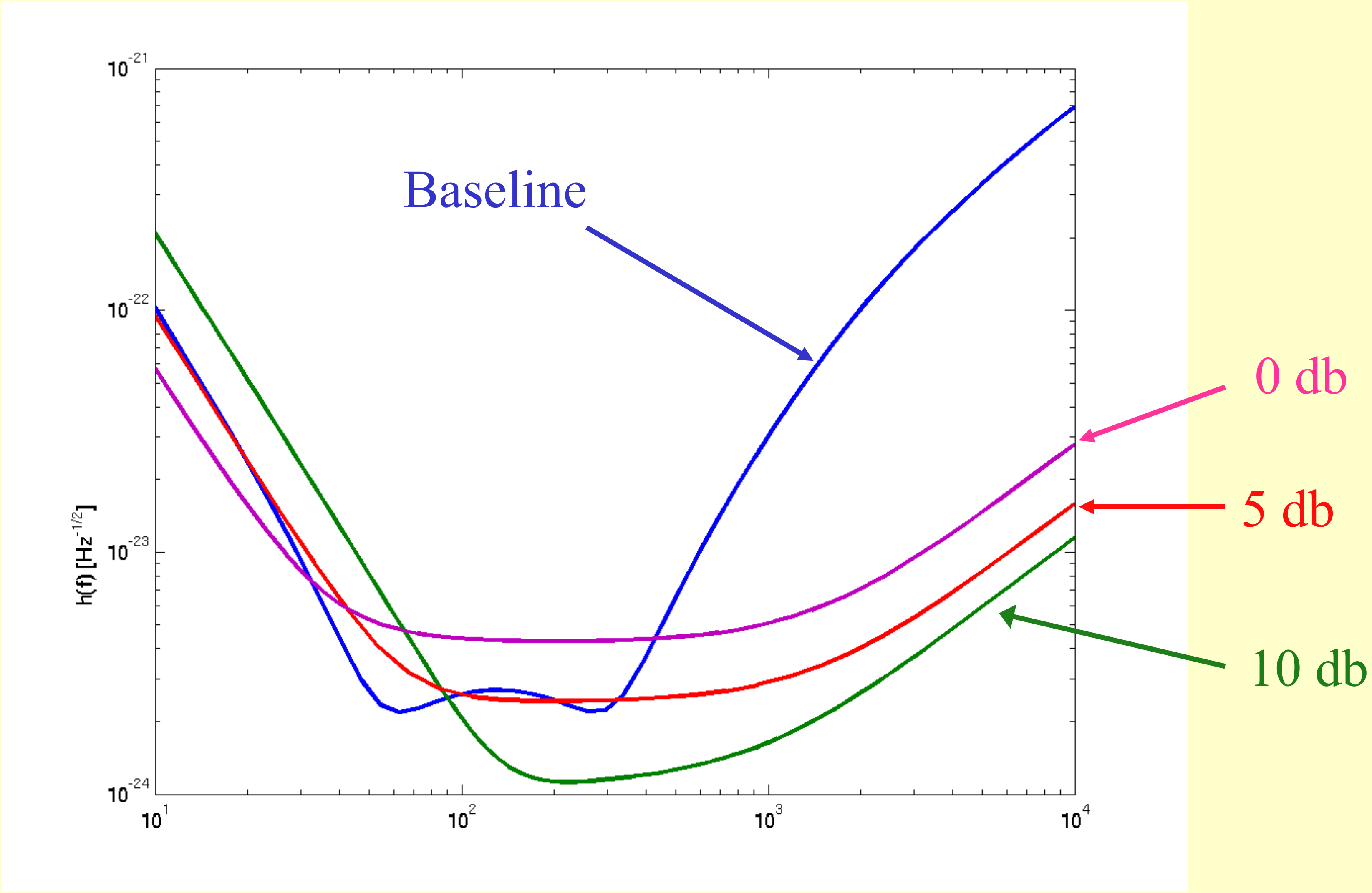
G030481-00R

March 2003 LSC meeting

- Thomas asked…
  - Is squeezing useful in an AdLIGO configuration?
  - What is an optimal configuration?
- Assumptions then…
  - ~10 dB of squeezing at fixed squeeze angle
- Result = Yes
  - Slightly different detuning and SEM reflectivity to get best advantage

