“Bi-linear” Noise Mechanisms in Interferometers

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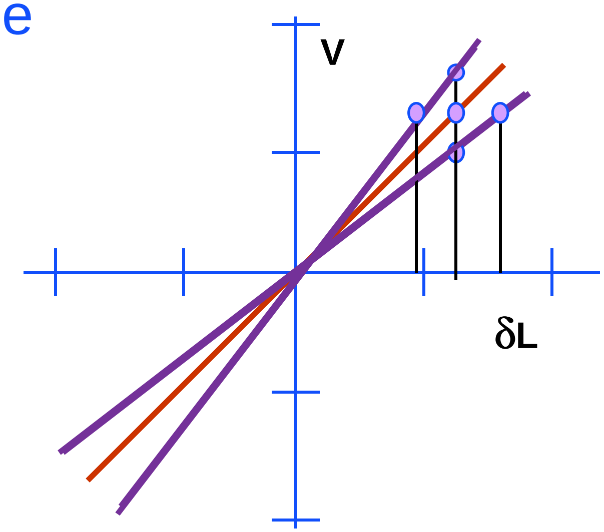
Scope of Talk

- Goal for talk
  - » Heuristic description of a common class of noise sources
  - » Description, some real world examples, and a challenge
- Point of view: Instrument Builder
  - » Understanding of noise sources has one primary purpose: to eliminate them
  - » “If it can be sensed, it can (and should be) eliminated”
- Acknowledgments
  - » Nothing in this talk is original or new!
  - » Just what I have learned over the years from Rai Weiss, Mike Zucker, Seiji Kawamura, Peter Fritschel, David Shoemaker, Ron Drever, Bob Spero, …

Simplest Example

- Sensing of arm length difference is proportional to input laser intensity



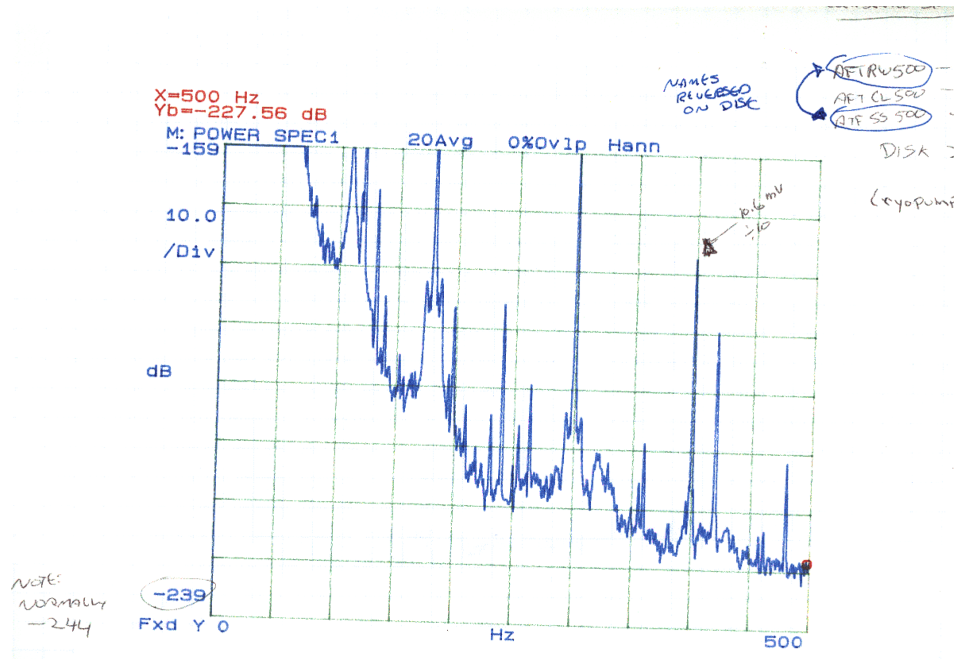
$$"\Delta L"(t) \approx I(t) dL(t)$$

$$"\Delta \tilde{L}"(w) \approx \tilde{I}(w_1) d\tilde{L}(w \pm w_1)$$

- Noise term linear in two variables (“bilinear”) creates output noise at sum and difference frequency

