SQL Related Experiments at the ANU

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Conor Mow-Lowry, G de Vine, K MacKenzie, B Sheard, Dr D Shaddock, Dr B Buchler, Dr M Gray, Dr PK Lam, Prof. David McClelland

THE AUSTRALIAN NATIONAL UNIVERSITY

Y Chen and Prof. Stan Whitcomb

CALTECH

Experiments at the ANU

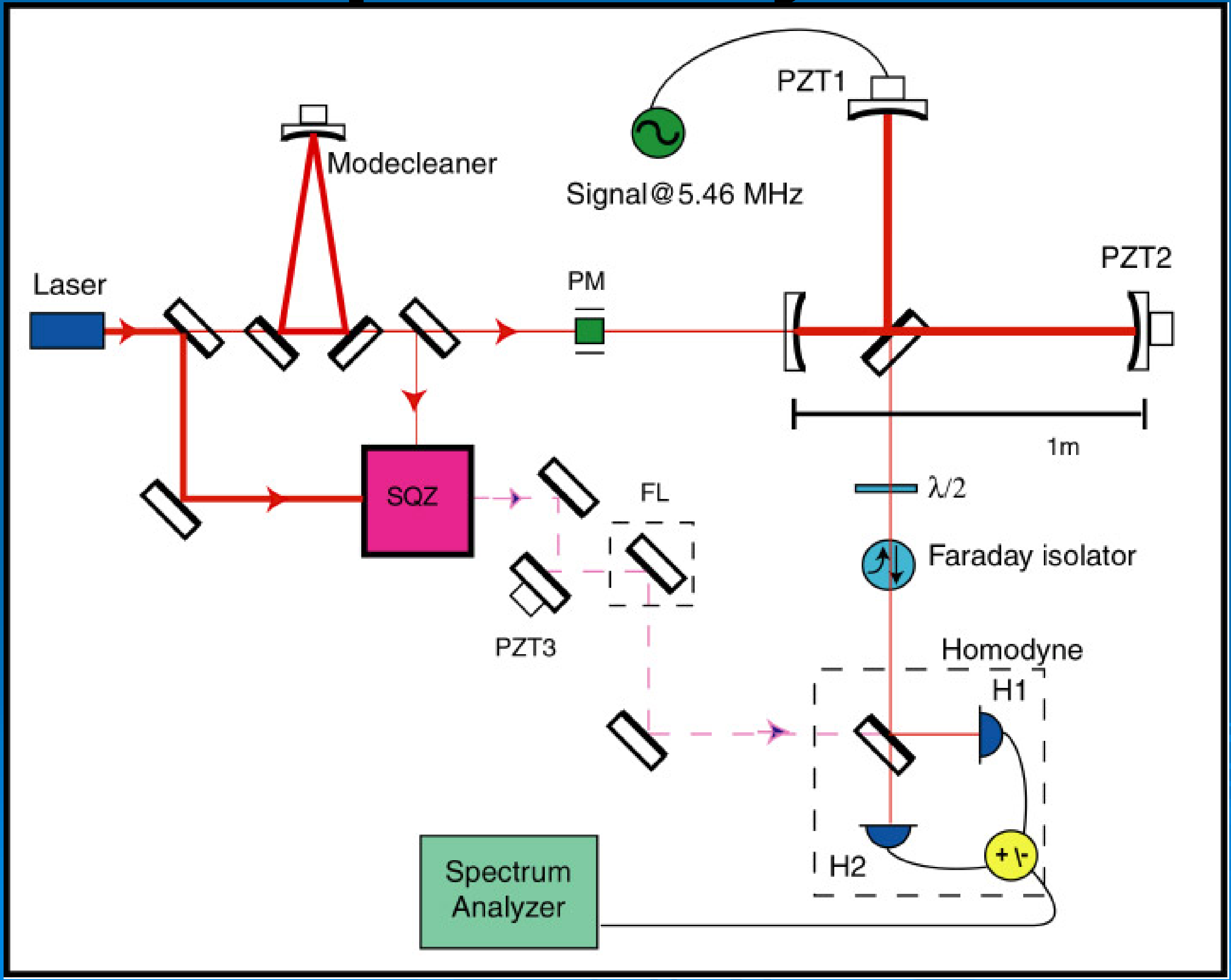
Squeezing enhanced power recycled Michelson
(K. McKenzie, D. A. Shaddock, B. C. Buchler, M. B. Gray, P. K. Lam, D. E. McClelland)

Speed meter control scheme and frequency response

(G. De Vine, Y. Chen, M. B. Gray, S. Whitcomb, D. E. McClelland)

Classical noise cancellation
(C. Mow-Lowry, B. S. Sheard, M. B. Gray, S. Whitcomb, D. E. McClelland)

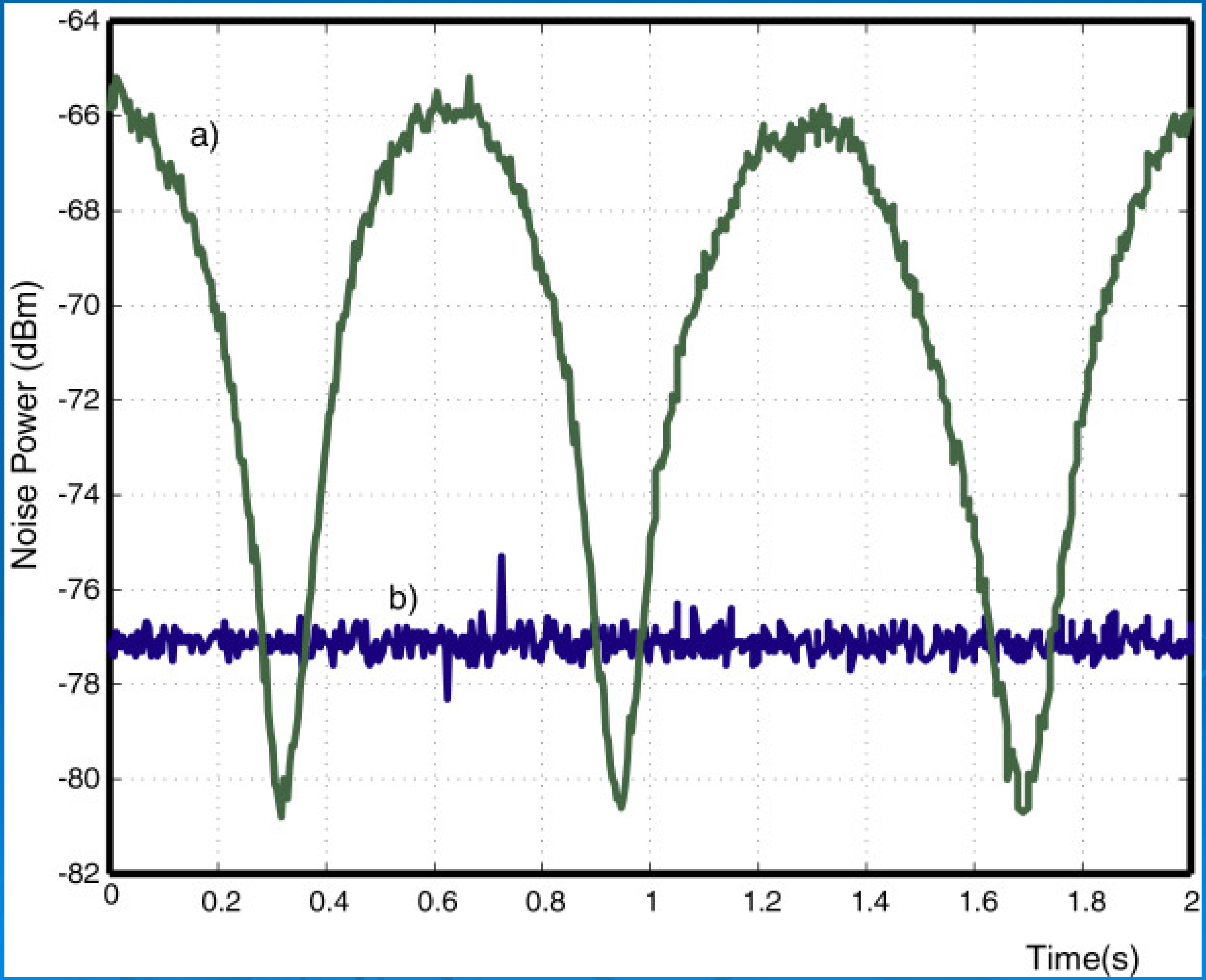
Squeezing Enhanced Michelson Optical Layout