Frequency INdependent Squeeze Angle

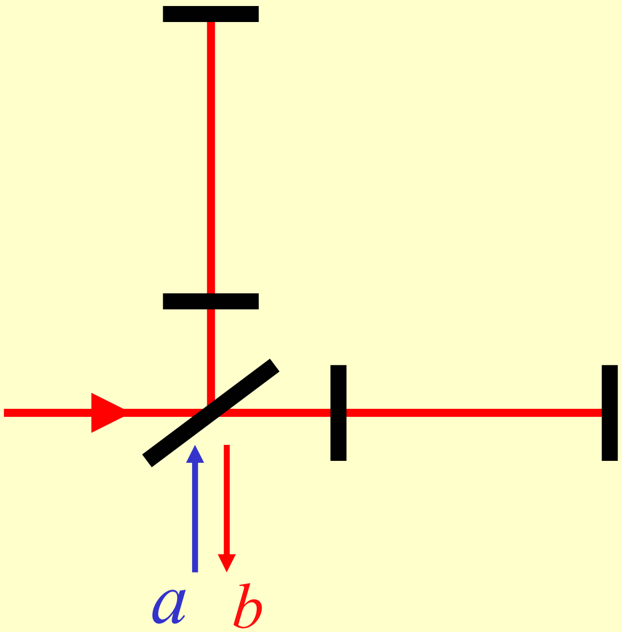


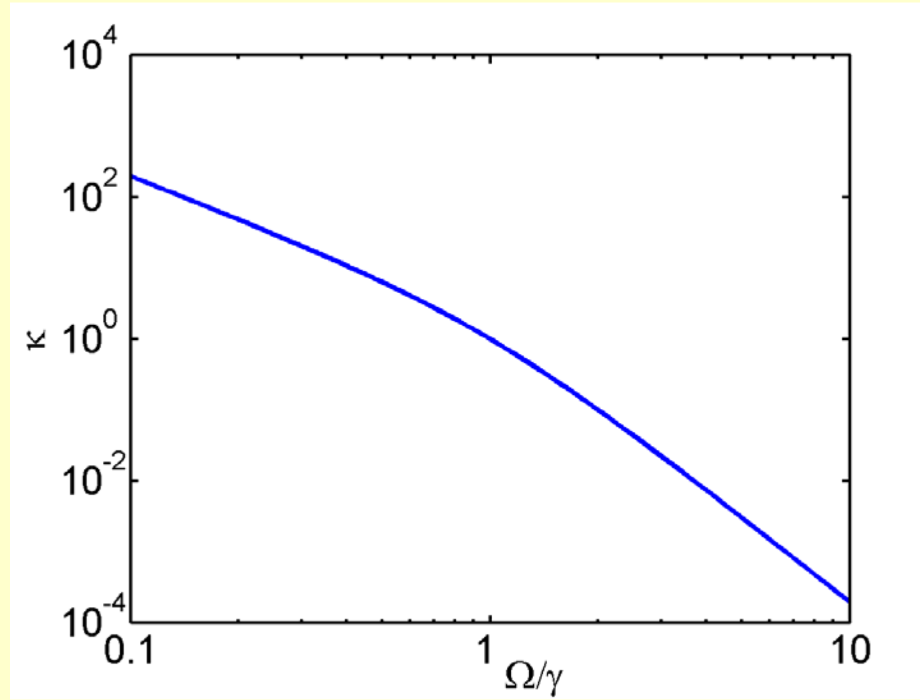
Today…

- Filtering to
  - Rotate squeeze angle
  - Tailor squeeze amplitude

