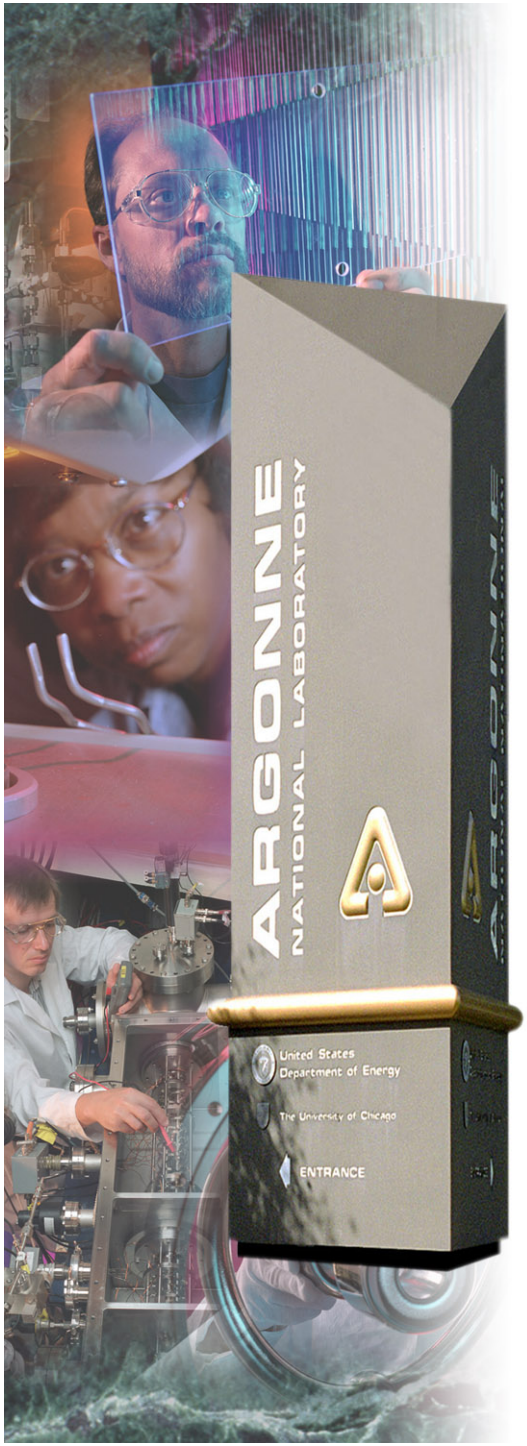


Advanced Photon Source
Argonne National Laboratory

Orbit feedback at APS

(Consolidation of previous talks)

John Carwardine

1/19/06

Argonne National Laboratory

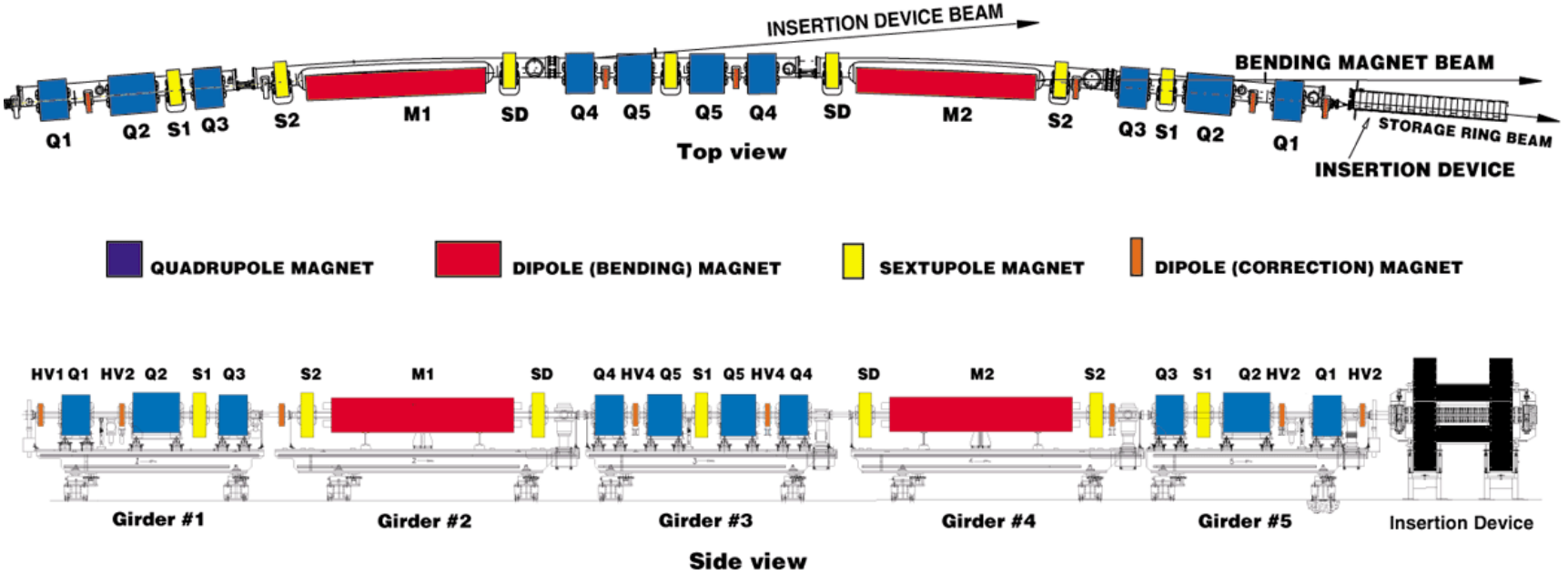
Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Advanced Photon Source
Storage Ring Design Characteristics

• Energy:	7.0 GeV
• Stored Beam Current (design):	100 mA
• Stored Beam Lifetime (design):	>10 hrs
• Circumference:	1104 m
• Number of Super-periods:	40
• Harmonic Number:	1296
• RF Frequency:	351.93 MHz
• Horizontal Tune:	35.2
• Vertical Tune:	14.3
• Synchrotron Tune:	0.0072
• Horiz. Beam Size at ID Source:	325 μm rms
• Vertical Beam Size at ID Source:	86 μm rms
• X-Y Coupling	10 %
• Straight Sections for I.D.'s:	35

One Sector of the Advanced Photon Source Storage Ring



27.6 meters

(APS has forty sectors - 1104 meters total circumference)

Orbit Feedback System Requirements

APS Orbit Stability Specifications

- Beam must be stable to within 5% of its size.
- Horizontal stability specification: 17μm rms.
- Vertical stability specification: 4.4μm rms.

Orbit Feedback System Functionality

- ‘Global’ (long wavelength) feedback to minimize rms orbit errors.
- ‘Local’ feedback to steer the orbit through x-ray source points.

Systematic Effects Impacting APS Orbit Correction

RF BPM systematic effects

- Timing / trigger stability
- Intensity dependence
- Bunch pattern dependence
- The "rogue" microwave chamber modes
- Electronics thermal drift