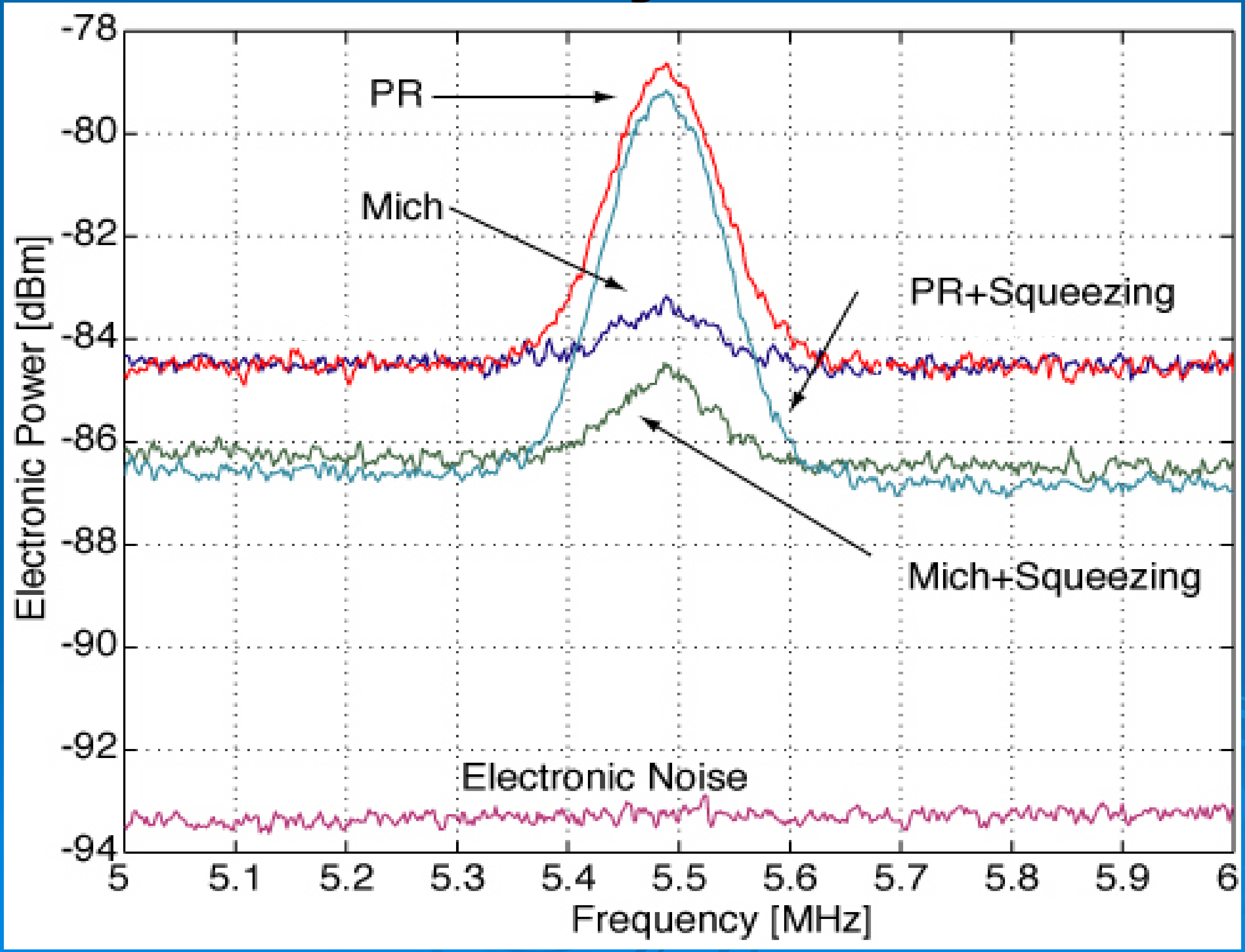
Squeezing Enhanced Michelson
Squeezed State Measurement

Squeezing at 5.5 MHz

3.5 dB below shot noise



Squeezing Enhanced Michelson
Sensitivity Results



Squeezing Enhanced Michelson
Summary of Results

- First experimental demonstration of a gravitational wave detector configuration operating below the shot noise limit

- The control scheme, configuration, and injection optics for the squeezed state are compatible with full scale detectors