- Basics of squeezing in interferometers

Conventional Interferometer





Amplitude → $b_1 = a_1$

Phase → $b_2 = \kappa a_1 + a_2 + h$

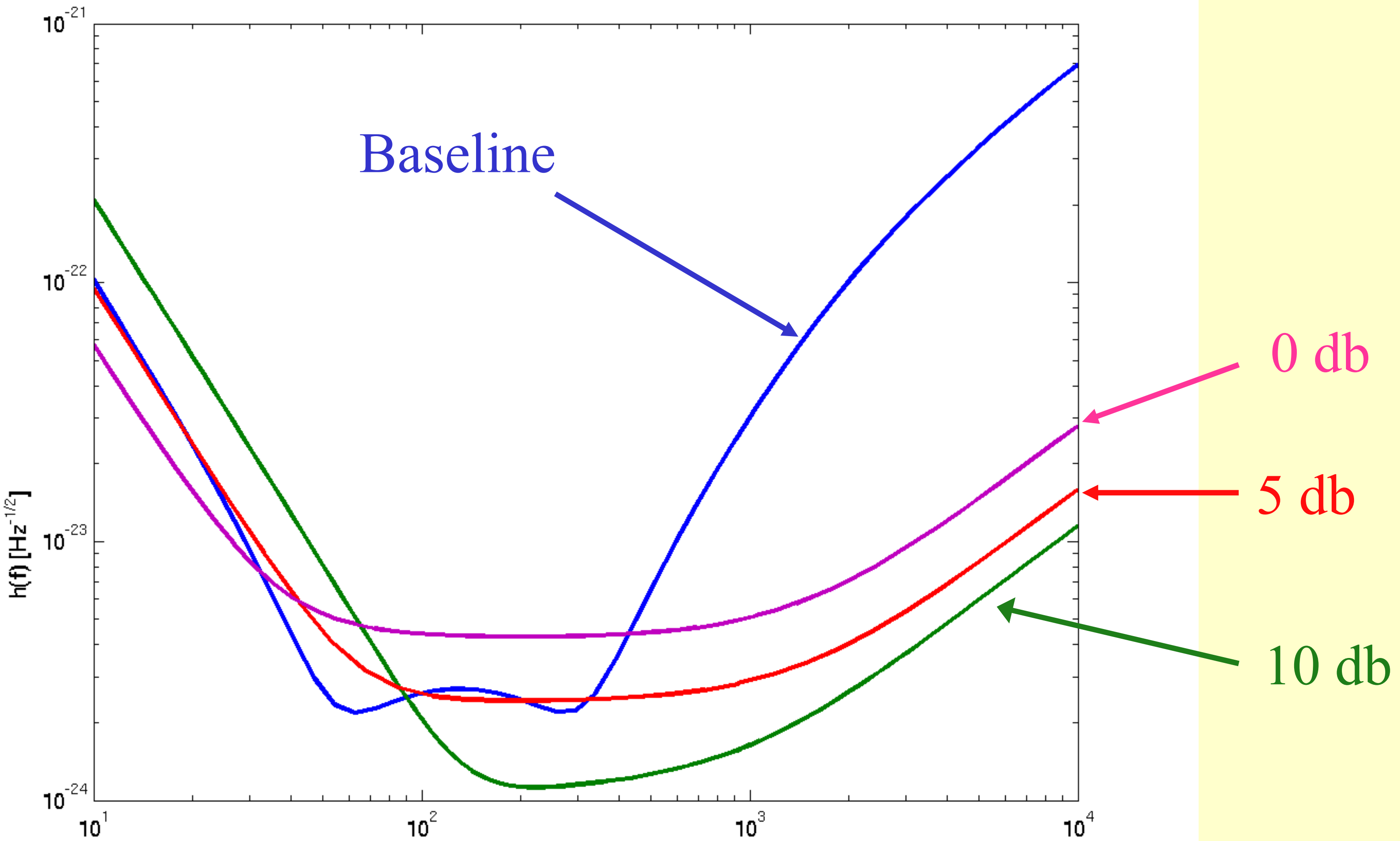
Radiation Pressure (κa_1)

Shot Noise (a_2)