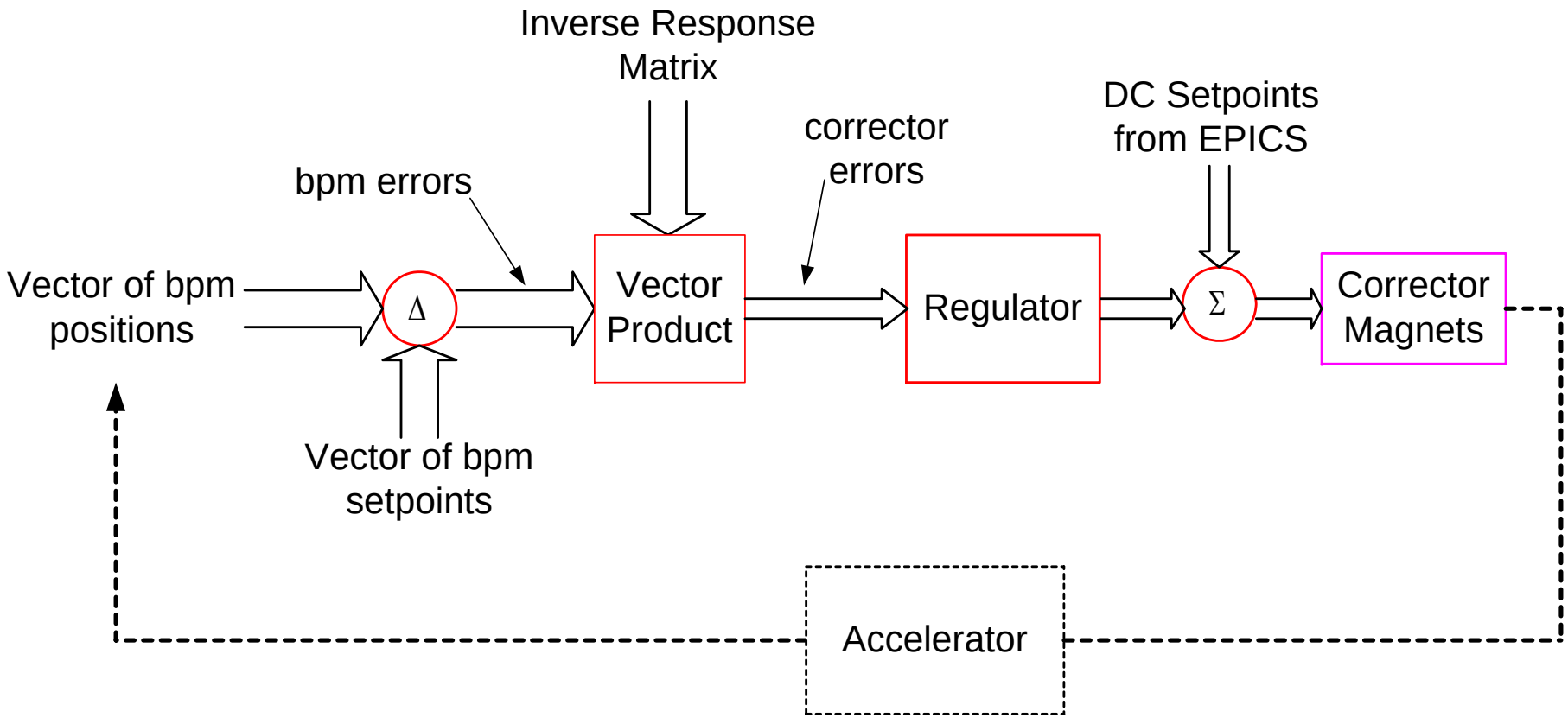
X-ray BPM systematic effects

- Stray radiation striking X-bpm blade pickups
- X-bpm blade misalignment
- Electronics thermal drift
- ID Gap-dependent effects (e.g. sensitivity, steering)

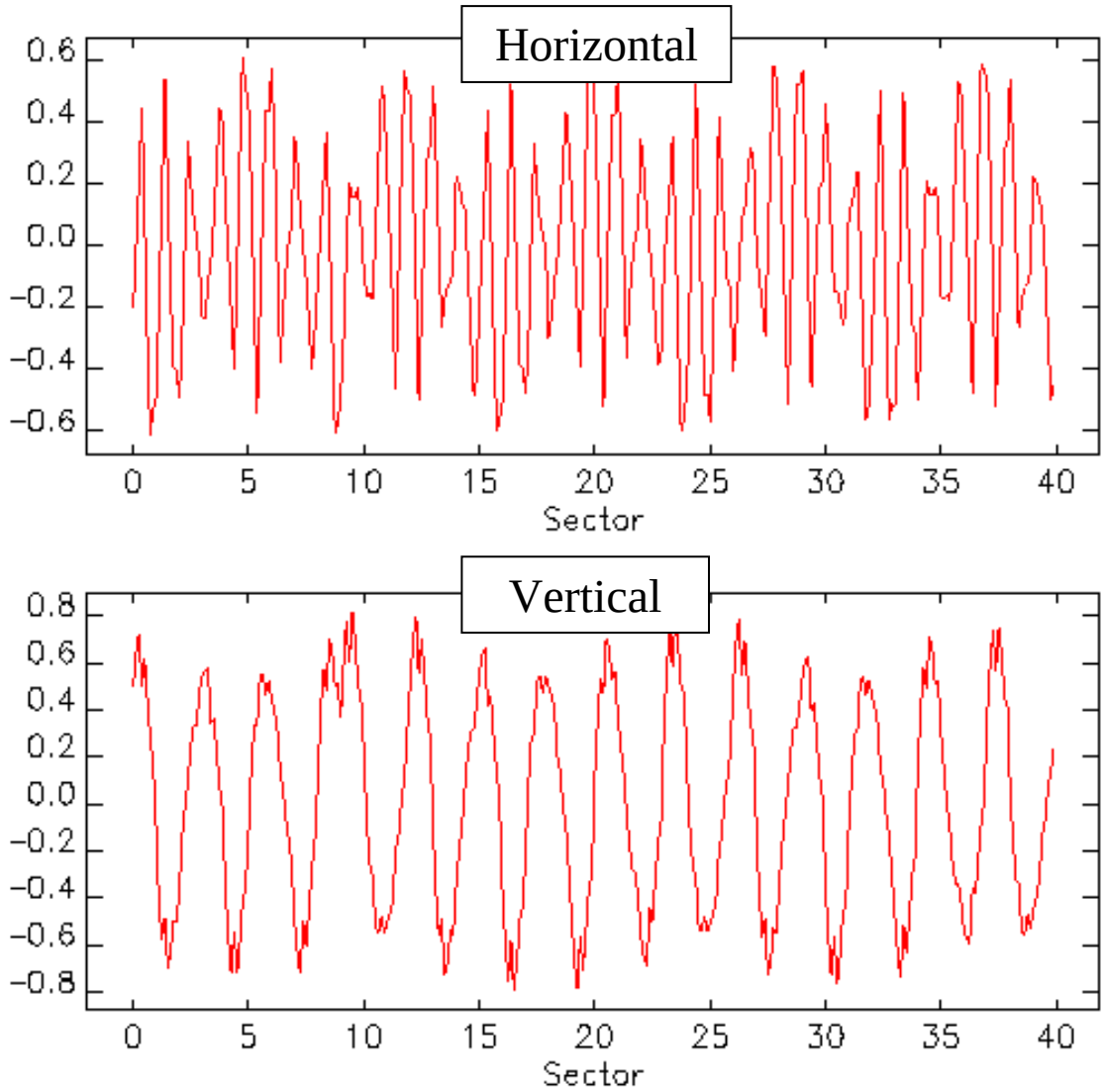
Extrinsic systematic effects (noise sources)

- Magnet power supply noise / ripple
- RF system high voltage power supply
- Mechanical vibration
- Thermal effects (Tunnel air / water temperature)
- Earth tides
- Insertion device gap changes

The Orbit Feedback Process



Betatron Orbit Motion



- Orbit disturbances produce an orbit error which follows a closed sinusoidal path relative to the reference orbit.
- This is true both for static disturbances and for dynamic disturbances.
- In the APS, the horizontal betatron tune is 35.2, and the vertical betatron tune is currently 19.3.

The Global Orbit Correction Algorithm

- The global orbit correction algorithm solves a set of linear equations describing the betatron orbit motion:

$$R \cdot \Delta c = \Delta x$$

- The ‘inverse response matrix’ maps orbit errors at the bpms to changes in corrector strength:

$$R^{-1} \cdot \Delta x = \Delta c$$

- Removal of ‘singular values’ improves the stability of poorly conditioned inverse response matrices.
- Different bpm & corrector selections will change the outcome.

Ex. *Many bpms and few correctors*…

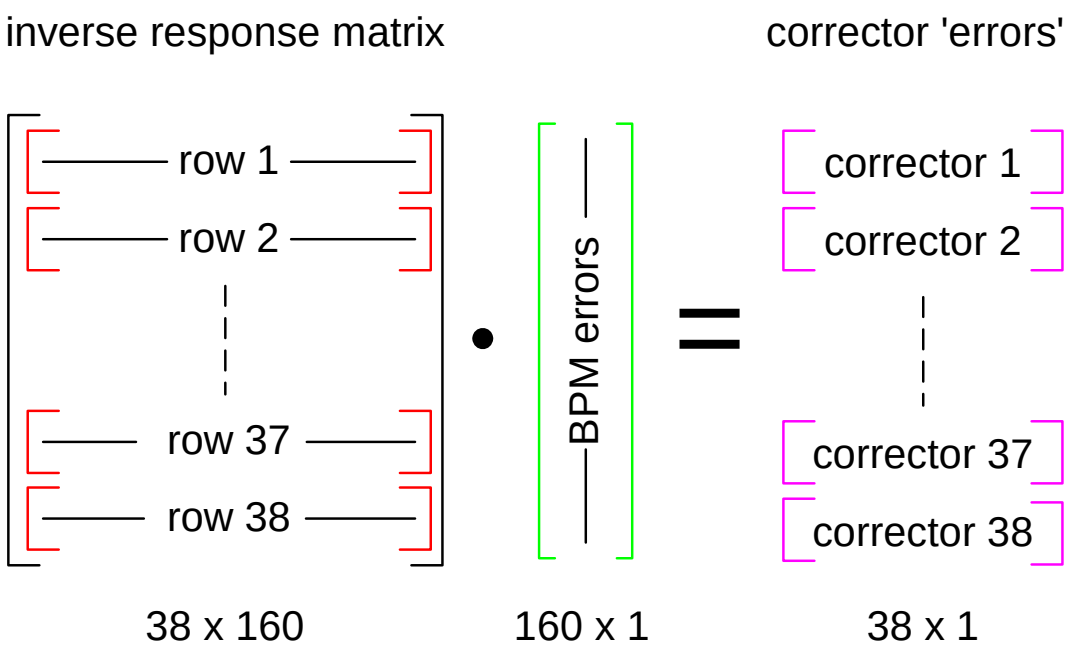
- Least squares minimization of bpm errors.

Ex. Few bpms and many correctors…

- Exact correction at bpm locations.
- Least-squares minimization of corrector power.