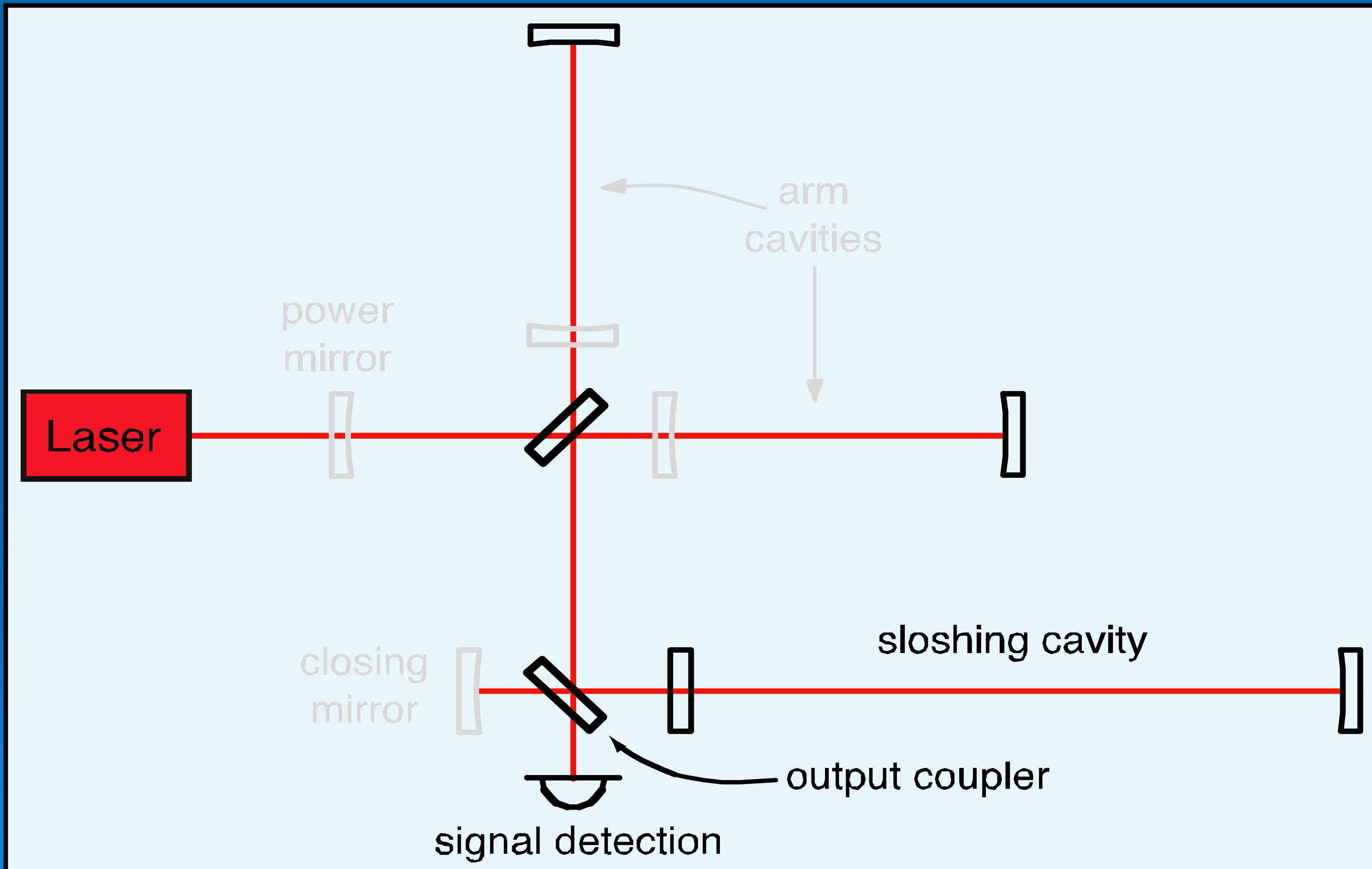
Speed Meter Configuration Demonstration

- Measures relative velocity of end test masses
- Involves the addition of a “sloshing” cavity and a signal cavity output coupler for signal extraction
- Theory: e.g. Phys. Rev. D **66**, 022001 (2002)

Speed Meter
How Does It Work?

- The sloshing cavity sends the GW signal back into the interferometer with a pi phase shift
- This then cancels the position signal (the interferometers response is like a differentiator up to the sloshing frequency)
- Thus the interferometer measures the relative velocity of the test masses
- Sloshing frequency determined by the storage time of the signal and sloshing cavities

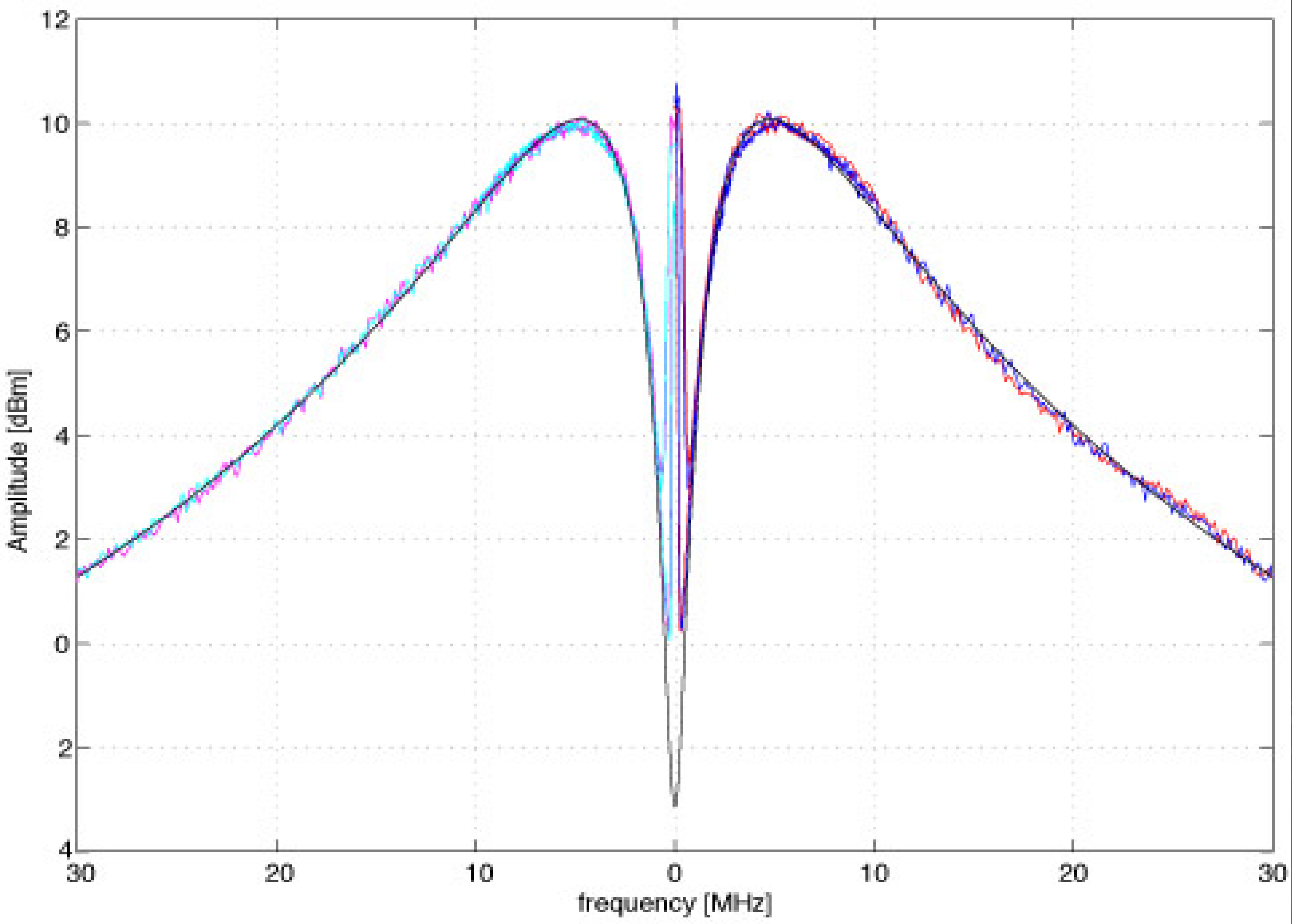
Speed Meter
Optical Layout



Speed Meter
Control and Readout

- An RF control scheme was devised using two resonant phase modulators
- Standard Schnupp and PDH techniques were used
- The frequency response was measured by injecting a ‘signal laser’ into the back mirror of an arm cavity