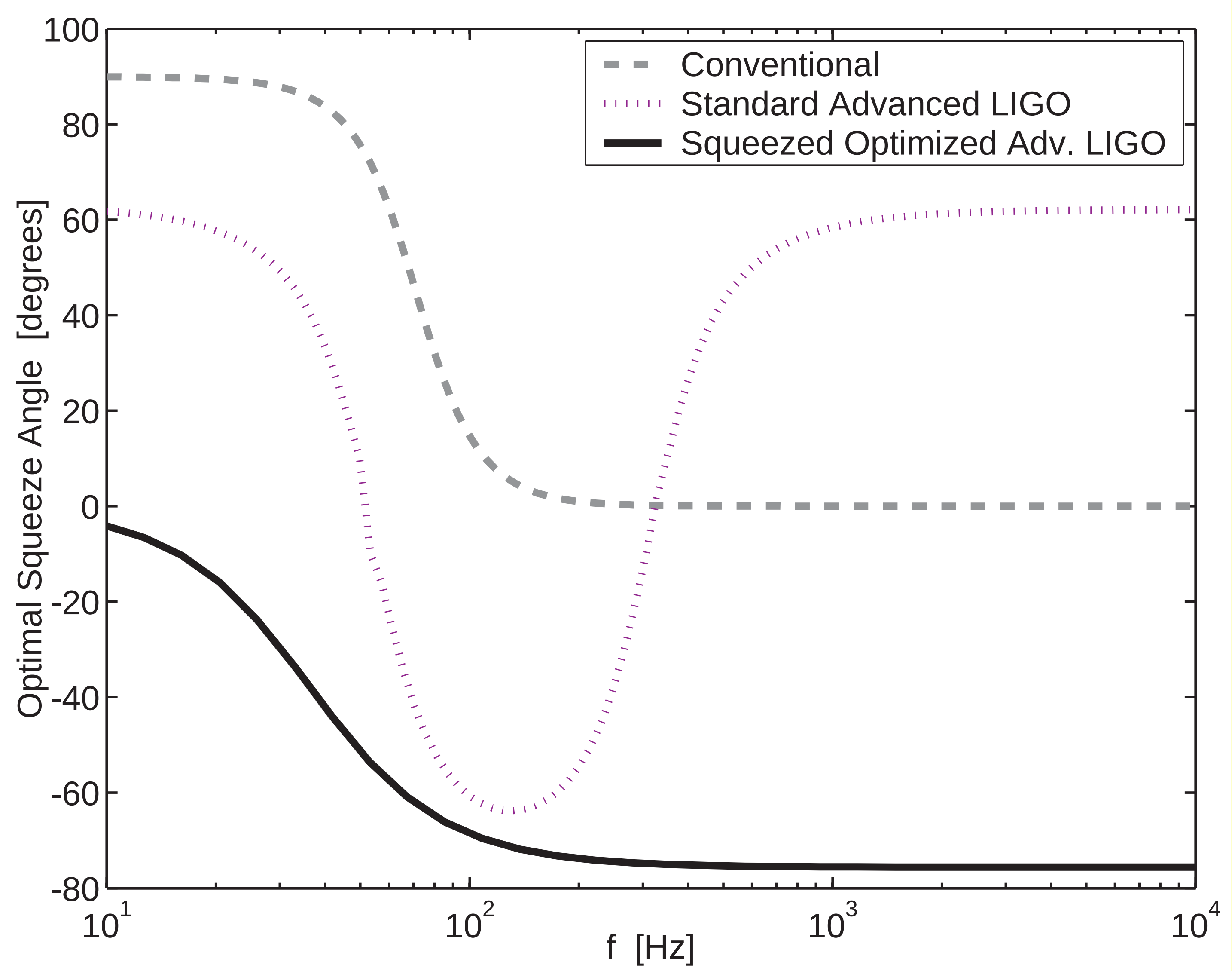
Optimal Squeeze Angle

- If we squeeze a_2
  - shot noise is reduced at high frequencies BUT
  - radiation pressure noise at low frequencies is increased
- If we could squeeze $\kappa a_1 + a_2$ instead
  - could reduce the noise at all frequencies
- "Squeeze angle" describes the quadrature being squeezed

Frequency INdependent Squeeze Angle



Frequency-dependent squeeze angle



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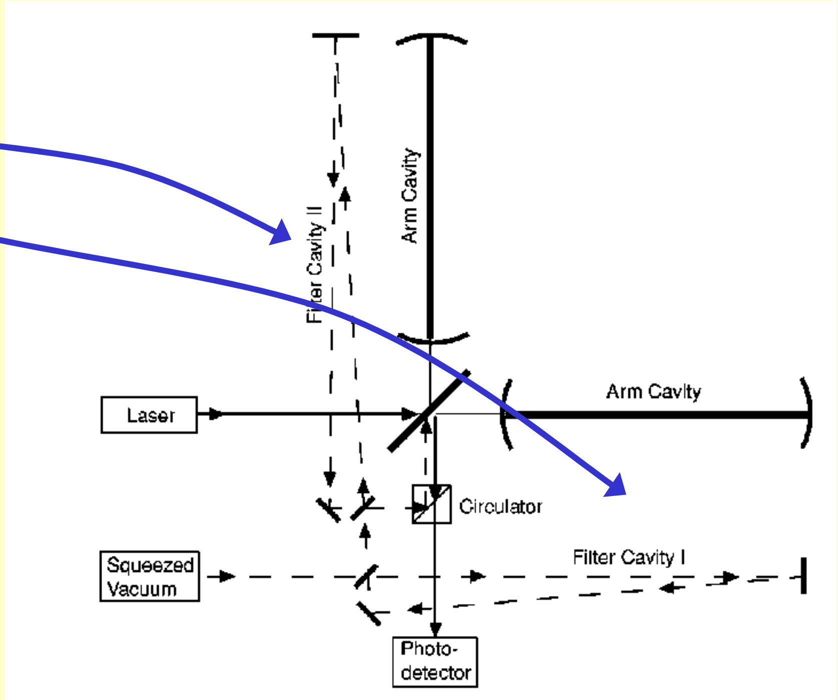
Corbitt and Mavalvala, gr-qc/0306055 (2003)