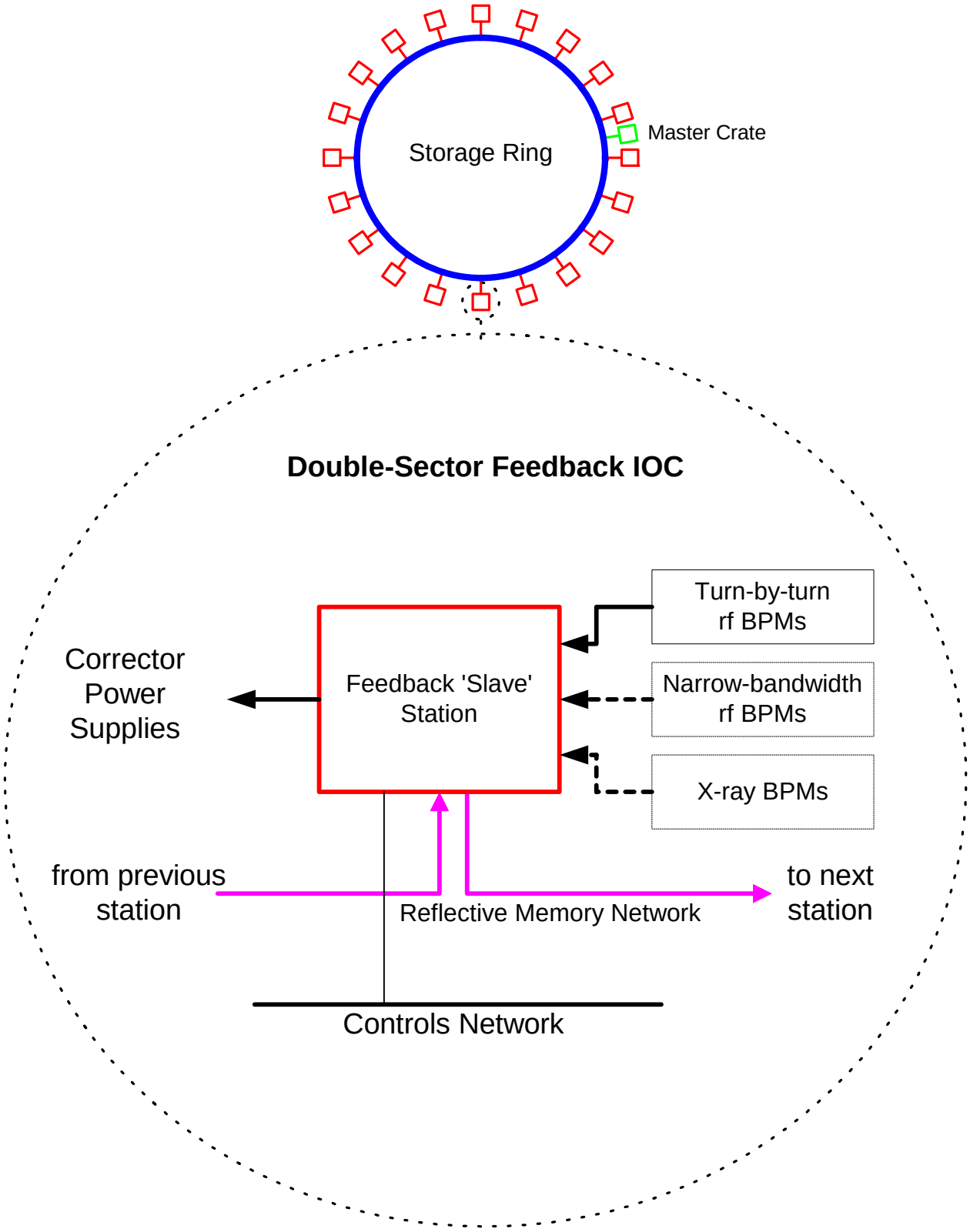
Implementation of the Real-Time Global Orbit Feedback Algorithm

- Computation of corrector ‘errors’ is conveniently separated into a series of vector dot-products, one for each corrector.



- Each corrector ‘error’ becomes the input to one of the 38 independent feedback regulators.

