Selected topics on orbit feedback implementation

John Carwardine

DSP future…

NEWS ON TECHNOLOGY, R&D, PRODUCTS, AND BUSINESS

TI's DSP Roadmap Promises 3 Trillion Instructions Per Second By 2010

At last month's IEDM conference, Texas Instruments' senior fellow and new business development manager Gene Frantz unveiled a DSP technology roadmap that promises 3 trillion instructions per second (TIPS) by 2010. This would be 230 times more powerful than today's DSP processors, which tout several billion instructions per second (BIPS).

"TI is combining advanced DSP architectures with leading system-level integration and process technologies, including copper interconnect and silicon-on-insulator (SOI), to propel the performance of its TMS320 DSPs beyond 1 TIPS and even 3 TIPS by 2010," Frantz noted. He also said that semiconductor suppliers must provide higher performance, increased power efficiency and functionality, and a greatly simplified software development process to meet the increased OEM demands for highly integrated system-on-a-chip (SoC) solutions.

TI will begin conversion to a 0.1-µm (drawn) CMOS process this year, with plans to migrate to 0.075-µm (drawn) geometries by 2005. This will allow the integration of over eight TMS320 DSP cores, each with over 100 million transistors, on a single CMOS chip in the next five years. While the new DSP roadmap calls for only a 15-fold improvement in the core DSP processing performance by 2005, it envisions a quantum leap in the technology by 2010. As per the roadmap, TI's process technology consequently will let dozens of DSP cores, with 500 million transistors each, be integrated on the same chip by the end of this decade.

Programming and generating hundreds of millions of lines of code for these powerful DSPs will be challenging.

TI asserts that its newest DMOS-6 fabrication facility and other internal fabrication capabilities are key drivers for DSP performance and growth. The company expects DMOS-6 to begin 300-mm wafer production by the second half of 2001.

Programming and generating hundreds of millions of lines of code for these powerful DSP processors will be challenging. To address these issues, TI is ensuring that reusable software components, combined with intelligent profiling compilers, will maximize hardware efficiency and make DSPs much easier to program.

For more information, visit the company's web site at *www.ti.com*.

Ashok Bindra

Outline

- Orbit feedback system architectures
- Insertion device gap feed-forward.
- Quantization and word-length effects.
- Real-time data analysis.

Digital vs analog implementation

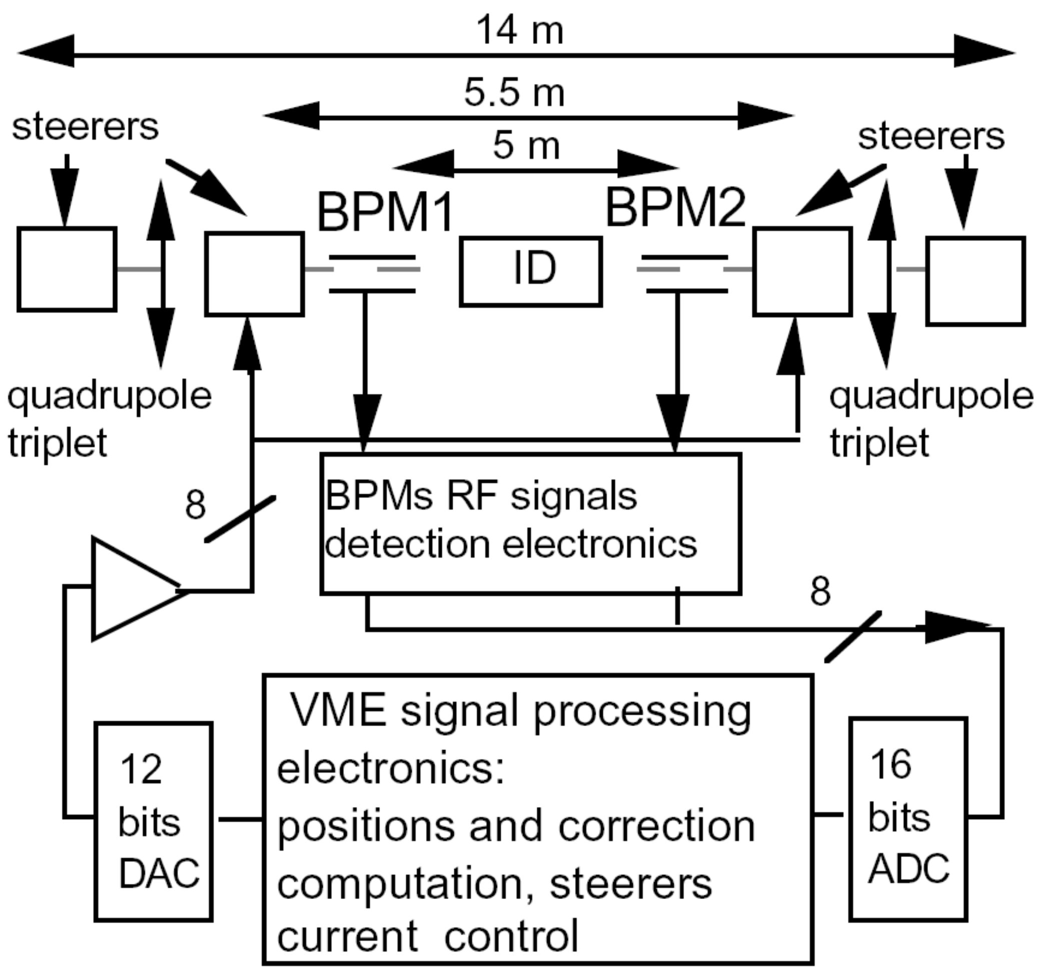
- All light sources are already using or are going to digital orbit feedback systems.
- It is virtually impossible to implement a global orbit feedback system in an analog system, other than for a harmonic system with few terms.