Speed Meter
Frequency Response

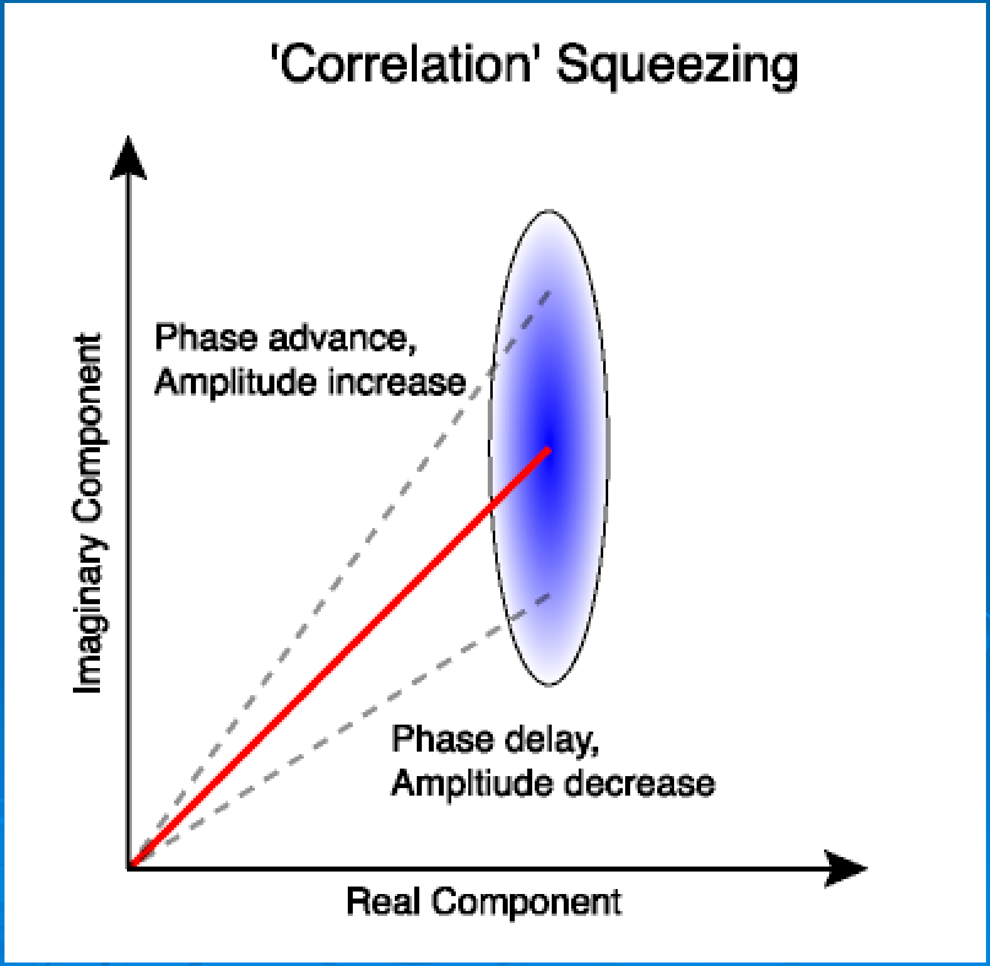


Noise Cancellation
The Principle

- At the SQL shot noise and radiation pressure noise are the same size
- If they are correlated with the appropriate phase, they will cancel
- Squeezing can be used to correlate the fluctuations
- Thus squeezing can be used to breach the SQL

Noise Cancellation
The Standard Quantum Limit

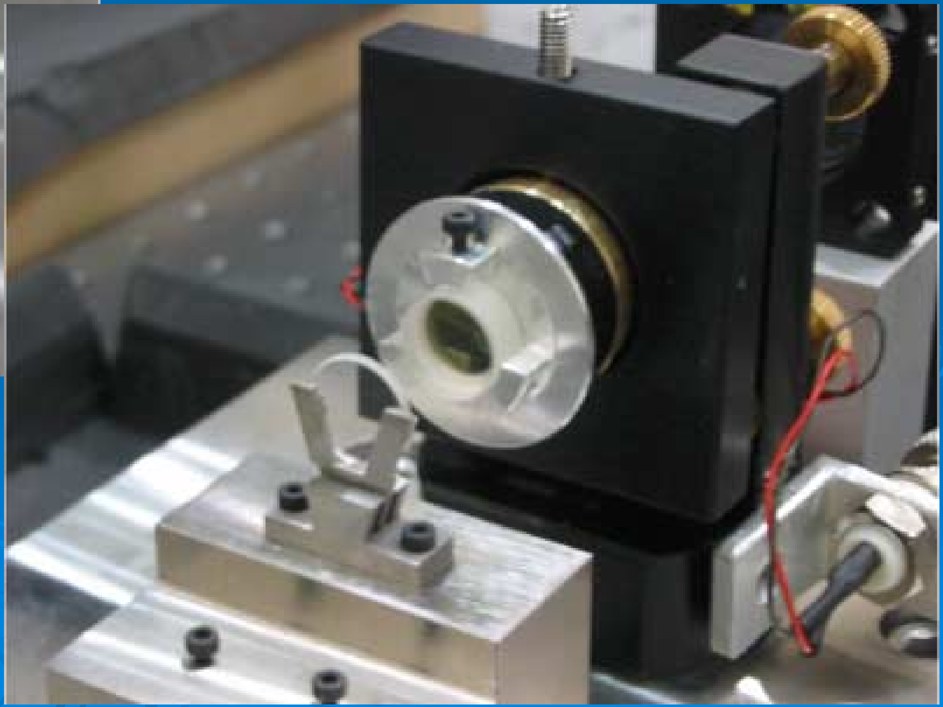
Squeezing at 45 degrees correlates fluctuations in the two quadratures