Real-Time Feedback Hardware Scheme



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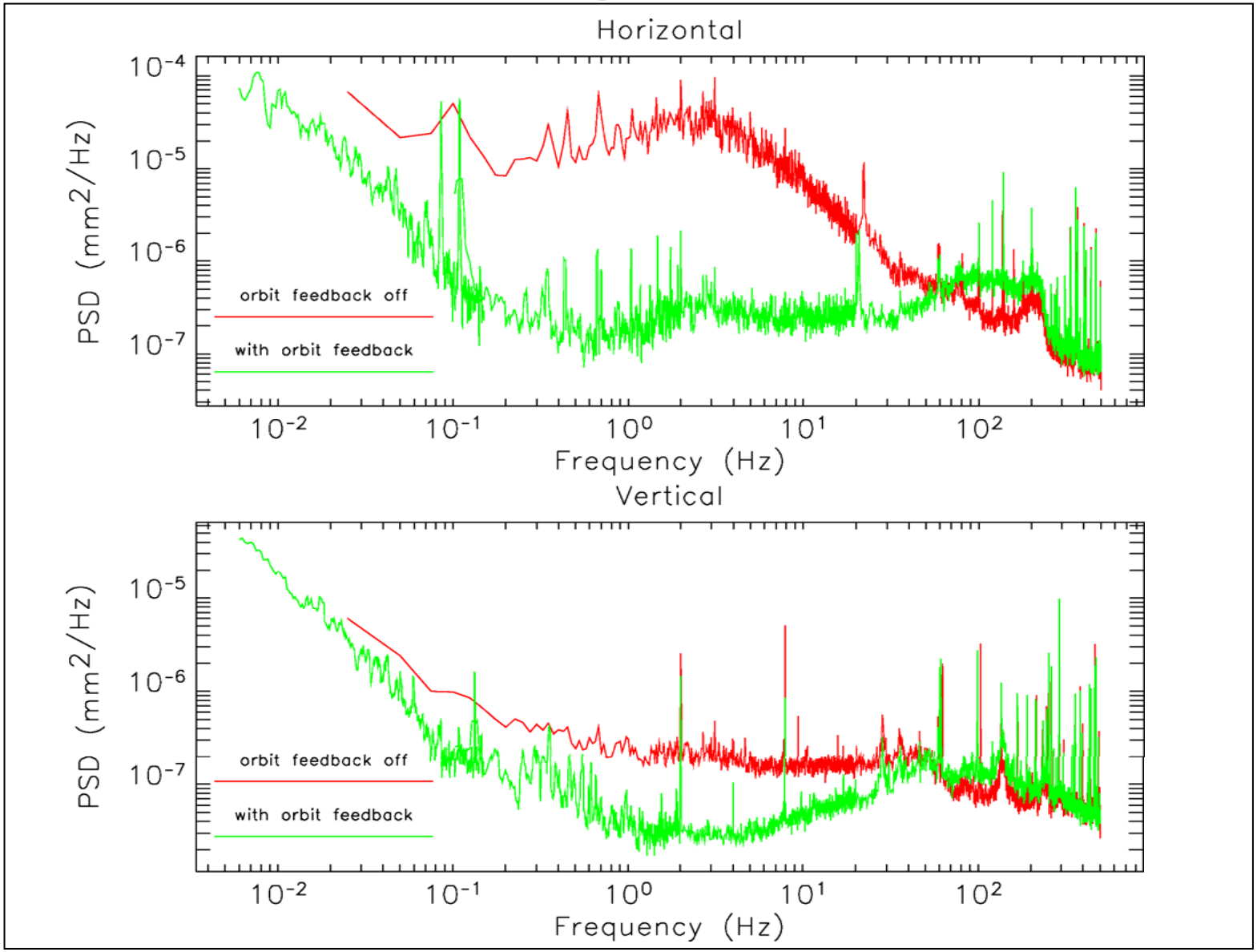
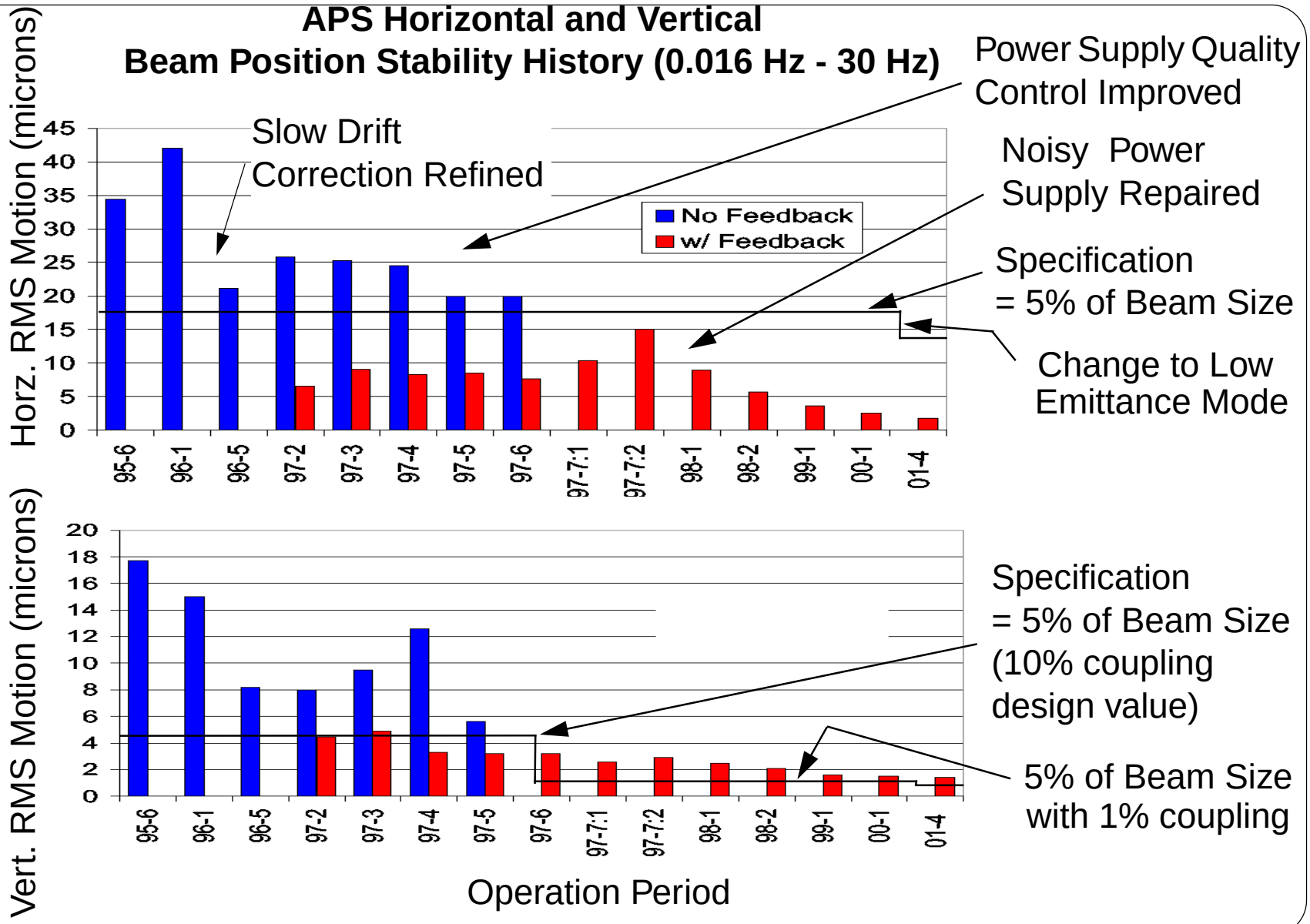
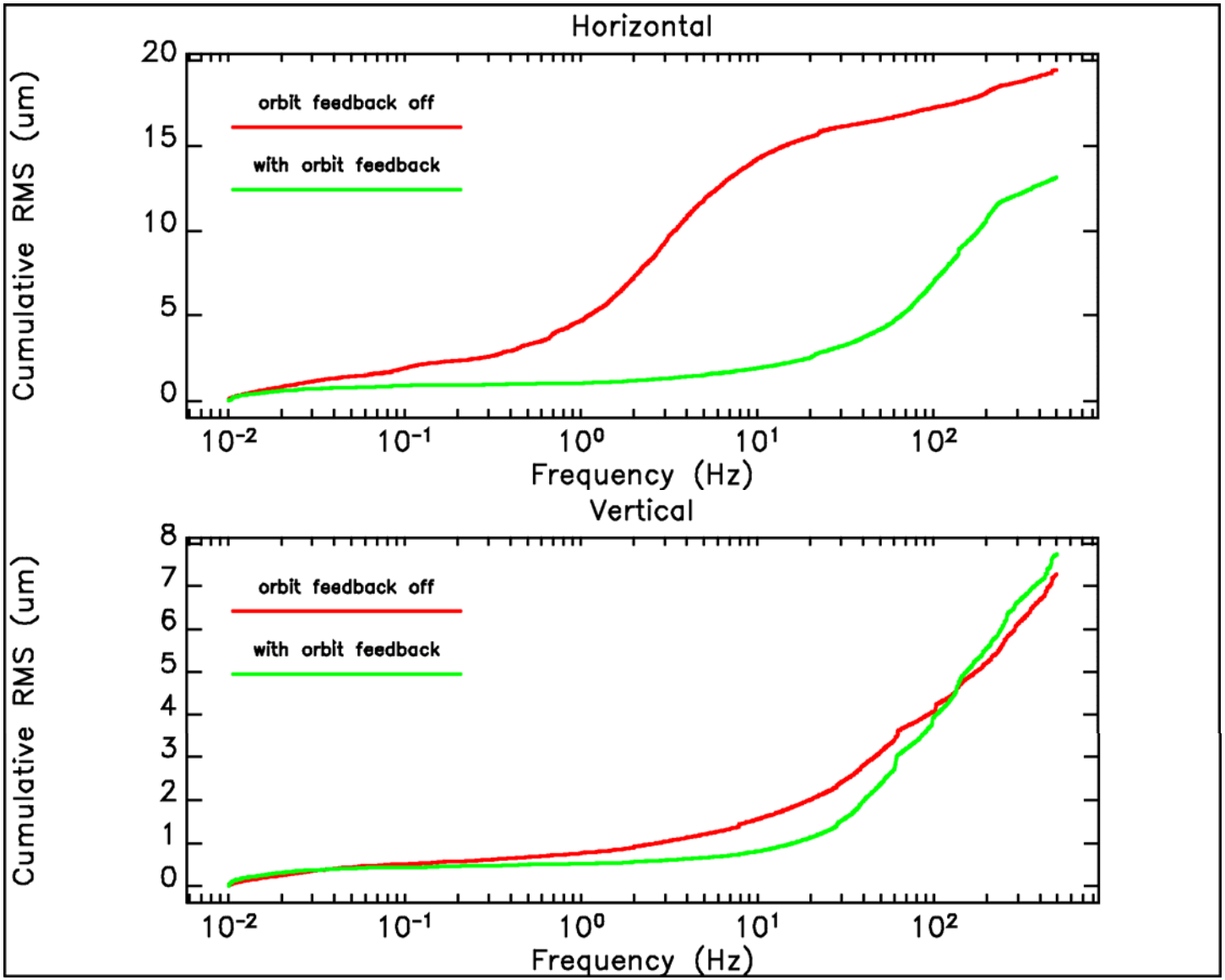
Orbit Motion Power Spectra at ID Source Points



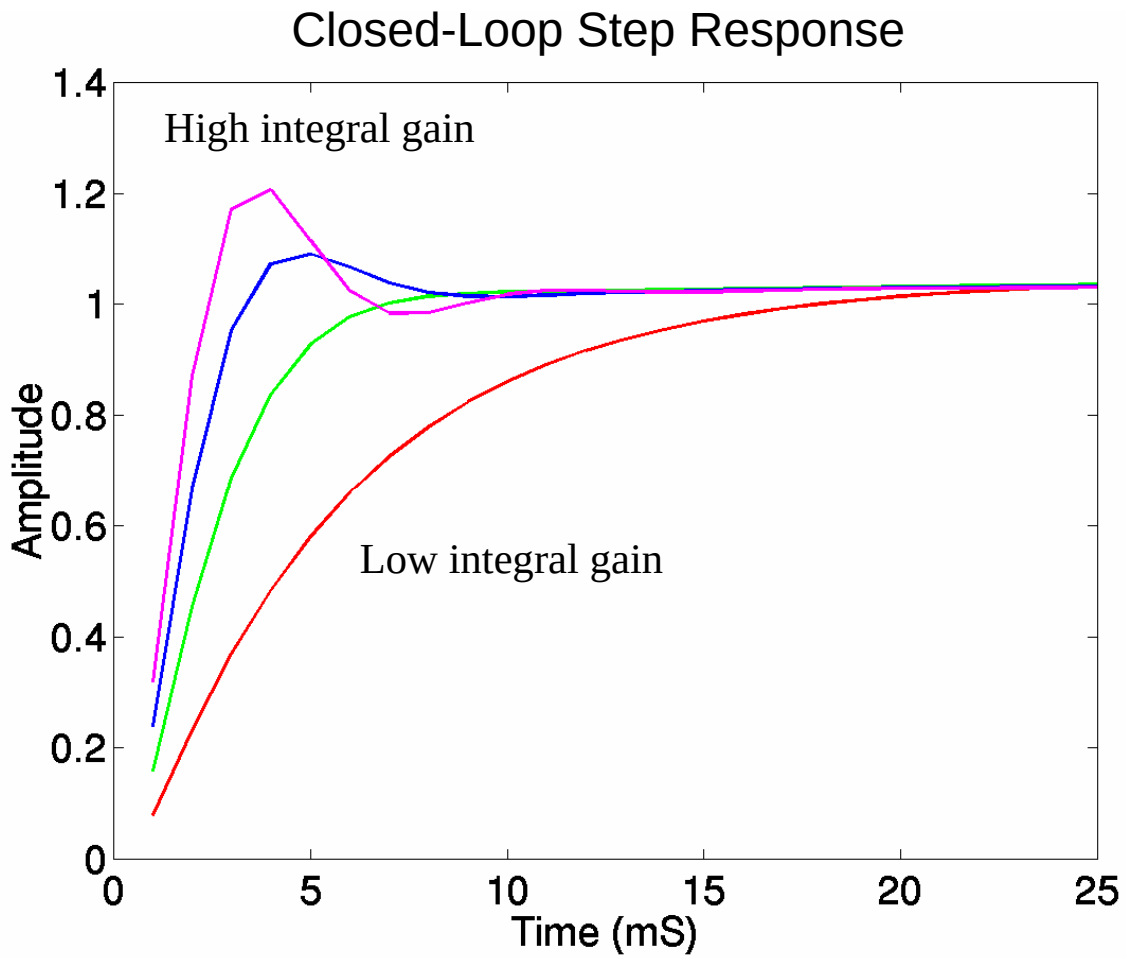
APS Horizontal and Vertical Beam Position Stability History (0.016 Hz - 30 Hz)