Example from LIGO 40m Interferometer

- Intensity stabilization servo had noise at multiples of 60 Hz
- Seismic noise at low frequencies suppressed by servo
- ….but not completely cancelled below 10 Hz
- Result was 20 Hz wide peaks at multiples of 60 Hz



Importance of Bilinear Noise Mechanisms

- Typical interferometer configurations are insensitive to first order noise sources
- "Traditional" noise investigation techniques (transfer functions, coherence) don't pin-point bilinear sources
  - » Requires alternative techniques (e.g., addition of band-limited white noise)
- Understanding full nature of noise source gives experimenter two chances to reduce the output noise
- Most importantly, bilinear noise sources are fairly common

Bilinear Combinations of the Same Source

- Rotation of cavity optics

- Length of cavity quadratic in mirror rotation angle

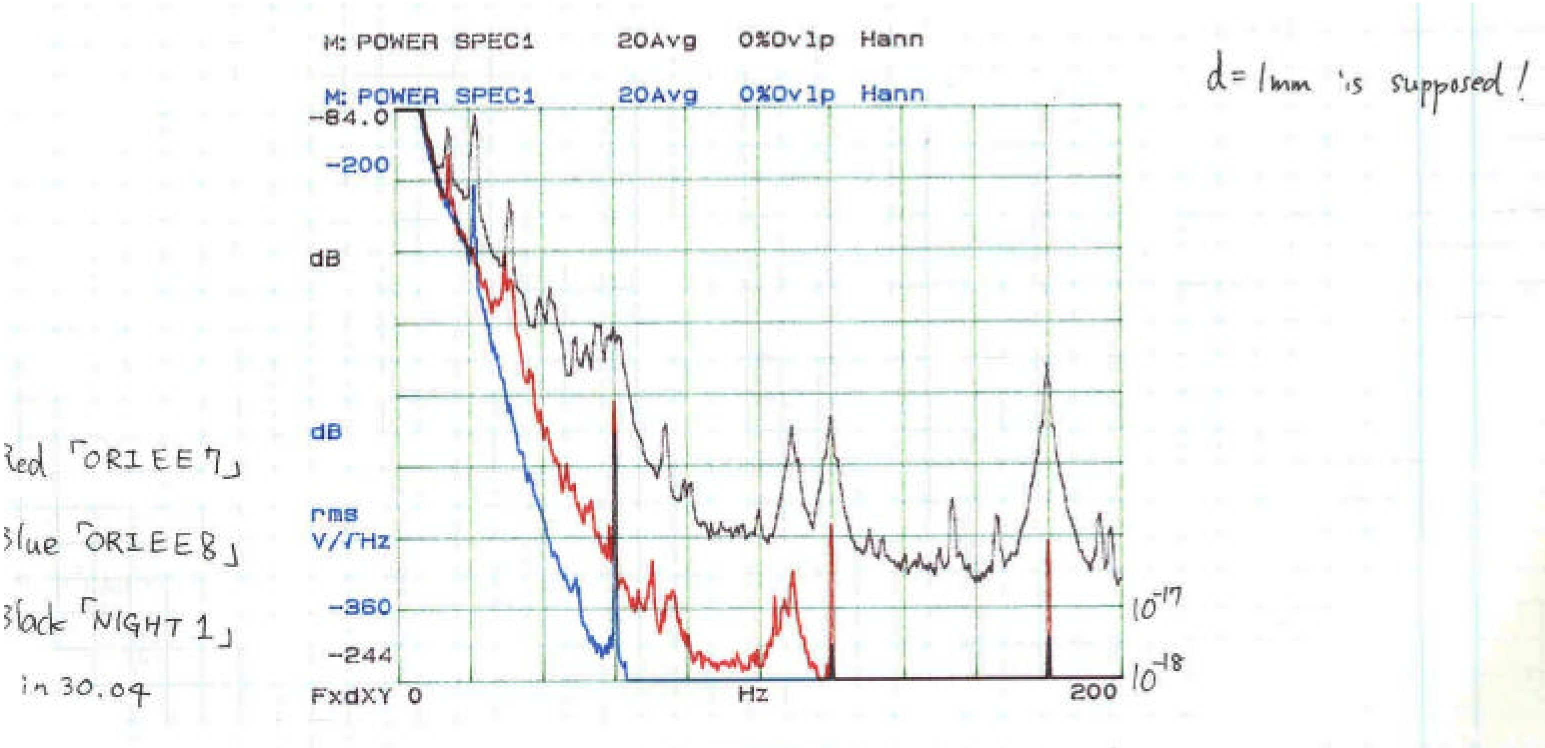
$$L \approx L_o + a q^2$$

- Large low frequency angular fluctuations mix with small high frequency fluctuations

$$\Delta L(w) \approx a q(w_{low}) q(w_{high})$$

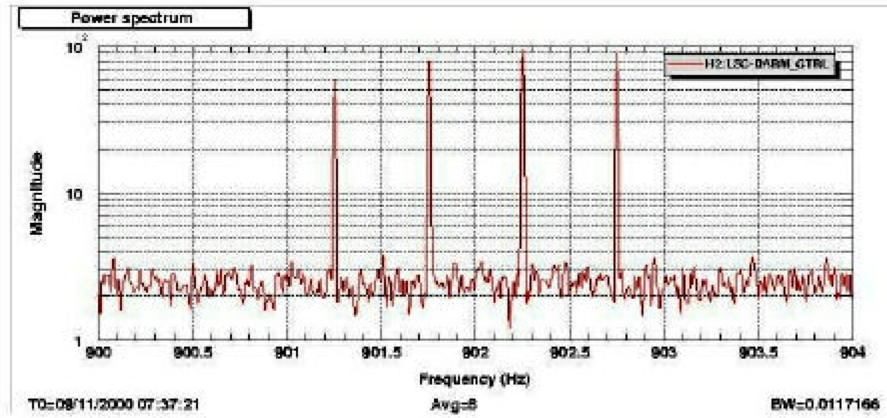
Another Example from 40 m

- Control systems for alignment had excess noise at high frequencies (few hundred Hz)
- Mixed with inevitable low frequency noise, in form of spot motion

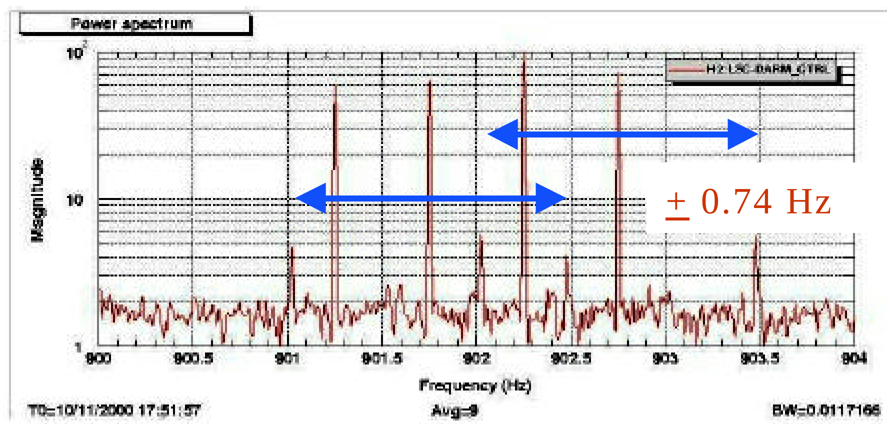


Another example from the 2km IFO?

- From the E2 “Engineering Run”
- ~900 Hz calibration peaks injected on individual test masses

