Readout techniques

- GW channel readout methods:
  - frontal RF modulation, resonant in PRC, as in LIGO I
  - frontal RF modulation, doubly resonant
  - frontal RF modulation, ‘1.5’ resonant (resonant in one arm)
  - external modulation with Mach-Zehnder
  - DC offset
- There is a large payoff to using a scheme which doesn’t suffer from RF sideband noise, as in LIGO I
  - taking advantage of the double-cavity pole filtering gives a factor of ~100 greater immunity to input intensity and frequency noise

DC offset readout

- Idea is very simple:
  - move slightly off the dark fringe and measure baseband power fluctuations directly
  - field at the AS port due to phase offset and signal phase:

$$E_{AS} \propto \phi_0 + \delta\phi$$

  - power is linear in the signal $\delta\phi$:

$$P_{AS} \propto 2\phi_0 \cdot \delta\phi + \phi_0^2$$

  - output mode cleaner would be used to reduce PD light power
- Advantages:
  - no loss of sensitivity from imperfect demodulation (demod waveform is the inverse of the mod waveform!; a ~2dB effect)
  - benefits from the filtering of the double-cavity pole
  - uses carrier only, which is less sensitive to thermal distortions in the ITMs
  - photodetector doesn’t need to operate at RF
  - output mode cleaner not constrained to pass RF sidebands

DC readout & amplitude noise

- Coupled cavity pole frequency:

$$f_{cc} \approx \frac{f_c}{2G_{rec}} = \frac{90\text{ Hz}}{200} = 0.45\text{ Hz}$$

  - at 150 Hz (where shot noise becomes dominant), filtering factor is 330x
    - thus, RIN (relative intensity noise) at ifo input can be up to 30x larger than the RIN of shot-noise in the detected beam, and still be 10x below shot-noise at output
    - eg, if 1W is detected at AS port, input beam can have the RIN of a 1mW shot-noise limited beam

- AS port power (contrast defect)
  - from BBochner's thesis, P_{as}/P_{in} = 0.01 for lambda/800 mirrors and R_{srm} = 0.7
  - however, output mode cleaner will suppress all higher order modes by at least a factor of 10^3, leaving only the TEM_{00} component
    - TEM00 component: $P_{as}/P_{bs} = (\delta r)^2/4$, where dr is the reflectivity difference between the two arms; if dr = 0.2%, then $P_{as} = 10^{-6}$x10kW = 10 mW
  - need to do proper optimization of 'local oscillator' power, but will probably need (10-100)xP_{as} = 0.1-1W detected
    - phase offset: 1-2mrad; equivalent to arm length offset of 1-3 x 10^{-12} m

Frequency stability req'd

- In present scheme, frequency coupling is dominated by δr (TEM_{00} c.d.); this effect should disappear with dc readout
- Left with coupling to unbalanced storage times
  - In LIGO I, the ratio of these two terms is:

$$\frac{S_{\delta\tau}}{S_{\delta r}} = \frac{(\delta\tau/\tau)}{\delta r} \cdot \frac{1-r_c}{1+s_c} \cdot \frac{f_{cc}}{f_c}$$

$$= \frac{(\delta\tau/\tau)}{\delta r} \cdot \frac{10^{-2}}{1+s_c}$$

  - for the same level of unbalance, $\delta\tau$ term is ~100x smaller
  - thus, frequency noise requirement compared to LIGO I may be:
    - 10x more stringent due to increased strain sensitivity
    - 100x more relaxed due to weaker coupling
    - giving $3\times10^{-6}\ \mathrm{Hz}/\sqrt{\mathrm{Hz}}$ at 150 Hz

- proper calculation needs to be done!