Cumulative RMS Orbit Motion at ID Source Points

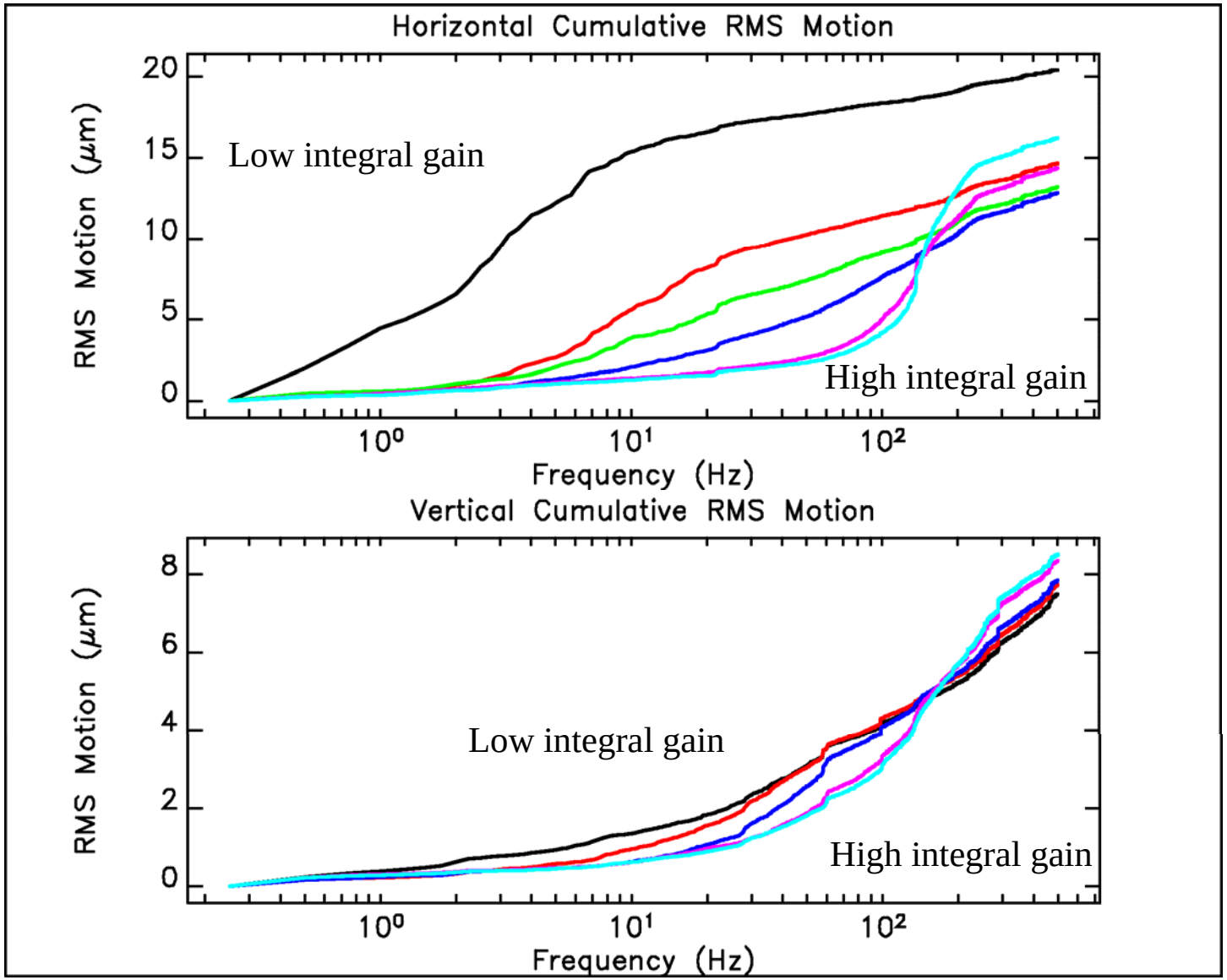


Effect of Regulator Tuning on Closed-Loop Response



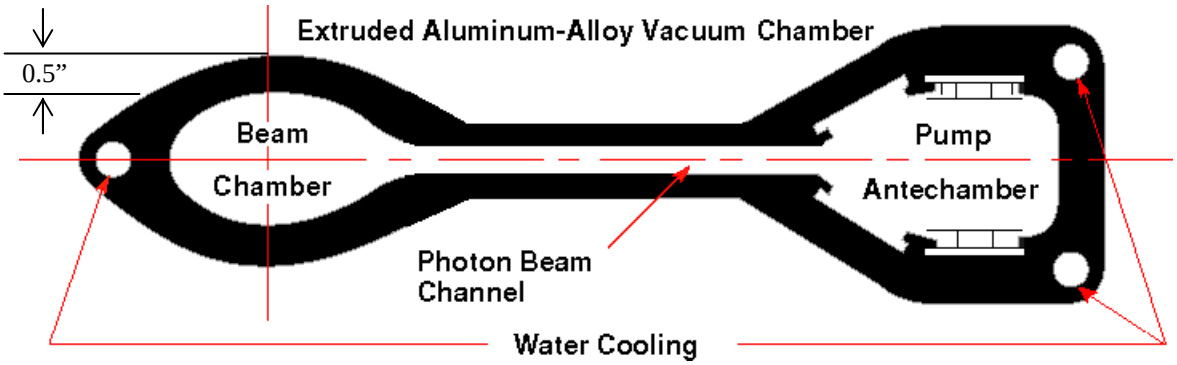
- As the regulator gain is increased, the rise-time is reduced, but the overshoot increases.

Impact of Regulator Tuning on RMS Orbit Stability



Eddy-Current Effects in Corrector Magnet Responses

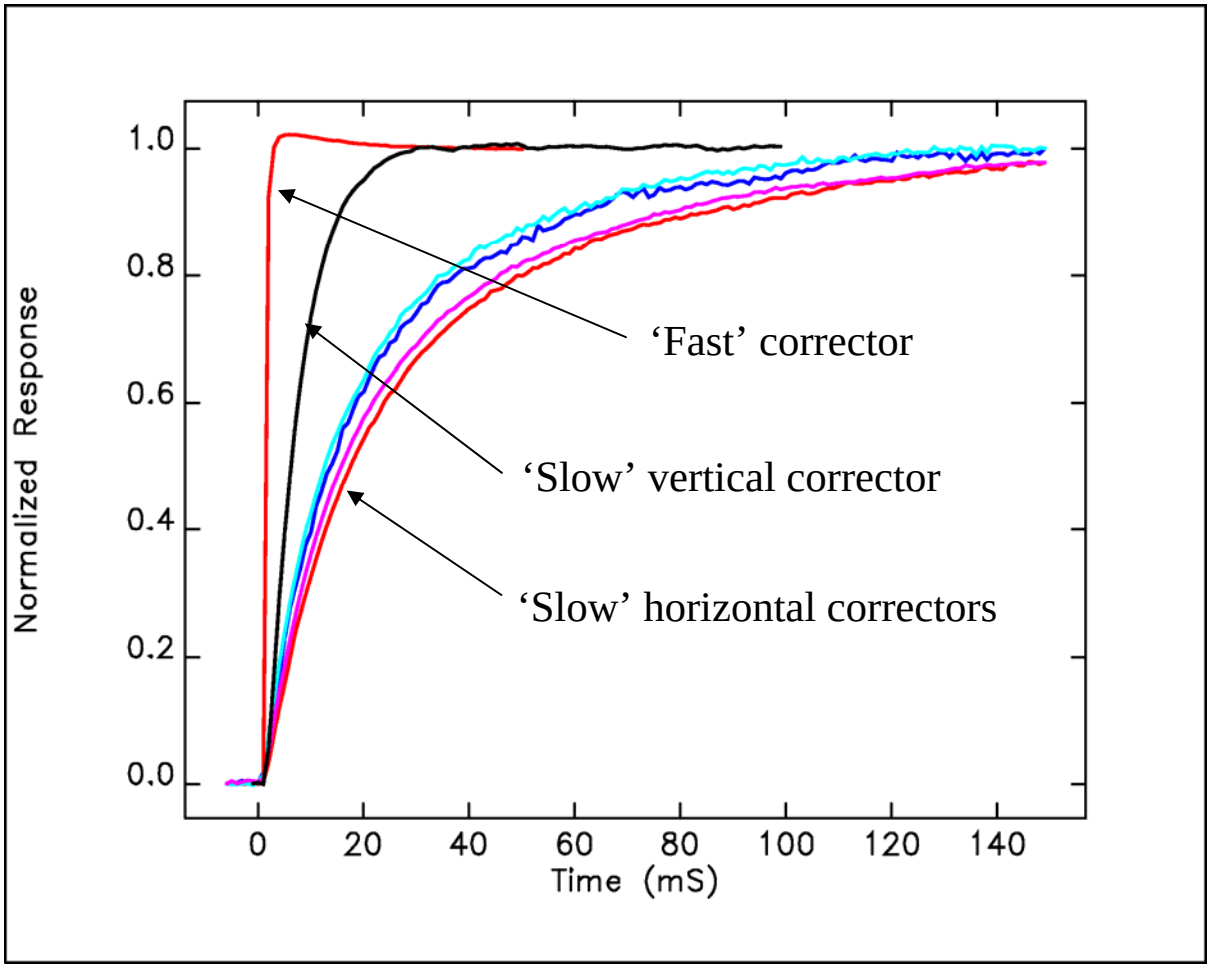
- There are 8 dual-function corrector magnets in each sector of the storage ring.
- All but one of the magnets are subject to eddy-current effects from the aluminum vacuum chamber that significantly slow the dynamic response.



