Advanced Interferometer Topologies 3

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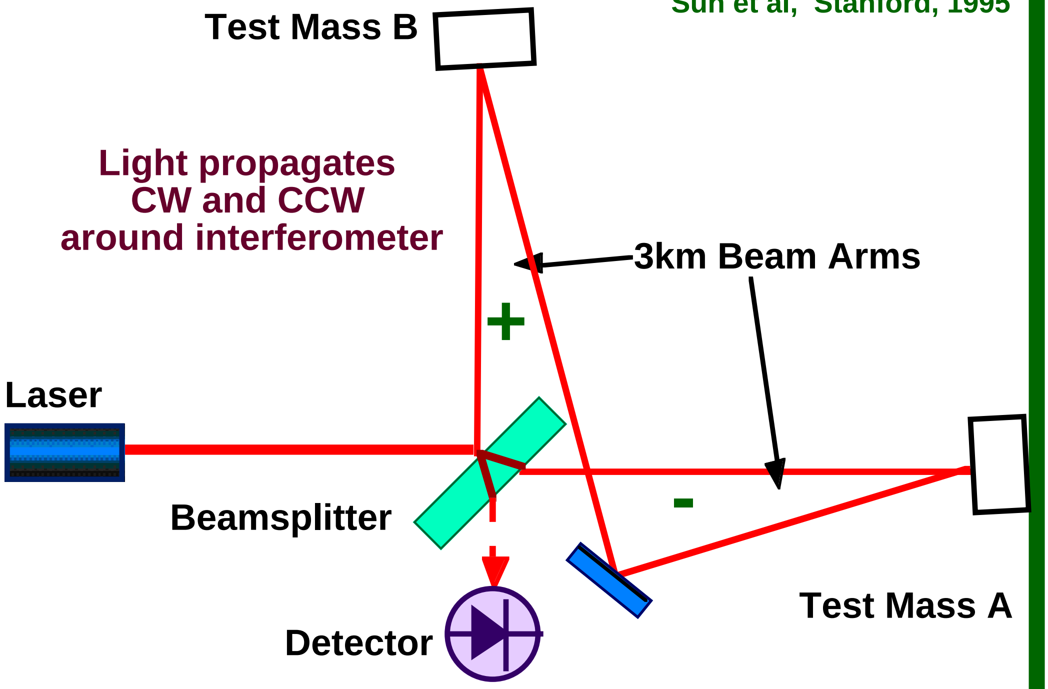
3.1 The Sagnac Configuration

- Layout shown in Fig:

Sagnac Interferometers for Gravity Wave Detection:

Sun et al, Stanford, 1995



Sagnac is automatically DC-locked to a dark fringe at the Detector port (due to common optical paths for CW,CCW).

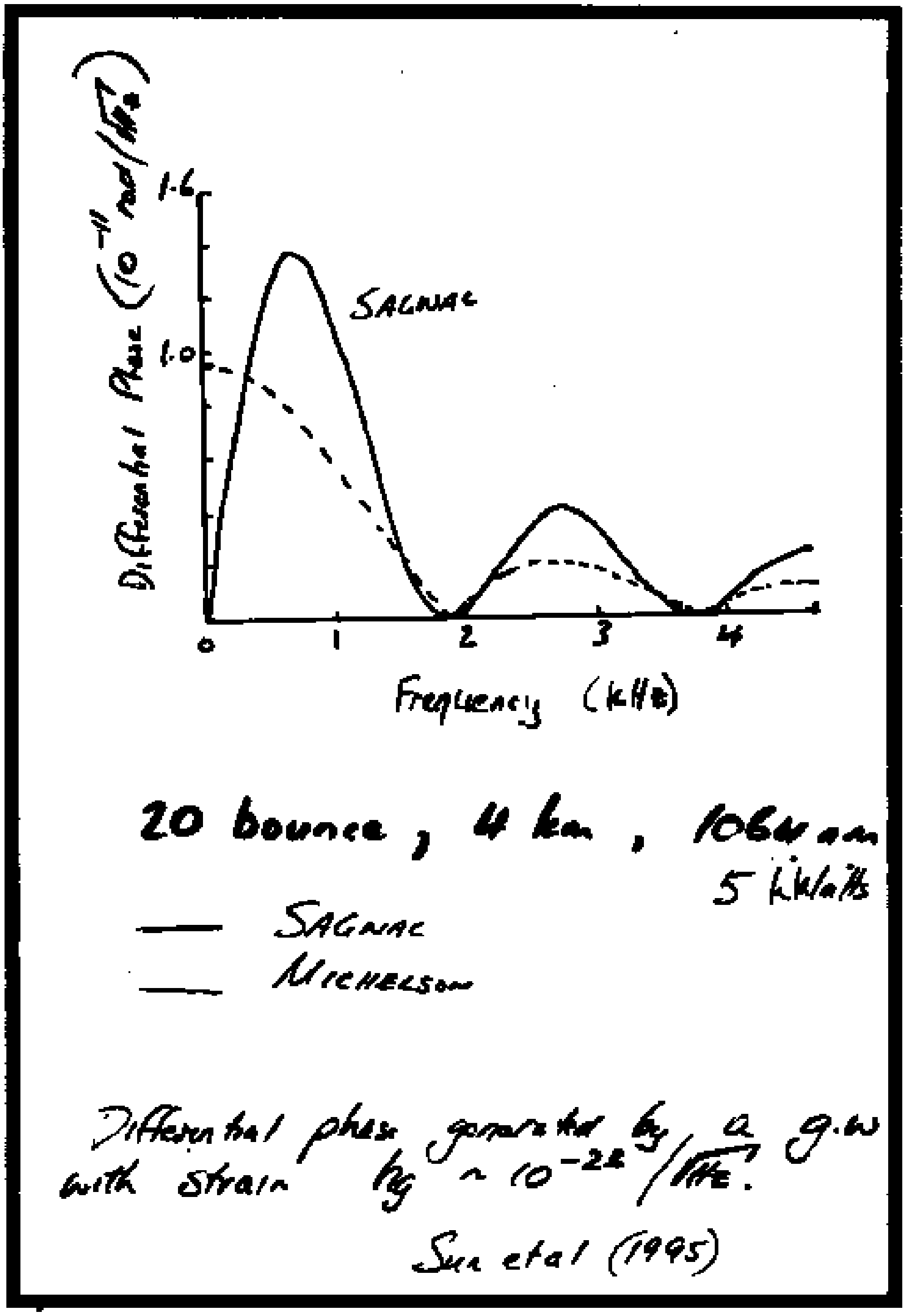
Area cancellation (+,-) leads to zero rotation sensitivity.