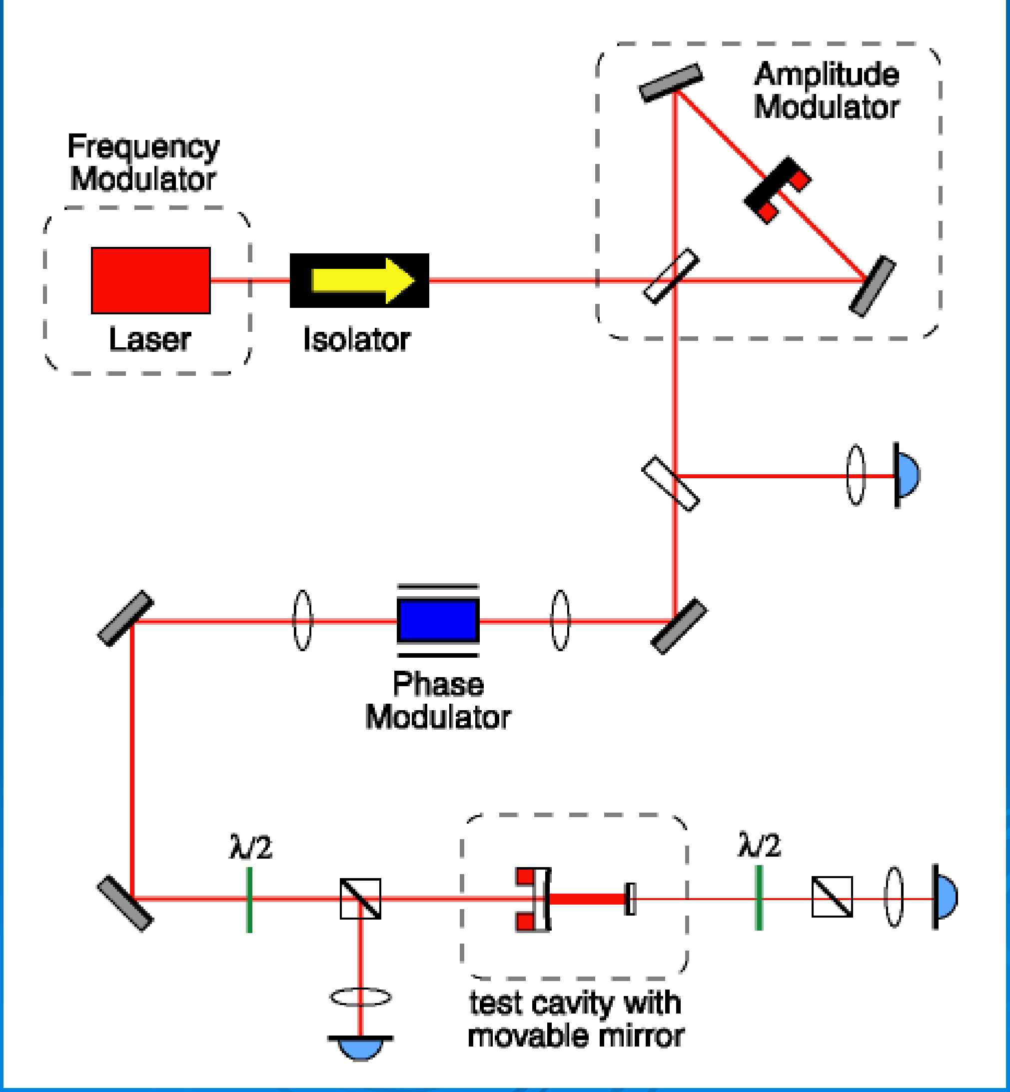
Noise Cancellation
The Classical Equivalent

- As a first step toward breaching the SQL, we performed the classical analogue
  - We used Amplitude modulation to replace radiation pressure noise, and
  - Frequency modulation to replace shot noise
- To sense radiation pressure, we used a light mirror, 300 mg, mounted on a thin cantilever flexure 240 μm thick

