DC Readout

in LIGO I

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RF v. DC

- Phase Modulate the light
- Pass through unstable PRC
- RF SB's are the LO for GW signals.
- GW signal is an audio frequency AM of the RF photocurrent
- RF signal is demodulated down to DC
- Resulting audio GW signal is acquired by ADC.

- Ouput Mode Cleaner strips off the RF sidebands
- Make DARM offset (3 pm) to move slightly off dark fringe
- Dark port *power* is then linearly proportional to GW *strain*.
- Resulting audio GW signal is acquired by ADC.

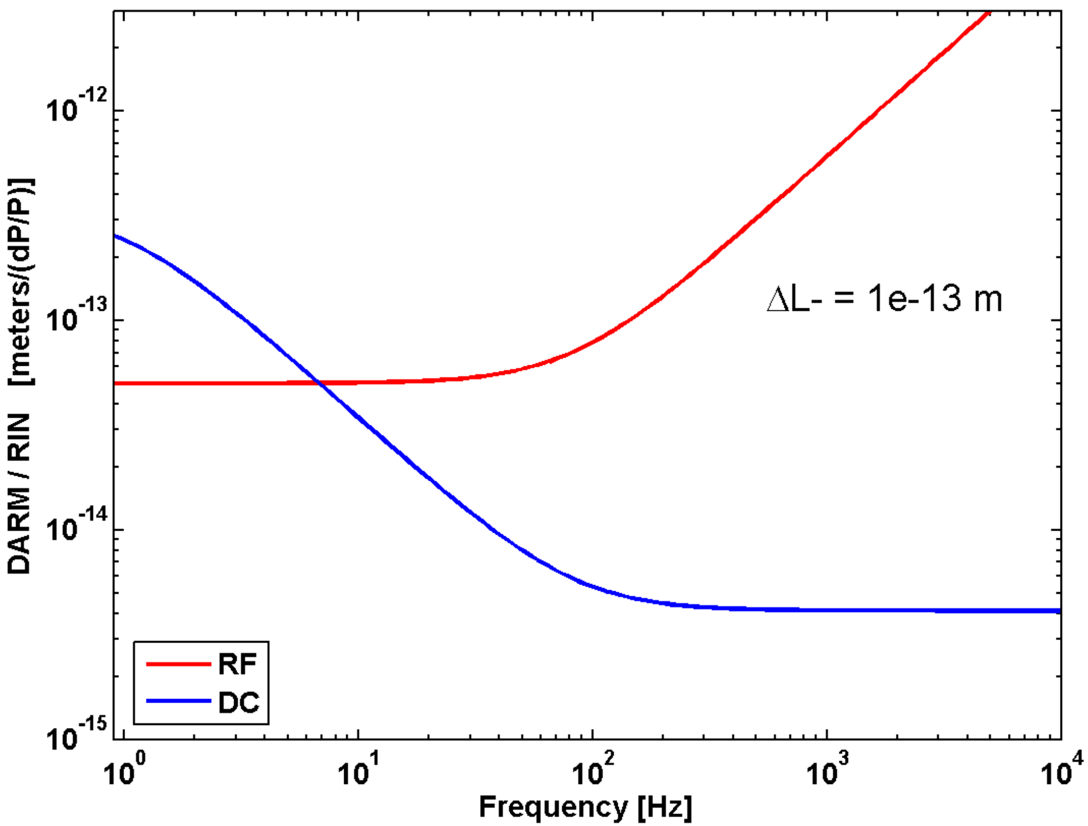
Laser Intensity Noise

- RF – AS_Q is bilinearly sensitive to AM:

  AS_Q ∝ δL- * RIN
- DC – AS_DC is first order sensitive to AM:

  AS_DC ∝ RIN

- RF – sidebands transmitted to the dark port unfiltered (only a 4 kHz MC pole)
- DC – carrier filtered at 1 Hz by the coupled PR-Arm cavity