- The one ‘fast’ corrector in each sector is used in the global feedback algorithm since it offers the best correction bandwidth.
- The ‘slow’ correctors will be used to implement local feedback.

Corrector Step Responses

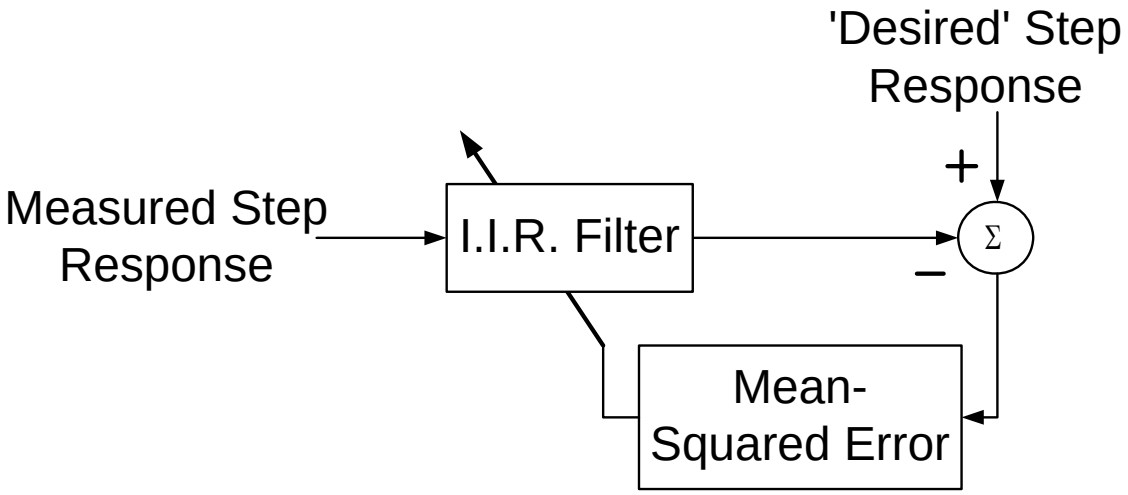
- Corrector 'system' step responses have been measured from the transient response of the global orbit.



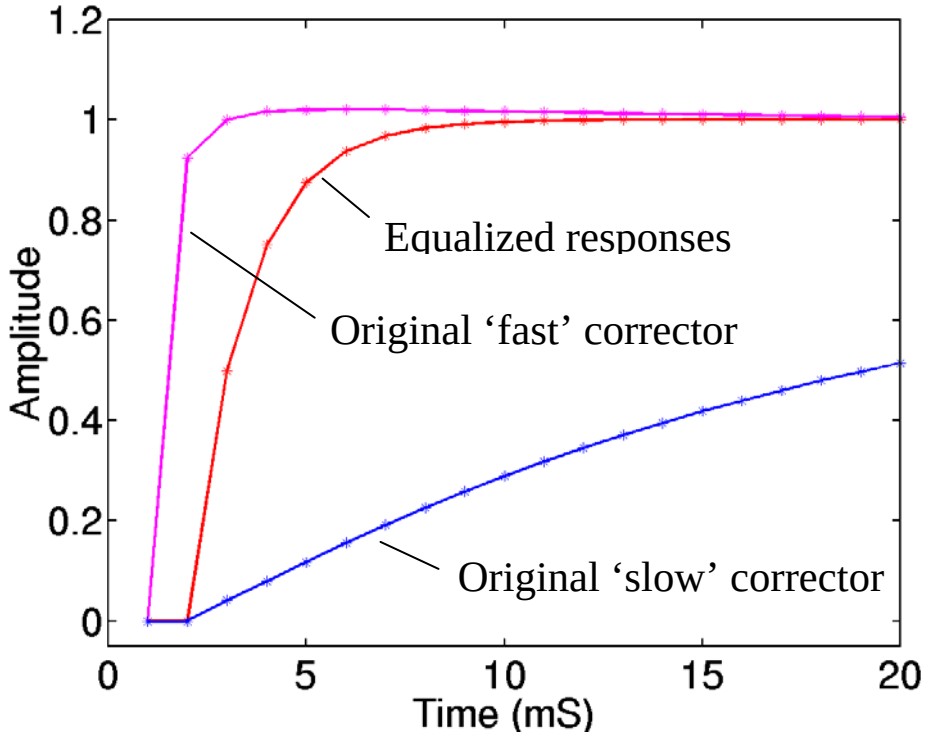
- Significant differences exist between the responses of the horizontal and vertical 'slow' correctors.
- Subtle differences also exist between different slow correctors because of small differences in the mechanical layout of the vacuum chamber.

Step Response Equalization

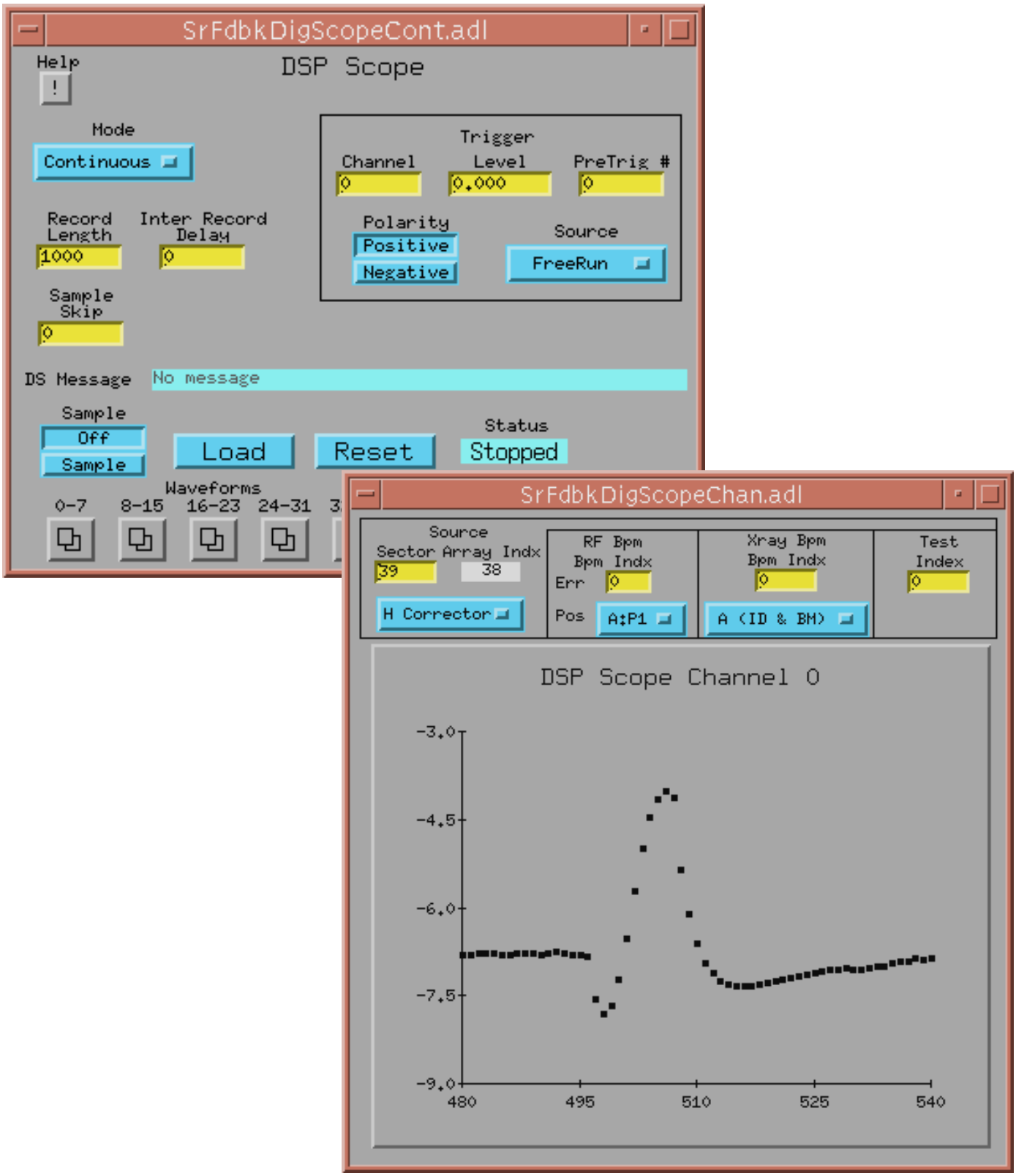
- Least-squares filter design problem



- 'Desired' response was chosen to be a simple low-pass filter with a one-sample delay.
- Resonable results were obtained with a 3-pole, 3-zero IIR filter.