Gravity waves distort arms differentially as for Michelson. Time delay around arms leads to phase difference $\Delta\phi$ for CW and CCW beams arriving at beamsplitter, and hence a signal at detector - Better GW response than Michelson ! !

No differential phase response at or near DC - Immune to low frequency differential noise sources (e.g. thermal, seismic, laser instabilities, birefringence, asymmetry ...)

Similar to resonant recycling, light after leaving 1 arm is directed into the other arm before interfering at the beam splitter.

- Response cf Michelson:



Sun et al, Opt.Lett. (1995).

See that there is no response at dc; frequency of max response = 1/round trip time => to get low frequency response (100 - 1000 Hz), must employ arm storage; apart from dc, zeros are at same frequencies as for Michelson. Extra response is due to the Sagnac pathlength being twice as long.

- With impedance matched power recycling, peak sensitivity is the same in both instruments.

- Analysis by Mizuno et al (Opt.Comm, 1996) shows that, in terms of sensitivity, there is nothing to choose between a Michelson and a Sagnac. Choice comes down to physical path length available, topology chosen, and technical issues.

- Major technical advantage is the zero at dc. Basically, the counterpropagating beams sample the same distortions. This gives the Sagnac perfect common mode rejection. Relaxes requirements on dc length control.

- Major disadvantage: sensitivity to beam splitter ratio. This becomes very serious for RSE type devices.

- Sensitivity to wavefront distortions depends on where the distortion occurs (see Beyersdorf, Thursday) but under many circumstances, more sensitive than the Michelson.

- Basically, the design of a Sagnac instrument must use its inherent advantage
=> must avoid using optical cavities
=> use delay line arms and high power lasers, which can then have a broad spectral character.

3.2 Length Sensing and Alignment sensing Issues

- need a phase modulation signal readout system - external or frontal

- need to be able to lock positions of all mirrors to some dc longitudinal position ==> need a feedback system

- need to be able to lock alignment of all mirrors ==> want an auto alignment system

- like to be able to extract independent error signals to perform these functions

- the more complex the topology the more difficult these tasks become

- Need to adopt a strategy:
  - LIGO, Virgo decide to use only modulations applied to the input beam
  - GEO600 use both frontal and external modulation
  - full control plant for RSE with PR yet to be developed (Mason, Caltech)

3.3 **Sensitivity Theorem**

- Clearly stated in Mizuno (1995):