Laser Frequency Noise

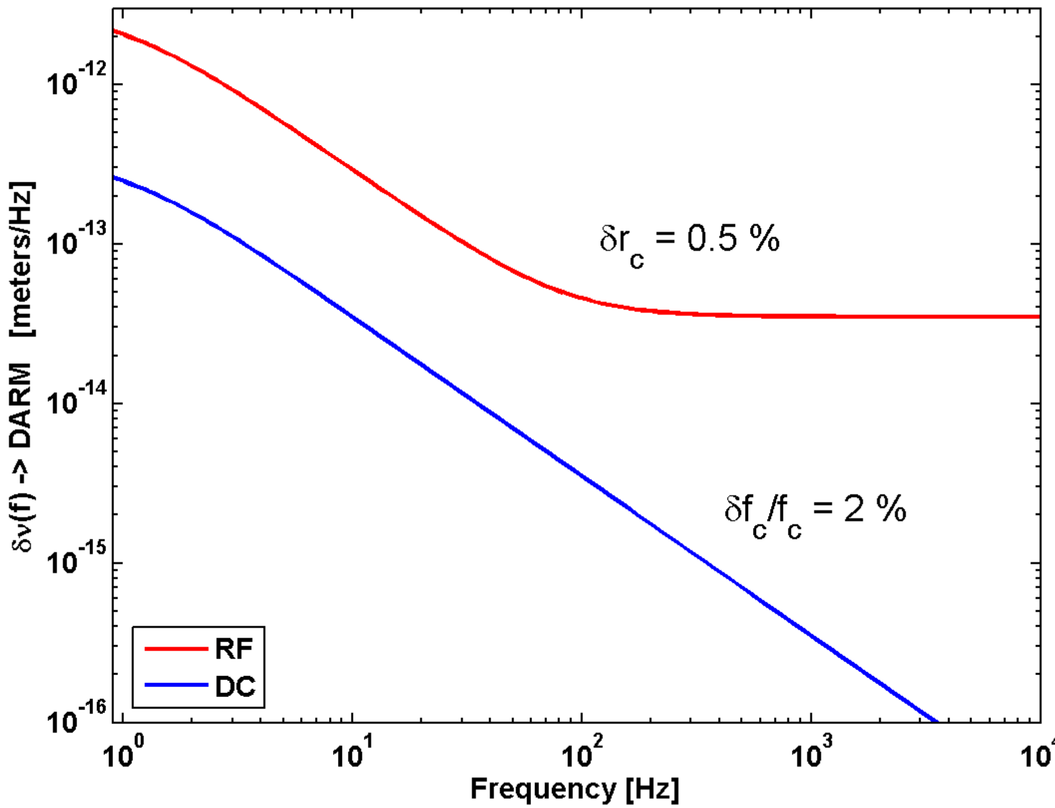
- RF – audio noise sidebands beat with the carrier contrast defect:

  $$AS\_Q \propto C_D * \delta\nu$$

- DC – arm cavity pole imbalance couples carrier frequency noise to dark port

  $$AS\_DC \propto \delta f_c / f_c$$

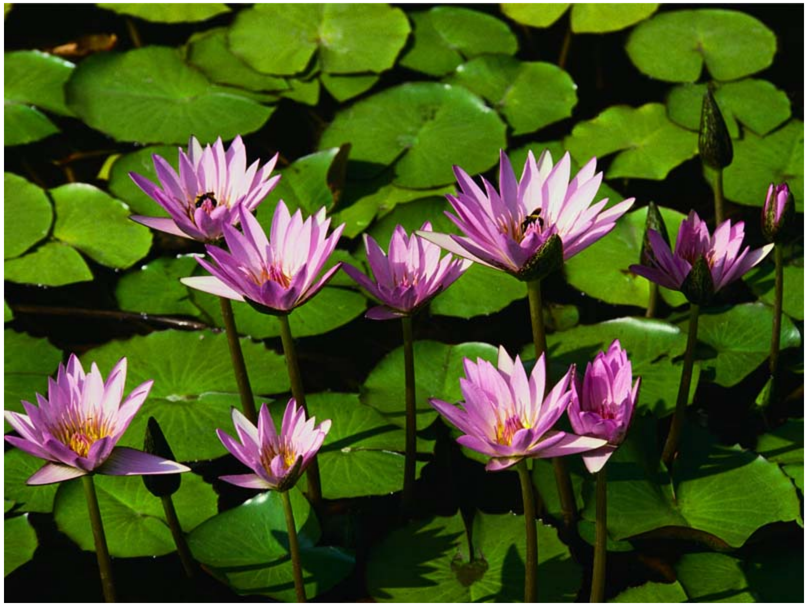
- RF – sidebands transmitted to the dark port unfiltered (only a 4 kHz MC pole)
- DC – carrier filtered at 1 Hz by the coupled PR-Arm cavity



Oscillator Phase Noise

- RF – who knows? Something to do with sideband imbalance maybe and higher order modes somewhere.
- With the RF electronics (crystals, distribution,etc.), we can probably get to SRD, but noise floor is not presently known.
- DC – No sidebands….no noise. Maybe some coupling through aux. LSC loops (CARM, MICH, PRC)?

- RF – sidebands transmitted to the dark port unfiltered
  (only a 4 kHz MC pole)
- DC – sidebands rejected by OMC



Oscillator Amplitude Noise

- RF – very similar to laser AM (looks like a gain modulation). Below SRD level with the existing crystal oscillators ($\delta A/A < 10^{-8}$)
- DC – would show up as a sensing noise in the post MC ISS PD
- In the existing setup, the ISS stabilizes only the carrier and so it's a nice setup for DC readout. No outer loop necessary perhaps.

- RF – sidebands transmitted to the dark port unfiltered (only a 4 kHz MC pole)
- DC – sidebands rejected by OMC