Waveform Capture using ‘DSPscope’



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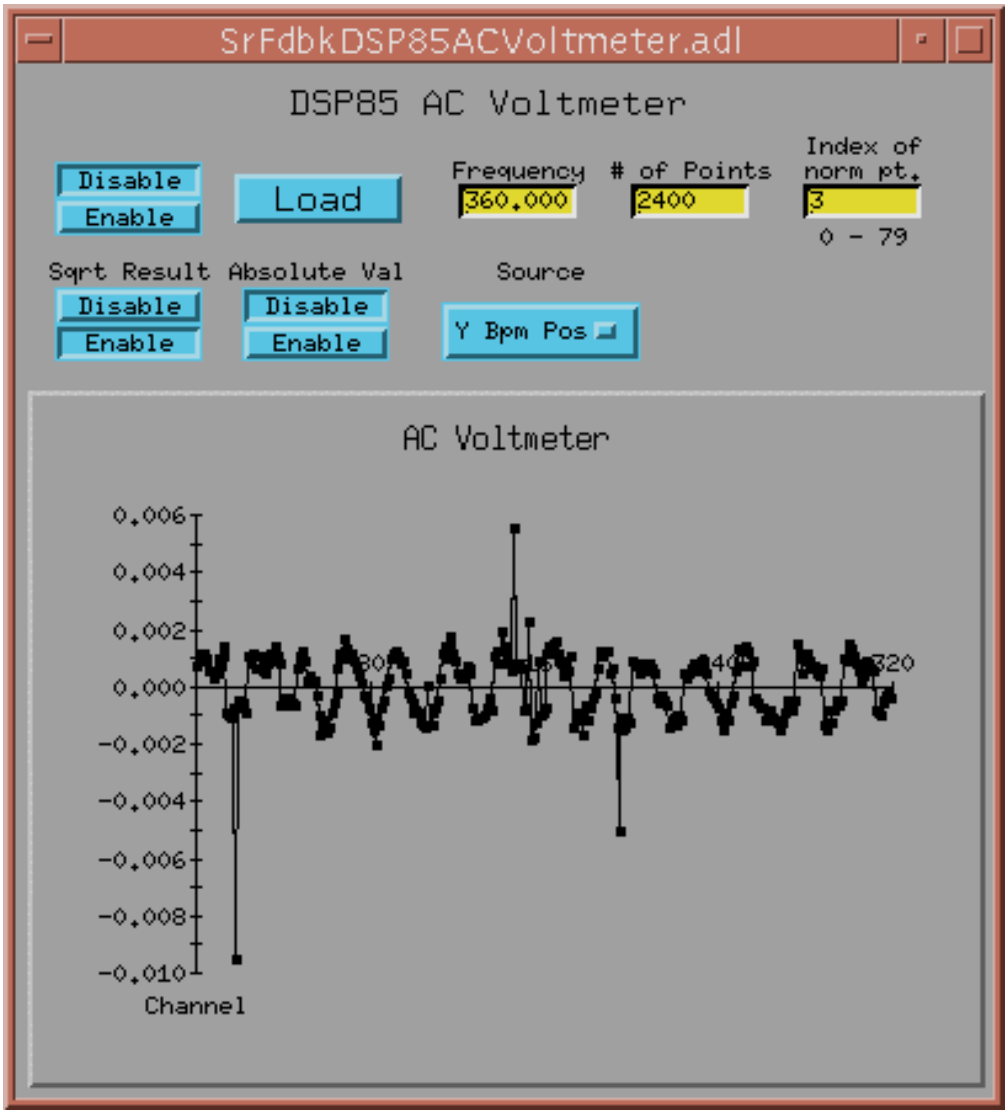
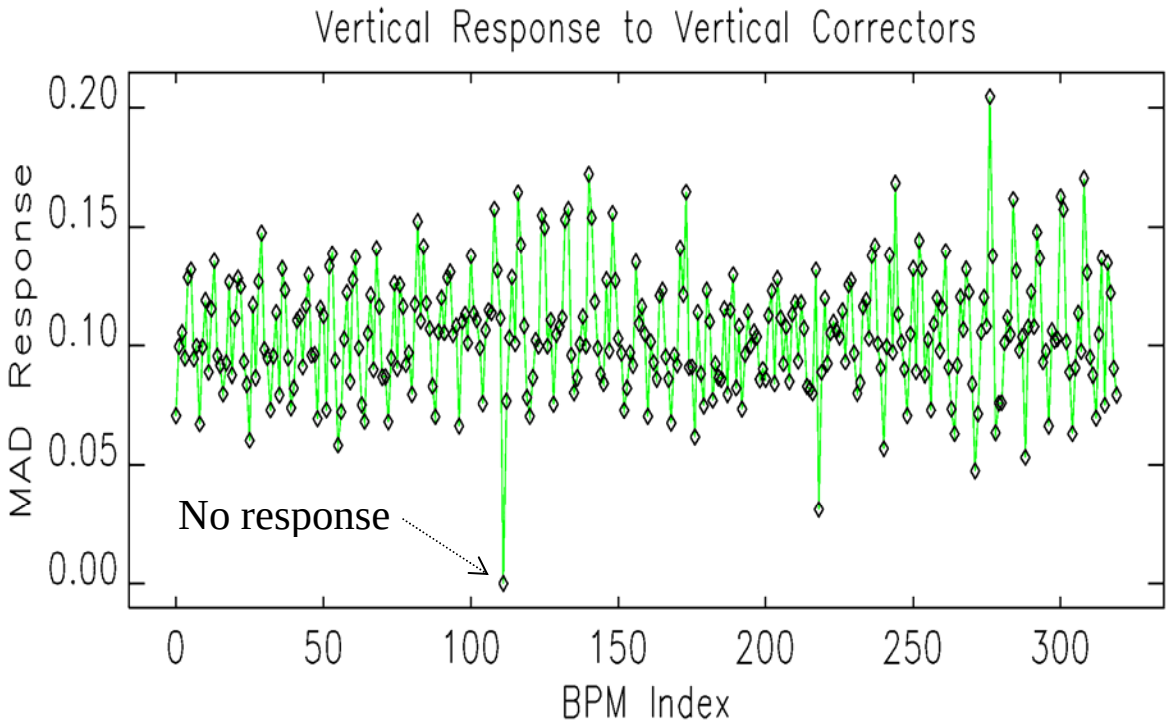
Sliding Fourier Transform ('AC Voltmeter')