$$h_o \geq \sqrt{(2h\,\lambda\,\Delta f_{bw} / \varepsilon\,\pi c)}$$

where

h = Planck’s constant/2π

λ = wavelength of the laser

Δf = detection bandwidth

ε = energy stored in interferometer

- For a Fabry-Perot arm storage instrument

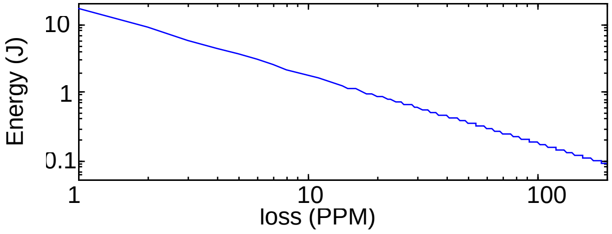
detection bandwidth = π/2 response bw

- For impedance matched FP instrument

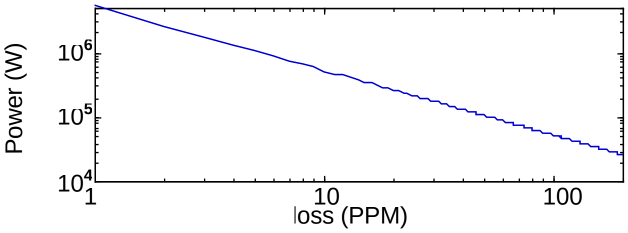
$$h_o \geq 5.9\mathrm{x}10^{-24} \{\lambda/1\ \mu\mathrm{m}\}\{\varepsilon/ 20\mathrm{J}\}\{\Delta f_{bw}/1\ \mathrm{kHz}\}$$

- Consider a 500 m long interferometer with 10 W of 1064 nm light incident; bandwidth variable from 10 Hz to 1 kHz

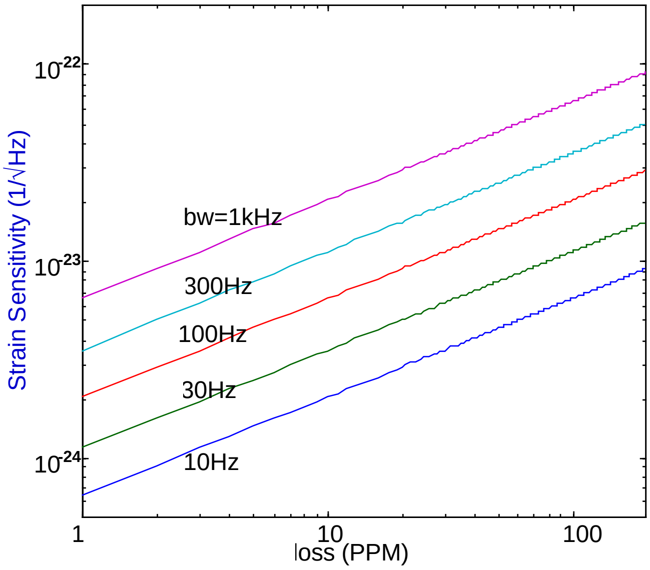
Energy stored in an interferometer



Circulating Power in an interferometer



Sensitivity as a function of loss (five detection bandwidths)

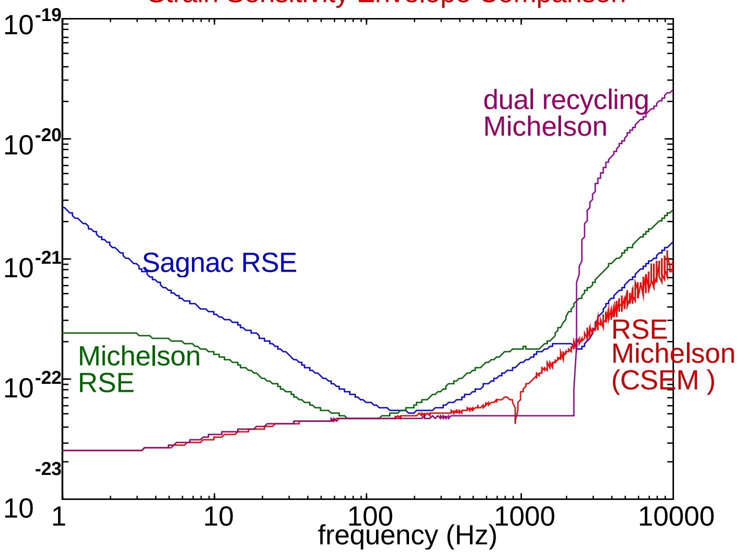


- Corollary: sensitivity governed by total losses.

3.3 Choice of Configuration

- Sensitivity theorem or Loss theorem: minimise optical components
- Consider heating effects: minimise power incident on critical, transmissive components
- Consider control plant
- Consider sensitivity to spatial and temporal errors
- Consider purpose: broadband for burst sources; narrow band for continuous
- Consider role of other noise sources
- Funds available
- examples:

Strain Sensitivity Envelope Comparison



RSE Michelson vs Dual recycling Michelson

- To be competitive, the Resonant Sideband Extraction system requires a compound Signal Extraction Mirror.
- Resonant Sideband Extraction Michelson system (with CSEM) has greater flexibility; able to tune bandwidth and centre frequency independently, with no significant sensitivity penalty.
- Resonant Sideband Extraction Michelson system (with CSEM) avoids thermal problems in the beamsplitter. (all high finesse-high power sections are simple Fabry-Perot cavities --> greater energy storage).
- Greater complexity of control for the Resonant Sideband Extraction Michelson system (with a compound Signal Extraction Mirror) , however this complexity is associated with low power-low finesse components.

Conclude ??