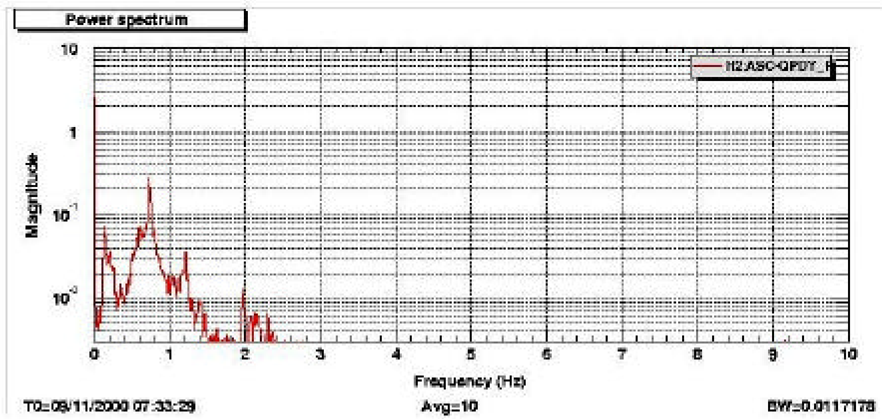


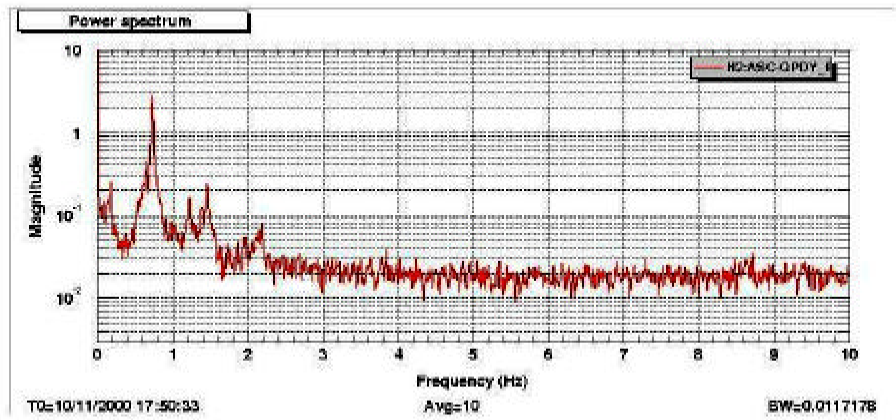
- Apparent mixing with 0.74Hz pendulum motion
- How to test?



Look for Low Frequency Tilting

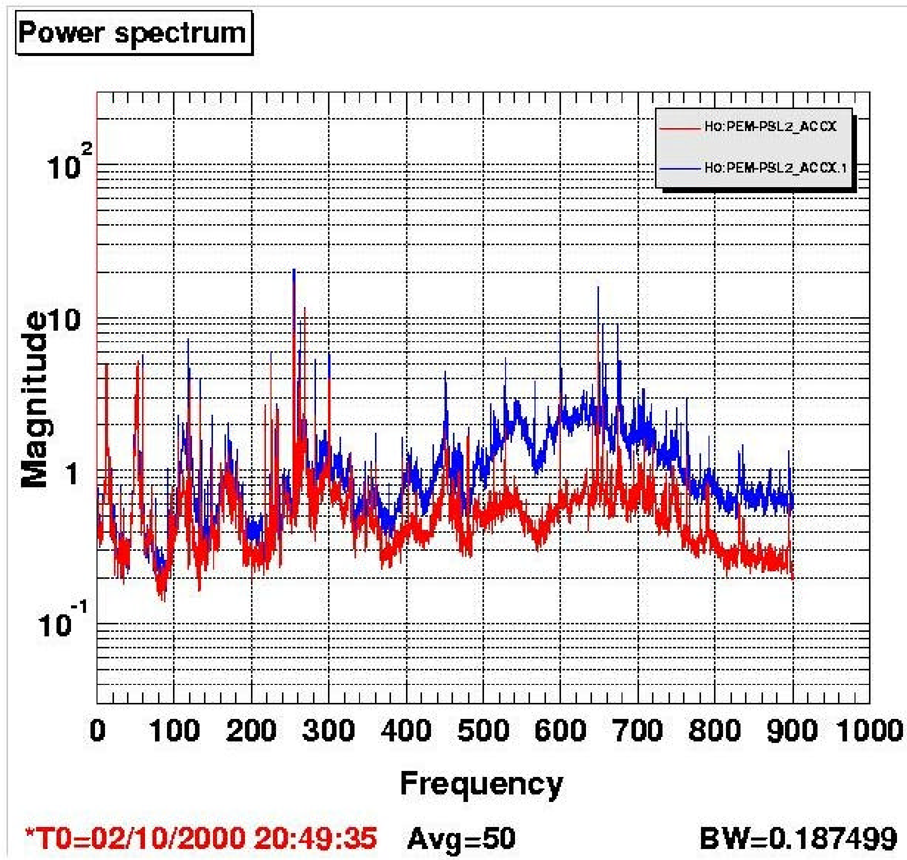
- Quadrant photodiode monitoring transmitted light gives measure of motion of cavity axis
- Low frequency spectrum clearly shows greater pitch motion when sidebands are present
- Reasonable hypothesis has imperfect balance of longitudinal drive, which leads to greater pitch motion when greater longitudinal drive is required