Realizing a frequency-dependent squeeze angle

filter cavities



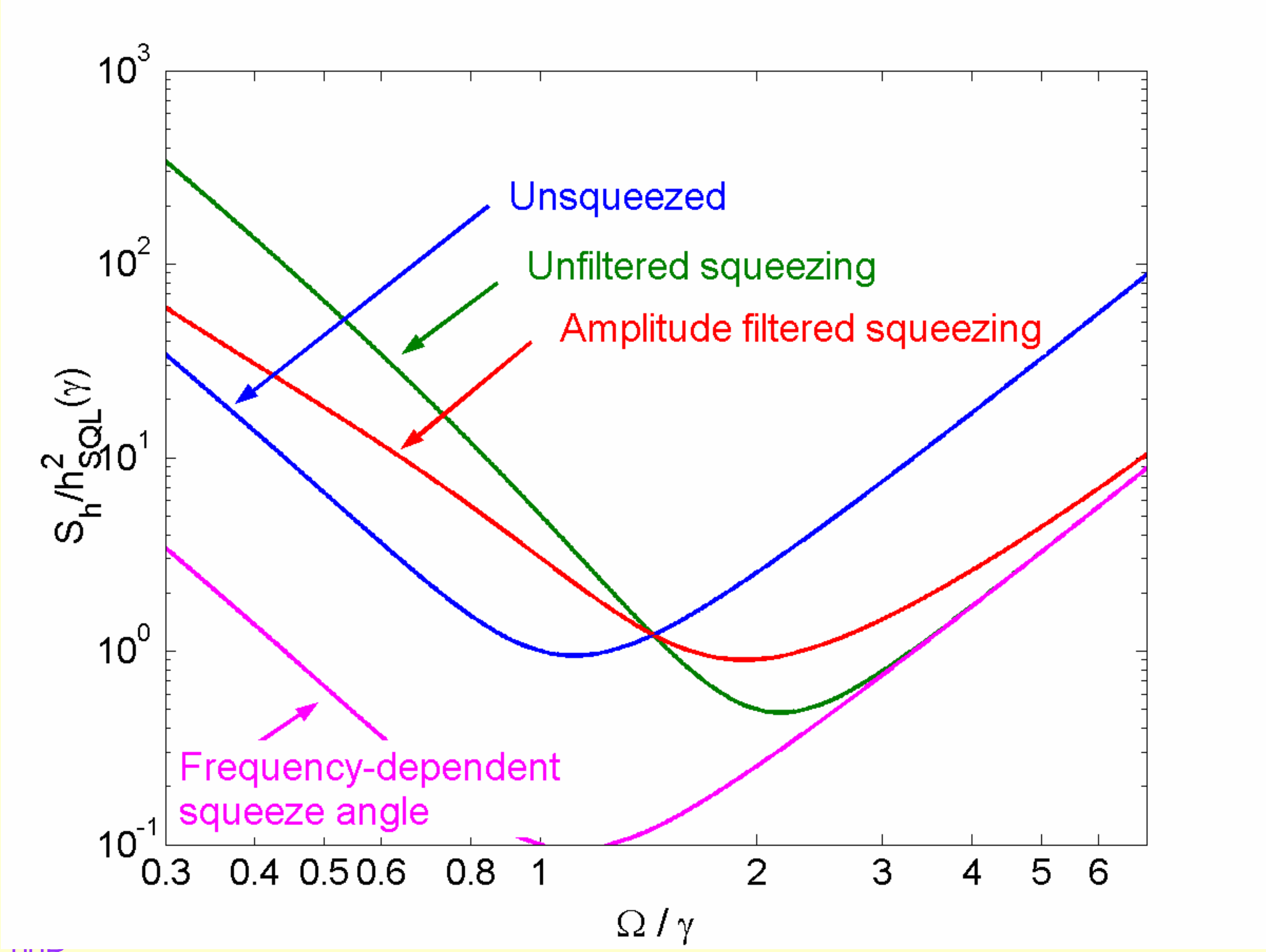
- Filter cavities
- Some difficulties
  - Low losses
  - Highly detuned
  - Multiple cavities

- Conventional interferometers →
  - Kimble, Levin, Matsko, Thorne, and Vyatchanin, Phys. Rev. D **65**, 022002 (2001).
- Signal tuned interferometers →
  - Harms, Chen, Chelkowski, Franzen, Vahlbruch, Danzmann, and Schnabel, gr-qc/0303066 (2003).