Noise Cancellation
Experimental Design



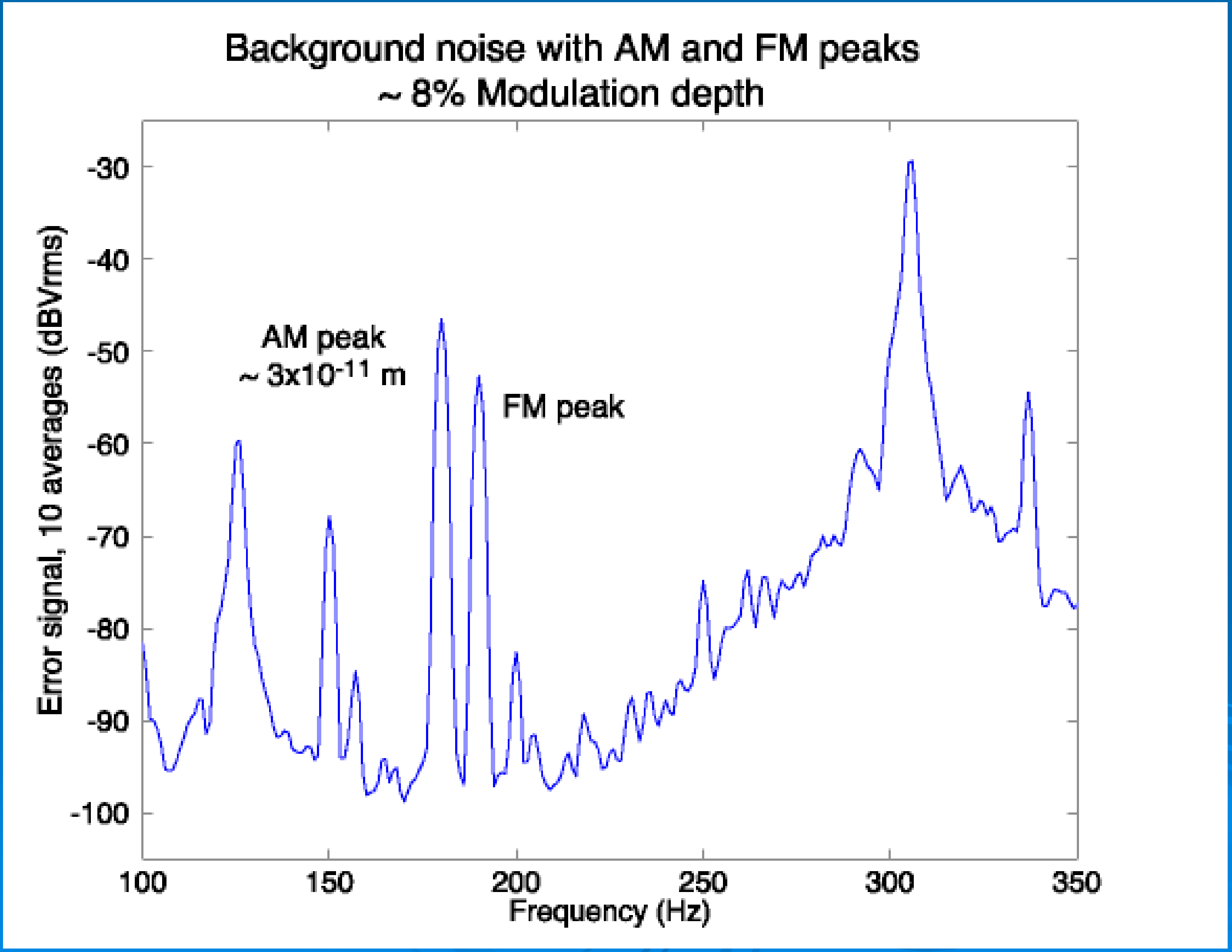
Noise Cancellation
Experimental Design



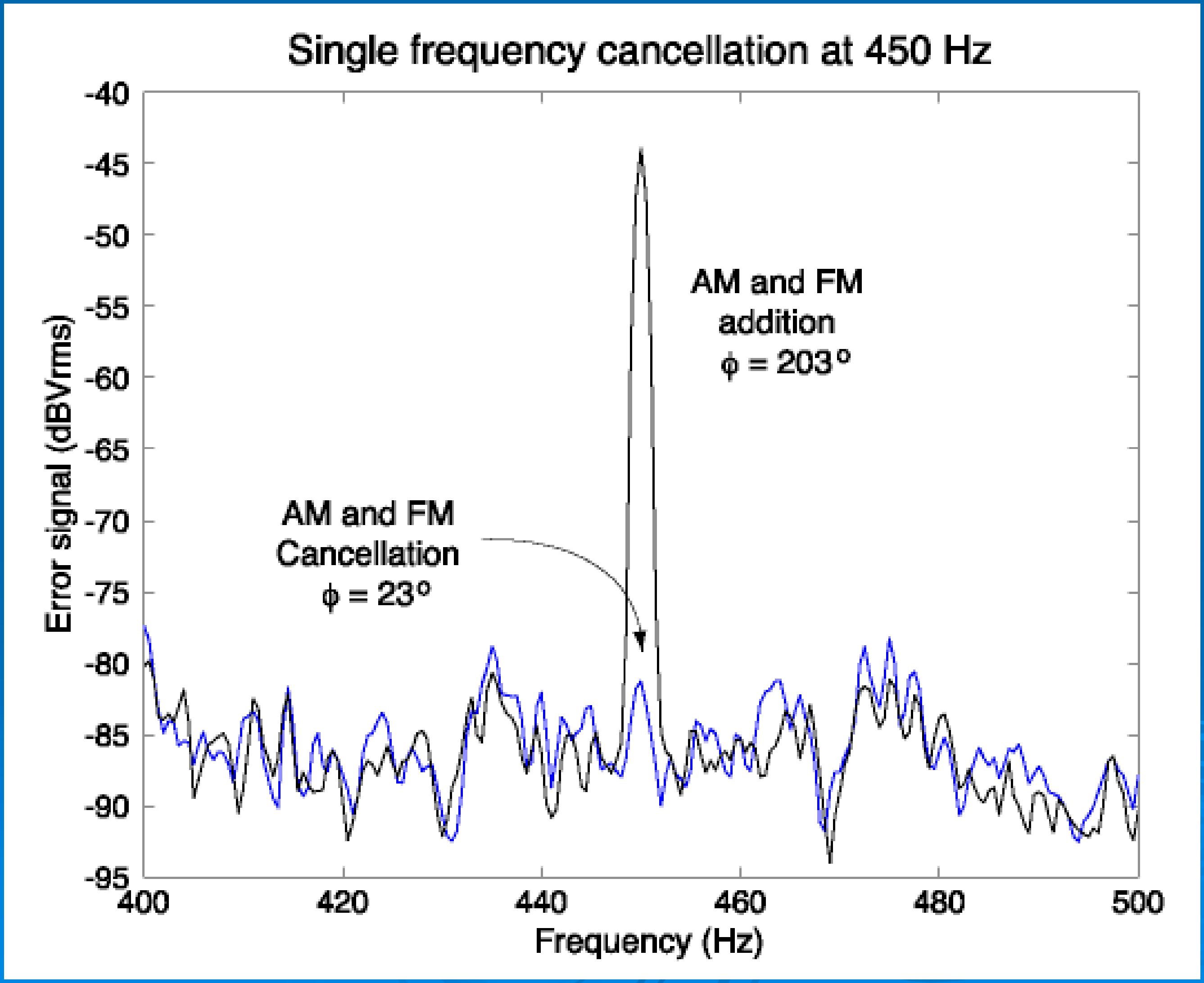
Noise Cancellation
Results

- Most data was recorded by observing the cavity transmission locking error signal
- The first data shows optical ‘noise’ at a single frequency, achieved by:
  - Introducing a sinusoidal AM signal
  - Adding an FM signal at a different frequency, and matching their error signal amplitudes
  - Phase locking the signals at the same frequency
  - Adjusting their relative phases and amplitudes until the peak reached a minimum