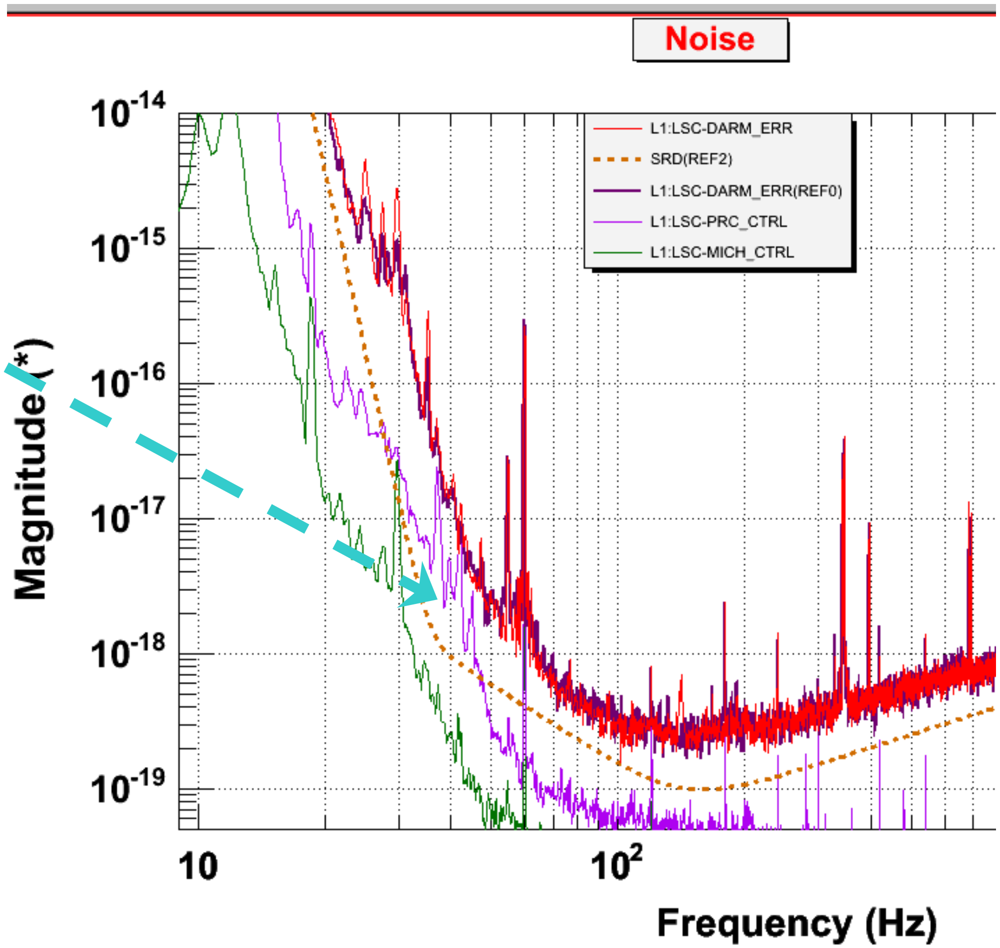
PRC -> AS_Q

- RF – AS_Q is sensitive to modulation of the PRC:

  $AS\_Q \propto C_D * \delta l_+$

- DC – AS_DC is second order sensitive to the PRC:

  $AS\_DC \propto (\delta l_+)^2$



- RF – sidebands transmitted to the dark port unfiltered (only a 4 kHz MC pole)
- DC – sidebands rejected; no more PRC -> AS_Q

AS_I

1. Unsuppressed RF signal can saturate the RFPD.
2. Controlled by a noisy electronic servo.
3. Limits the detected power at the AS port. Causes lock loss. Spoils the PD SNR. Produces glitches in the data. And maybe even global warming?

AS_I does not exist in the DC readout scheme.

Photodetectors

- Large AS_I signal limits the power on each PD to ~20 mW (leaving some headroom)
- Scaling to the full LIGO-I power of 8W or 50 W in an upgrade would lead to a giant forest of PDs and an associated forest of AS_I servos, mixers, ADCs, CPUs, etc….**Big headache!**

# of AS port diodes

	RF	DC
L1	4	1
H1	8	1
H2	24	1

- ✓ DC: No RF electronics!
- ✓ Easy photodetector design. Don't care about diode capacitance: can select based on QE, spatial uniformity (EG&G 5 mm PD?)
- ✓ With the OMC, the $C_D \sim 5 \times 10^{-6}$
- ✓ 50 W into the MC

  -> 1800 W on the BS

  -> C_D = 10 mW!
- ✓ Including the arm offset $P_{AS} \sim 20$ mW

This is the LIGO-2 design.

Being prototyped at the 40m lab this year.