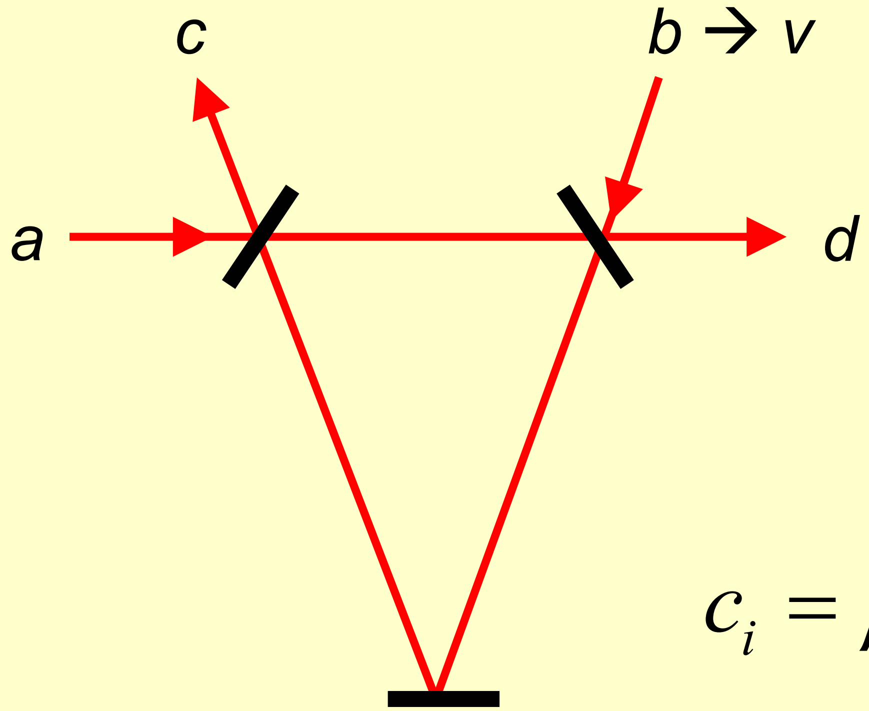
Other alternatives

- Squeeze at an angle to reduce noise at an intermediate frequency
  ➔ narrowband performance
- Squeeze at an angle to reduce high frequency noise
  ➔ reduced sensitivity at low frequency
  (same effect as increasing power)
- Squeeze at an angle to reduce high frequency noise and filter squeezed light to destroy (anti-) squeezing at low frequencies
  ➔ improved performance at high frequencies without compromising low-frequency sensitivity

Amplitude filtered squeezing



Principle of amplitude filter



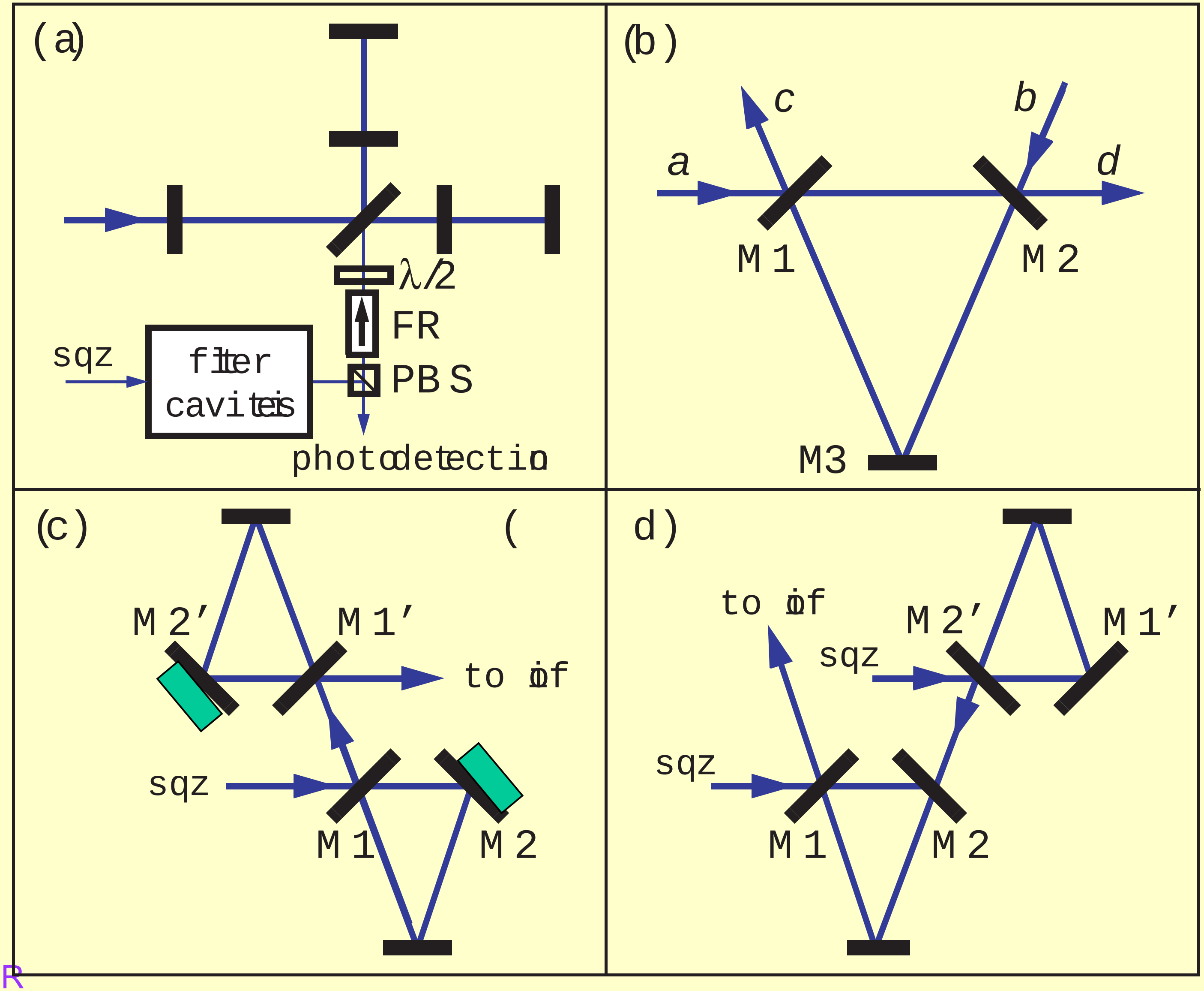
- Losses allow vacuum to leak in
- Ordinary vacuum replaces the squeezed field but only at frequencies where the anti-squeezing dominates