Noise Cancellation Results



Noise Cancellation Results

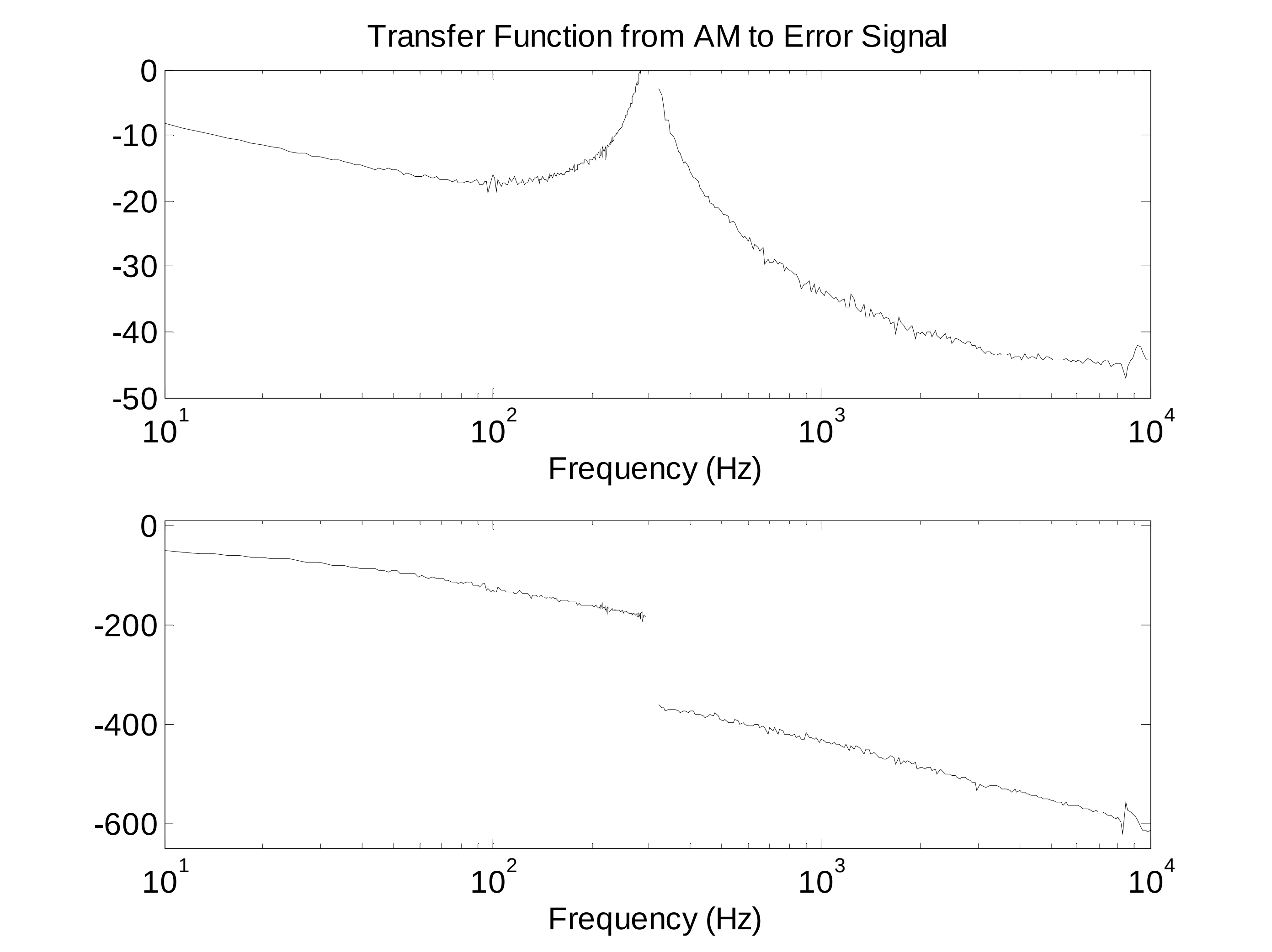


Noise Cancellation Results

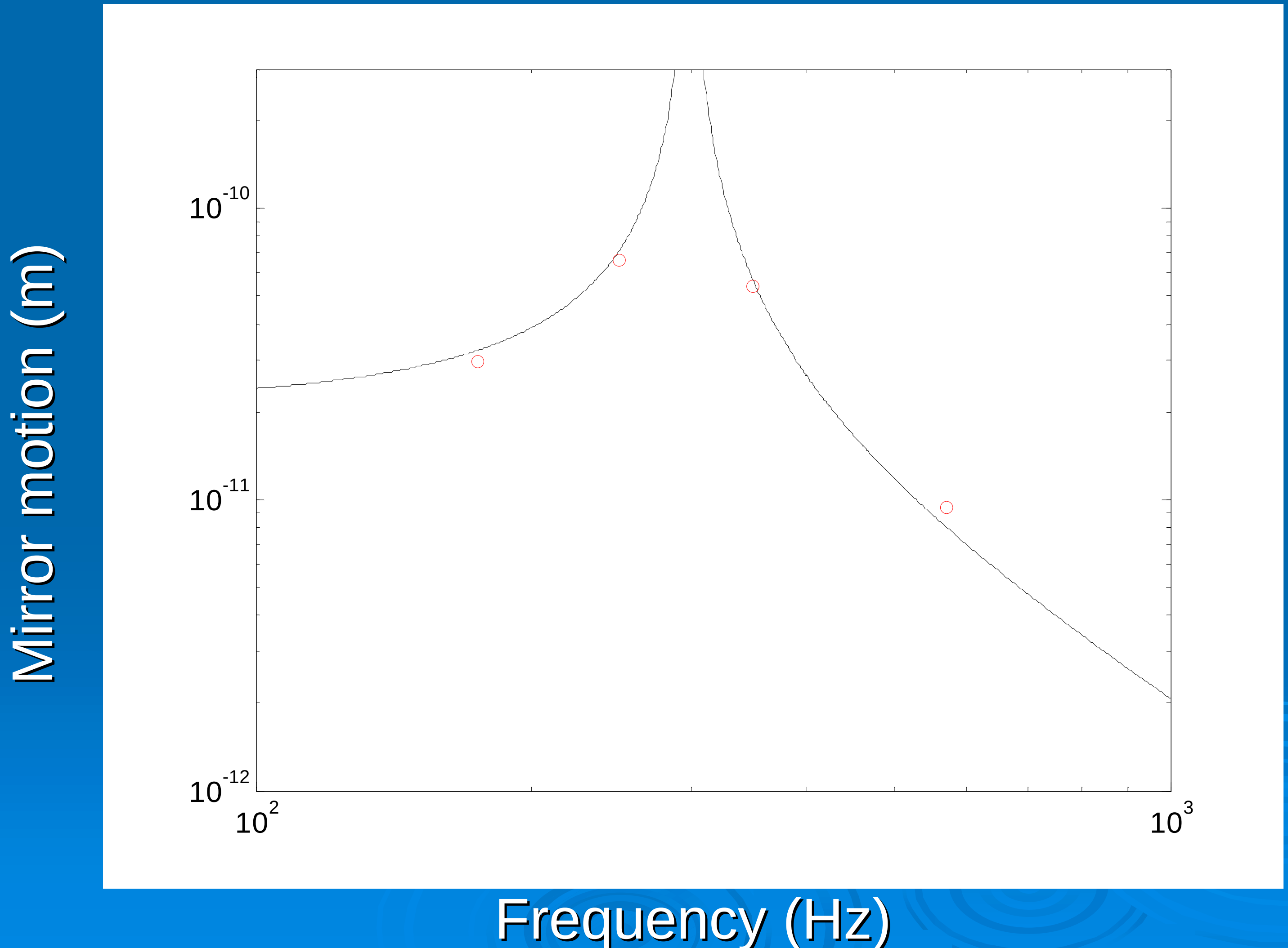
Verification that error signal disturbances from input AM were caused by radiation pressure was done in 3 ways:

- Observation of the scaling of the effect with input power (not shown),
- Measurement of the transfer function from amplitude modulation to error signal disturbance, and
- A calibrated measurement of motion for a known driving radiation pressure force