Another *Possible* 2 km IFO Example

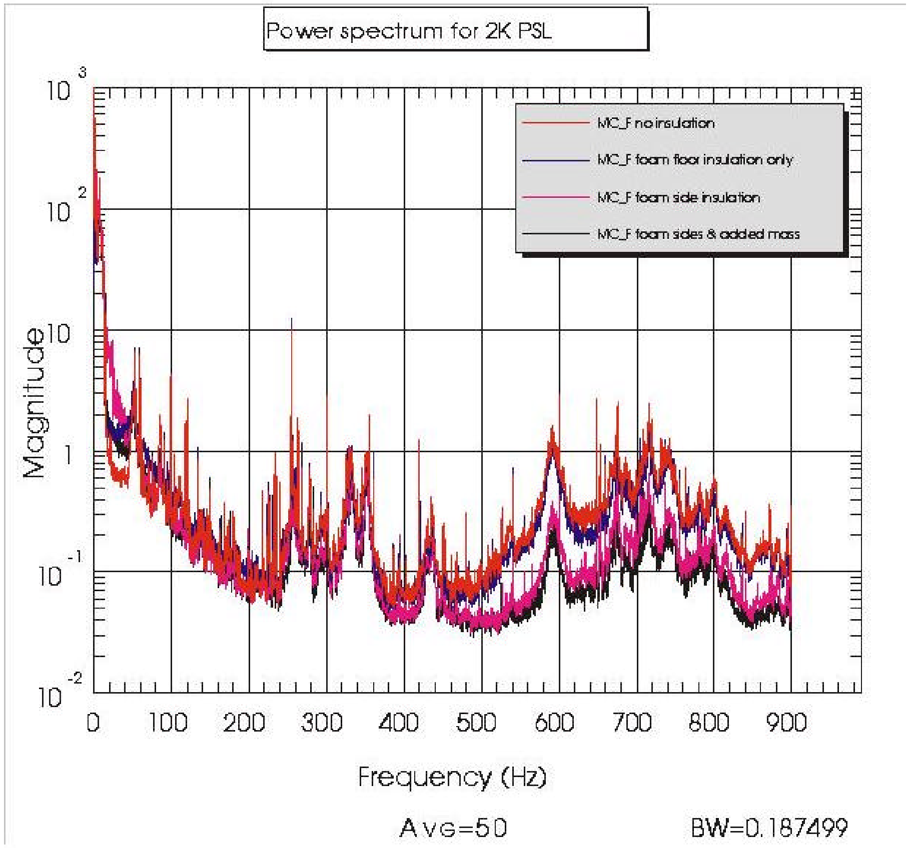
- Laser frequency noise drops when its optical table acceleration drops
- Acoustic shielding reduces vibrations of optical table



Laser Frequency Noise

- Approximately the same percentage drop as the accelerometer on optical table

- BUT no significant coherence with accelerometer, and although some general similarities in shape, detailed correspondence between spectra is poor



Ending Remarks

- Bilinear noise sources are important for GW interferometers
  - » Major thrust for instrument developers
- I know of EXACTLY one instance where noise in a GW detector was removed after the fact (and that was a linear noise source…)
- Challenges for this group:
  - » To demonstrate elimination of broadband bilinear noise cancellation
  - » Determine precision required for measurements of components of bilinear noise sources
  - » What about the case where one of the components is the quantity being measured?