$$c_i = \rho(\Omega) a_i + \sqrt{1 - |\rho(\Omega)|^2} v_i$$

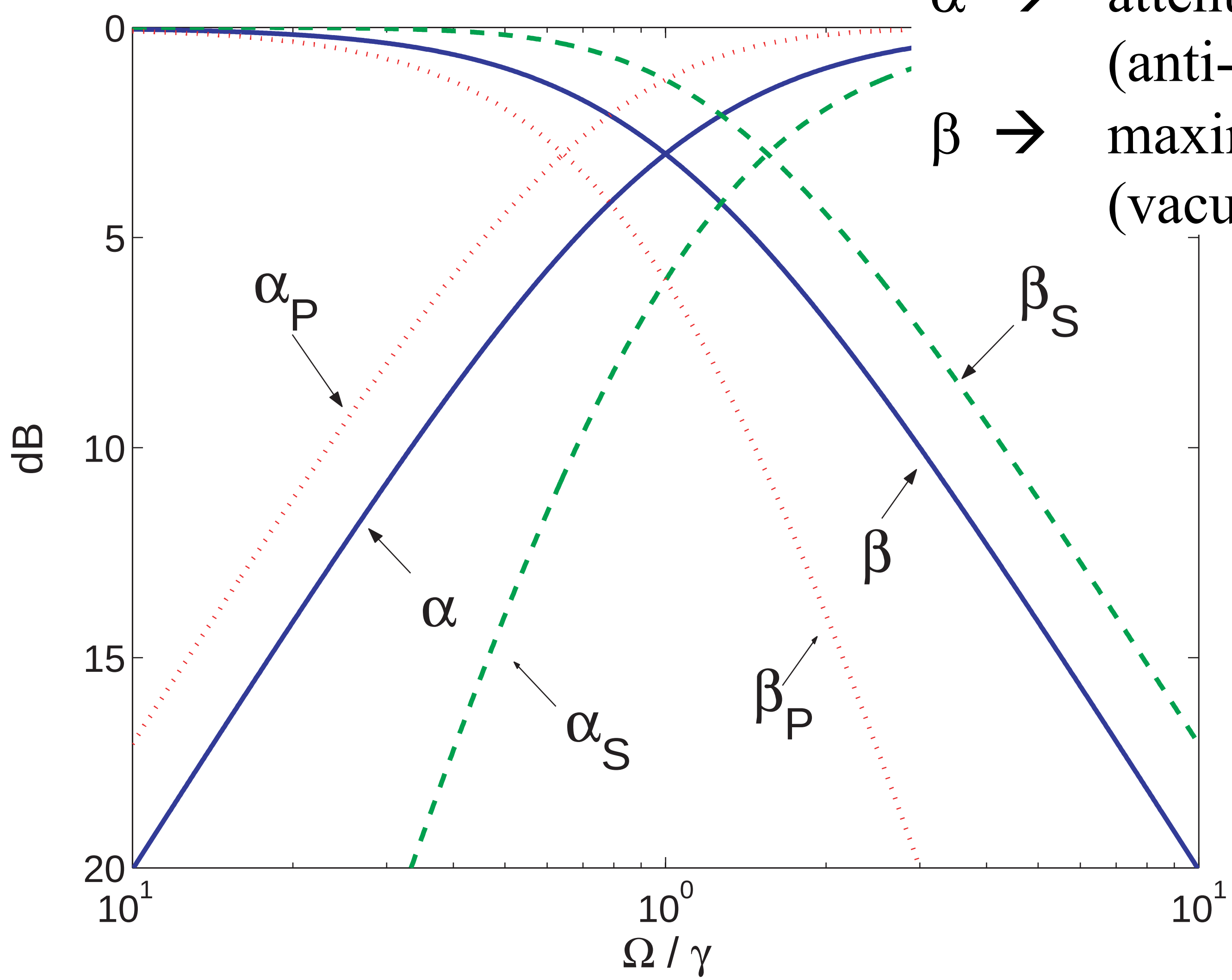
$$\rho(\Omega < \gamma_f) \sim 0 \Rightarrow c_i \to v_i$$