Noise Cancellation Results



Noise Cancellation Results



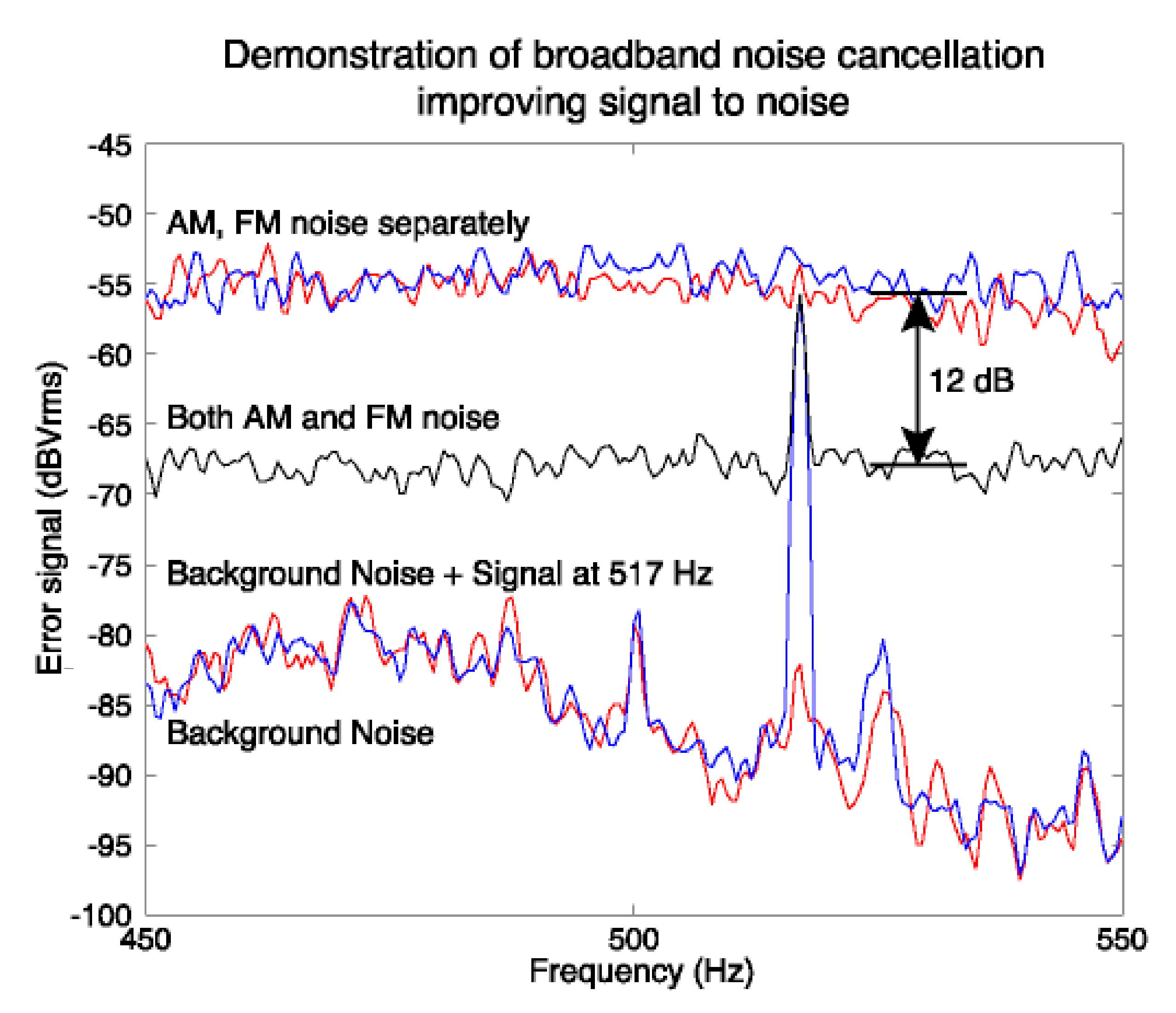
Noise Cancellation
Results

- To achieve broadband noise cancellation, bandwidth limited white noise was generated

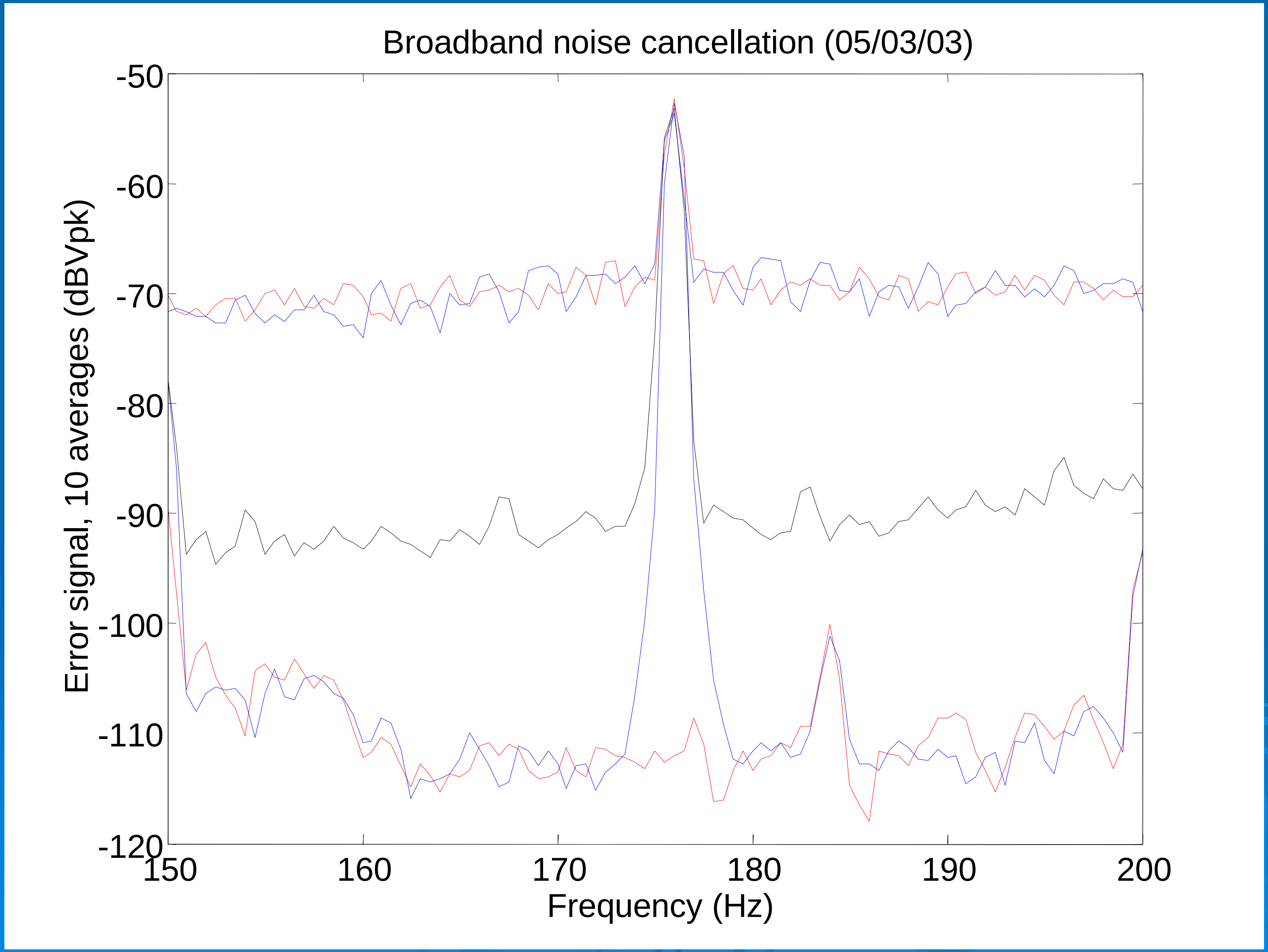
- The signal was split, to supply inputs to both the amplitude and frequency modulators

- To counter the effect of the mechanical transfer function, one path was shifted in amplitude and phase, then inverted

Noise Cancellation Results



Noise Cancellation Results



Noise Cancellation
Further Work

Several additions were made to the work shown here:

- An unmodulated, orthogonally polarized probe was used to readout cavity length
- Better optical power and cavity finesse measurements were made
- Measurements were made of frequency shifts from opto-mechanical coupling

Conclusions

- A squeezing enhanced Michelson interferometer was shown to operate with sensitivity better than the shot noise limit
- A speed meter control scheme and frequency response was demonstrated
- Correlated noise in the same quadratures as shot noise and radiation pressure noise was shown to cancel in the presence of a movable mirror