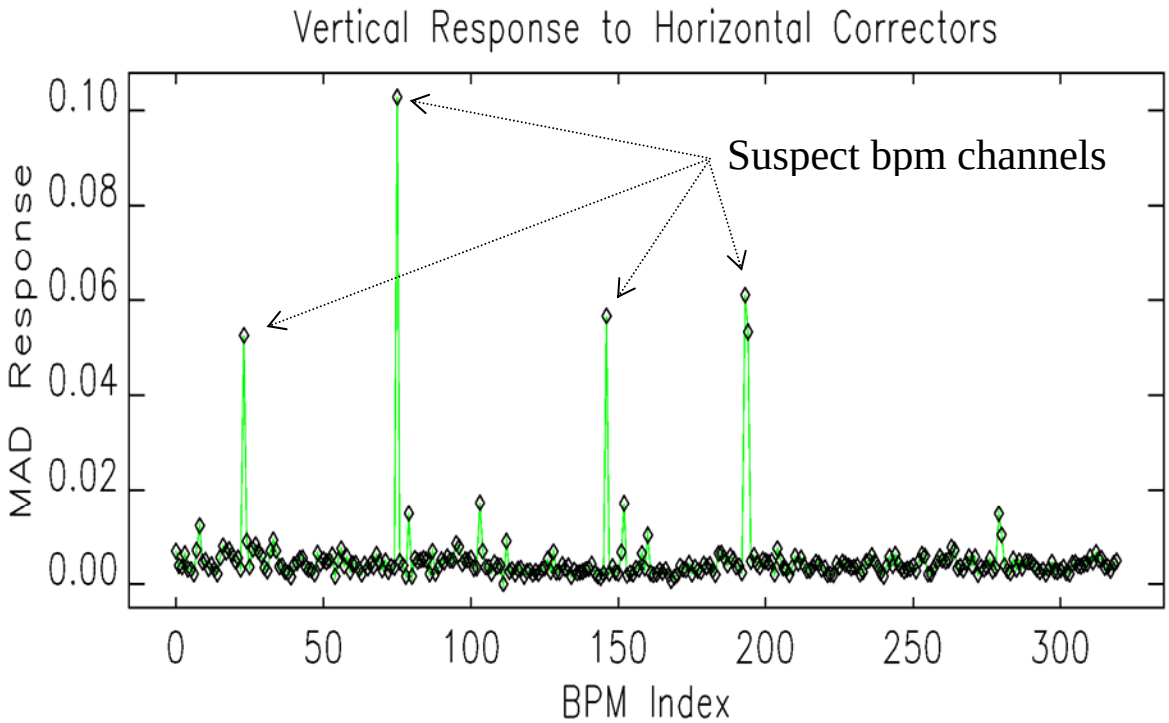


360Hz Fourier Component of 320 bpms

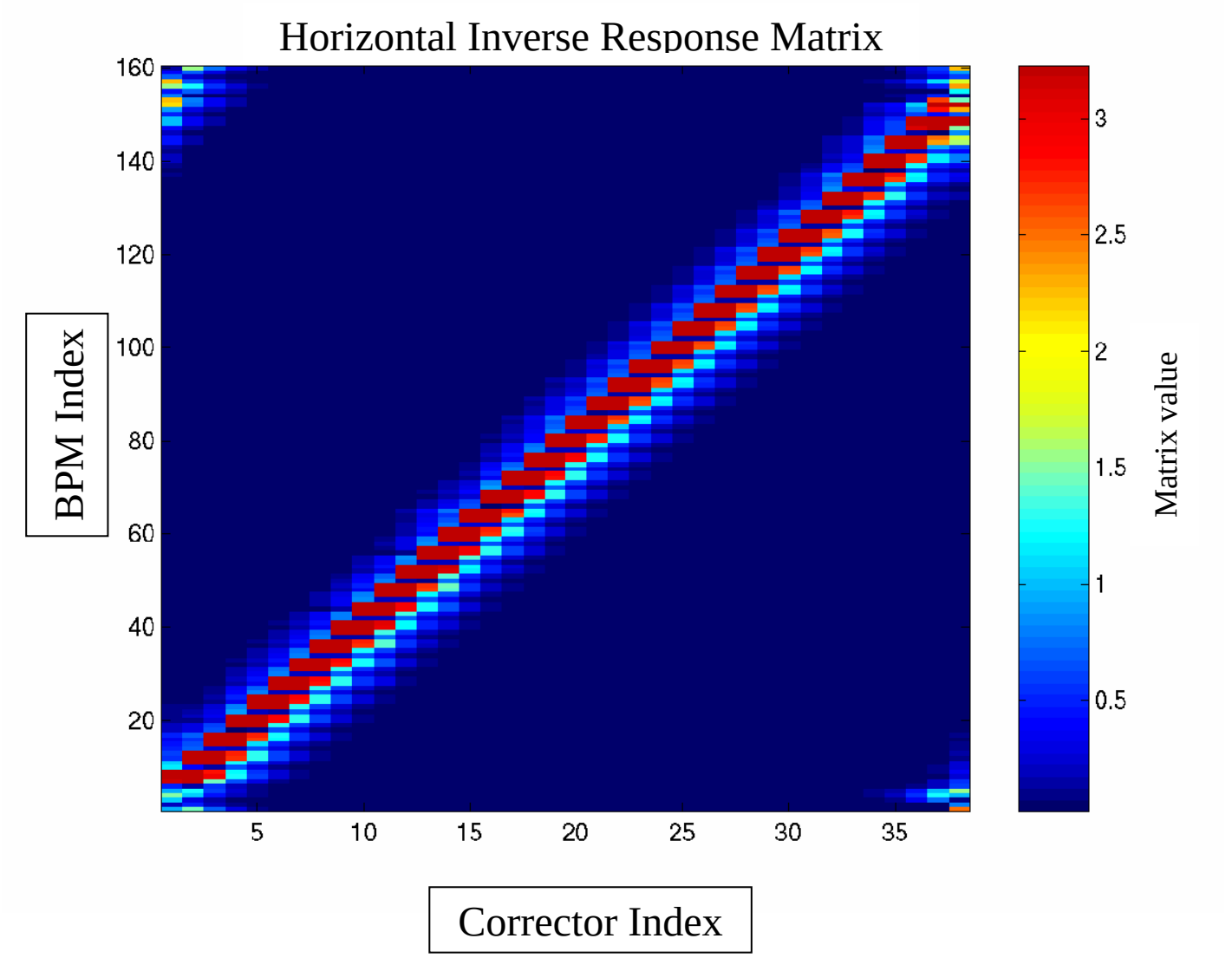
- All 320 bpm channels are simultaneously Fourier analyzed at a chosen frequency.
- One channel is used as a phase reference.
- Used with 'AC-lockin' measurements.

Result from AC-Voltmeter BPM Gain Test





Band-Diagonal Nature of the Inverse Response Matrix



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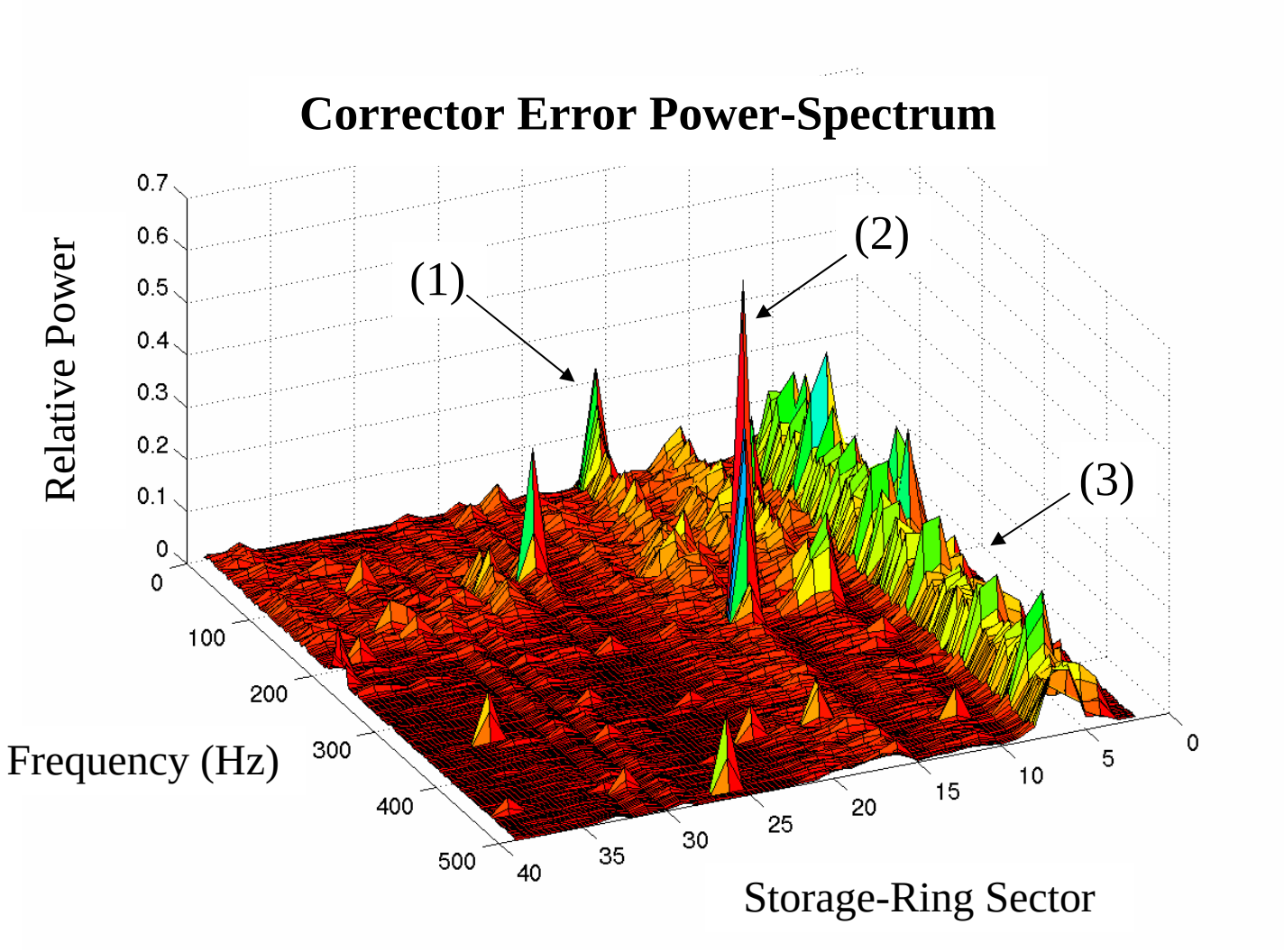
Roadmap of Horizontal Sources (September 1997)



(1) Low frequency random noise from sextupole power supply with poor regulation.
(2) Narrow-band source at 248Hz from oscillating corrector power supply.
(3) Broadband noise caused by bad bpm in sector 6 (not real orbit motion).