$$\rho(\Omega > \gamma_f) \sim 1 \Rightarrow c_i \propto a_i$$

Extend to multiple filters



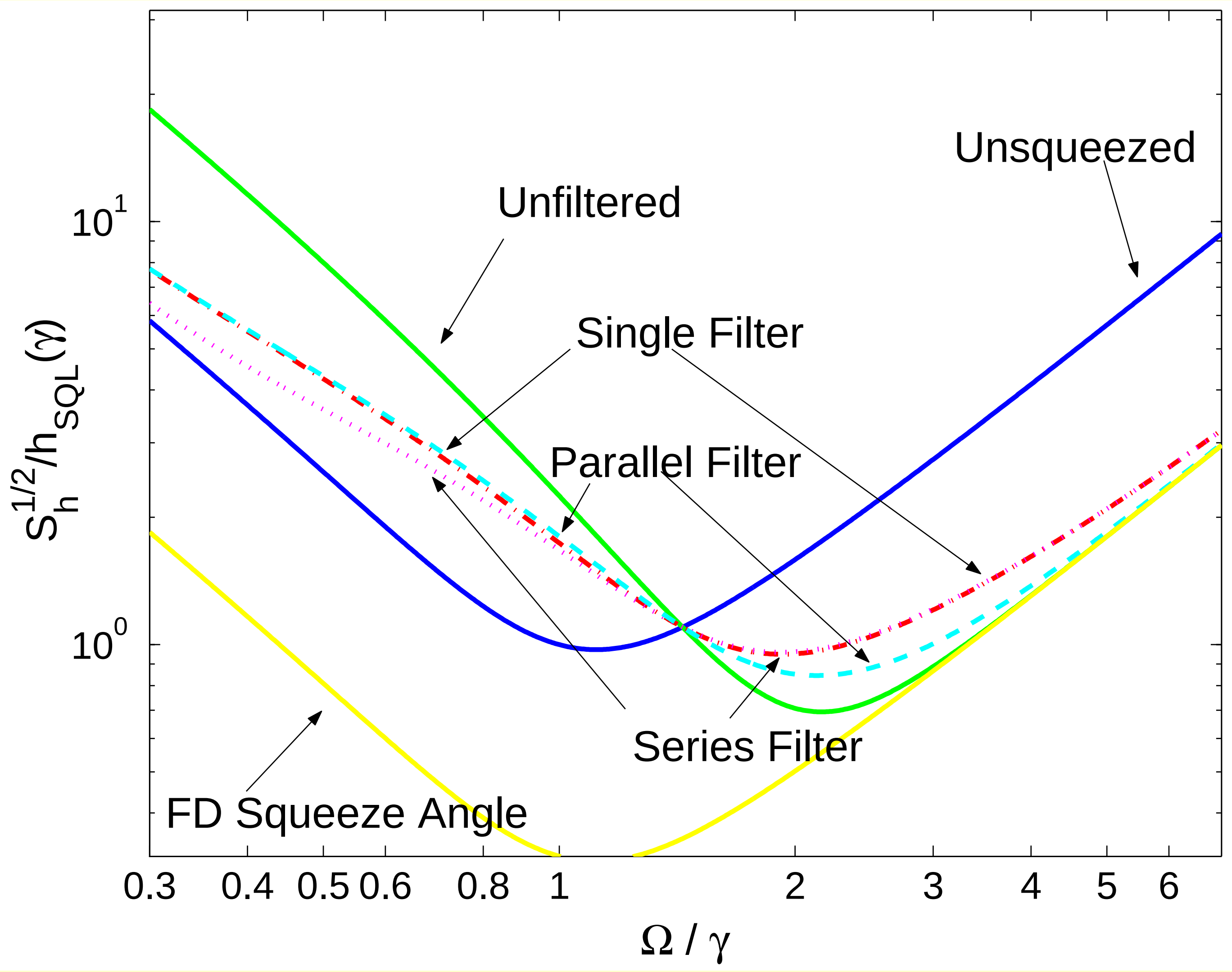
Filter properties



α → attenuation factor (anti-squeeze)

β → maximum squeeze (vacuum leakage)

Application to a conventional interferometer



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Astrophysical Performance

Configuration	$\frac{\gamma_f}{\gamma}$	Power $\left(\frac{I_0}{I_{SQL}}\right)$	NS SNR	$\frac{1}{\sqrt{S_h}}\left(\frac{\Omega}{\gamma}=10\right)$
Conventional interferometer	–	1.0	1.00	1.00
Conventional interferometer	–	0.1	1.26	0.32
Unfiltered fixed-angle squeeze	–	1.0	0.81	3.16
Single filter	1	1.0	0.81	3.16
Single filter	5	1.0	0.96	1.89
Single filter	1	0.1	1.14	0.96
Single filter	5	0.1	1.25	0.60
Series filter	1	1.0	0.89	3.00
Series filter	5	1.0	1.00	1.72
Series filter	1	0.1	1.25	0.93
Series filter	5	0.1	1.26	0.55
Parallel filter	1	1.0	0.84	3.16
Parallel filter	5	1.0	0.94	2.56
Parallel filter	1	0.1	1.11	1.00
Parallel filter	5	0.1	1.24	0.86
FD squeeze	1	1.0	3.16	3.16

Conclusion

- Squeeze magnitude filtering does not give as good a broadband performance as FD-squeeze angle

BUT

- Good wideband improvement over fixed squeeze angle

AND

- Amplitude filters easier to implement
- Flexible design depending on filter cavity linewidth