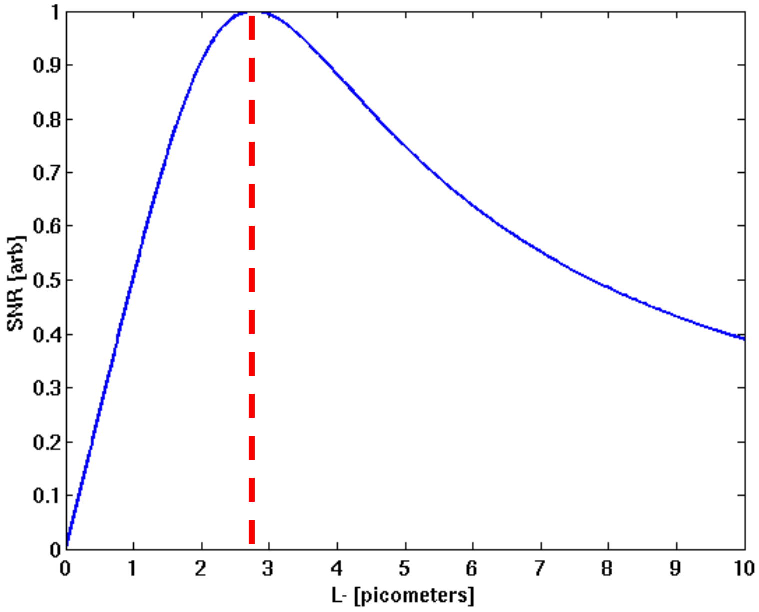
Optical Gain

- Active thermal compensation used to stabilize the degenerate recycling cavity and increase sideband buildup and DARM optical gain
- Kind of works…still an optical gain deficit:
- Assuming the recycling gain and input power are correctly measured and the PDs are well calibrated, the deficit may be in sideband carrier overlap.

L- gain (Watts/nm)

	Now	FFT
L1	?	2.5
H1	?	?
H2	?	?

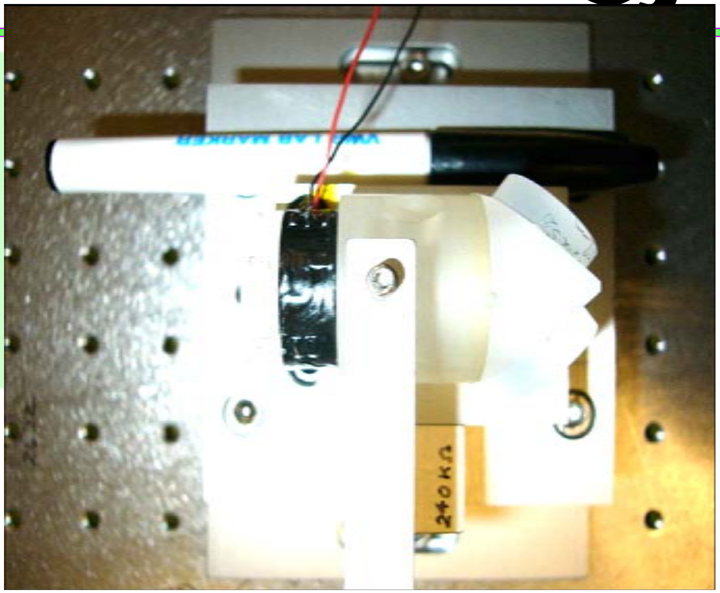
DARM SNR w/ C_D=5e-6



✓ DC: There is no overlap issue. Carrier perfectly overlaps with the carrier.

Output Mode Cleaner

- Initial tests with a short triangular OMC: **noisy**
- Further tests with a 4 mirror OMC: see Daniel's talk
- Design compromises: low finesse to pass RF sidebands, high finesse to reject HOM



- DC: Prototyping at the 40m this summer for a DC readout OMC and in vac PD. See Rob Ward's talk.
- Higher finesse: ~few hundred
- Longer: ~1/2 meter
- Hopefully, much less jitter induced noise
- Standard RF reflection locking
- Gains experience with a LIGO-2 technique

Why not use DC Readout?

- OMC Concerns
  - No one has demonstrated a low phase noise IFO with an OMC
  - Substantial down-time by going into the vacuum to do the install
- Photodetector concerns
  - Need to develop the low noise DC Photodetector (in-vacuum)
  - Need beam in-vac beam steering for OMC & PD (Daniel's talk)
- Unknown problems
  - Everytime we try something new, there are unpredicted problems
  - Unknown commissioning duration
- The Lazy Reason
  - We're so close now, why risk it? Why bother?
- Maybe the RF readout with the OMC is good enough.

Summary

- Noise Couplings
  - Most optical noise couplings are smaller with a DC readout
- Electronics
  - Vast simplification of the readout electronics
- Power handling
  - Can easily scale to higher power levels
- Similar to RF+OMC
  - Common issues to investigate for both schemes (RF or DC)
- The Warm Body advantage
  - Already an active research topic (has a live grad student !)
- The Way of the Future
  - **Experience gained directly adds to the LIGO-2 effort.**