- It is possible to implement analog local control
  - Bandwidth not limited by processor, digitizer, or I/O data rates.
  - susceptible to component drift.
  - Difficult to tune and/or reconfigure.
  - Difficult to handle non-linearities.
  - More difficult to handle multi-input, multi-output systems.

- Discrete-time (digital) implementation
  - Only practical means of implementing complex matrix math needed for global orbit feedback.
  - Can handle non-linear systems.
  - Digitizer, I/O, and computation delays can limit performance.
  - Technology limitations (ADC/DAC performance, processor speed, etc)
  - Quantization and numerical issues can impact performance and stability.

ARCHITECTURES

ESRF Local Feedback system layout



Centralized vs distributed global orbit feedback processing

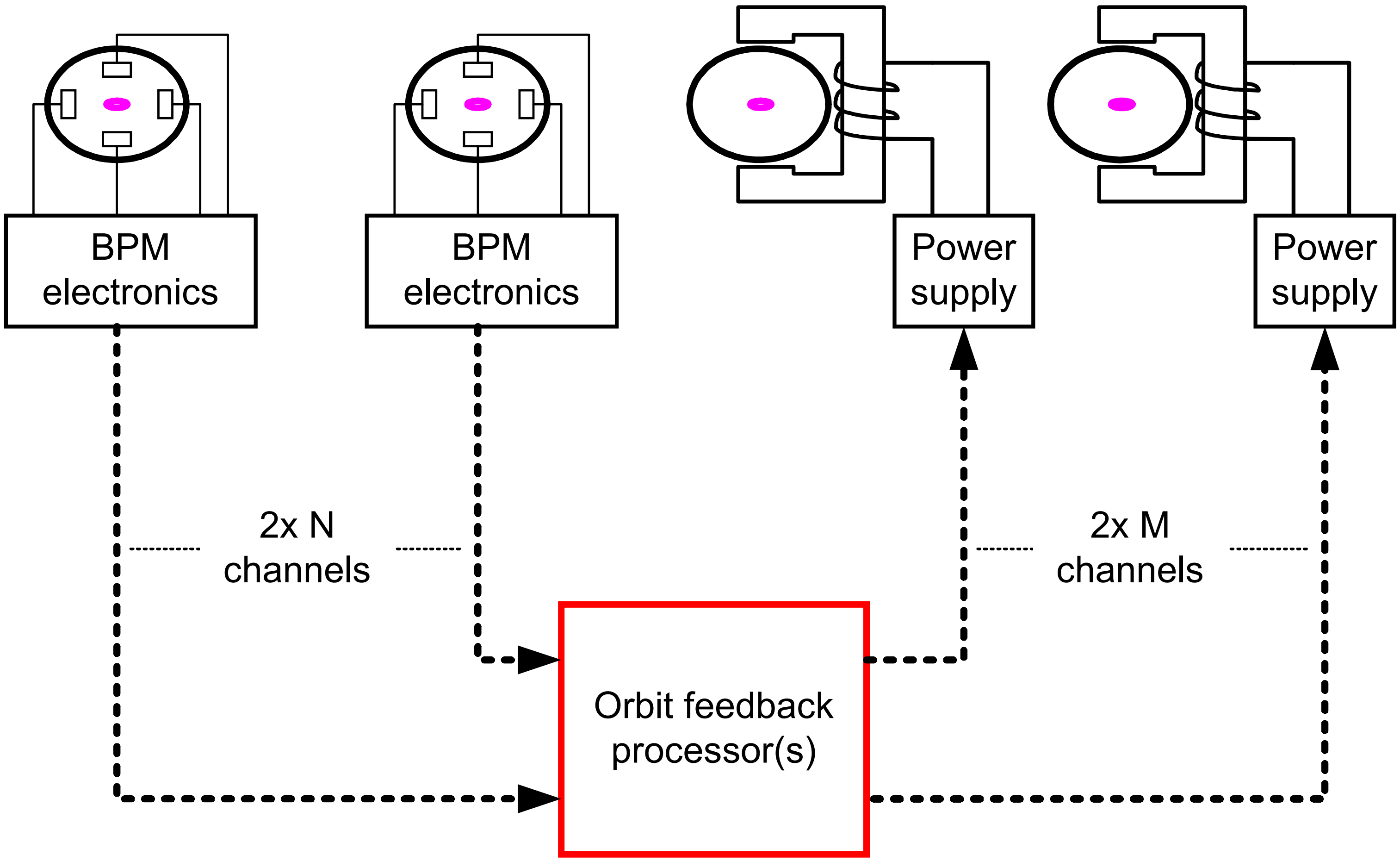
Centralized

- All I/O channels are available in the same location to the same process.
- Many data links required for bpm readbacks and corrector setpoints.
- Easy to implement bpm outlier elimination.
- Easy to develop complex algorithms that require all of the data

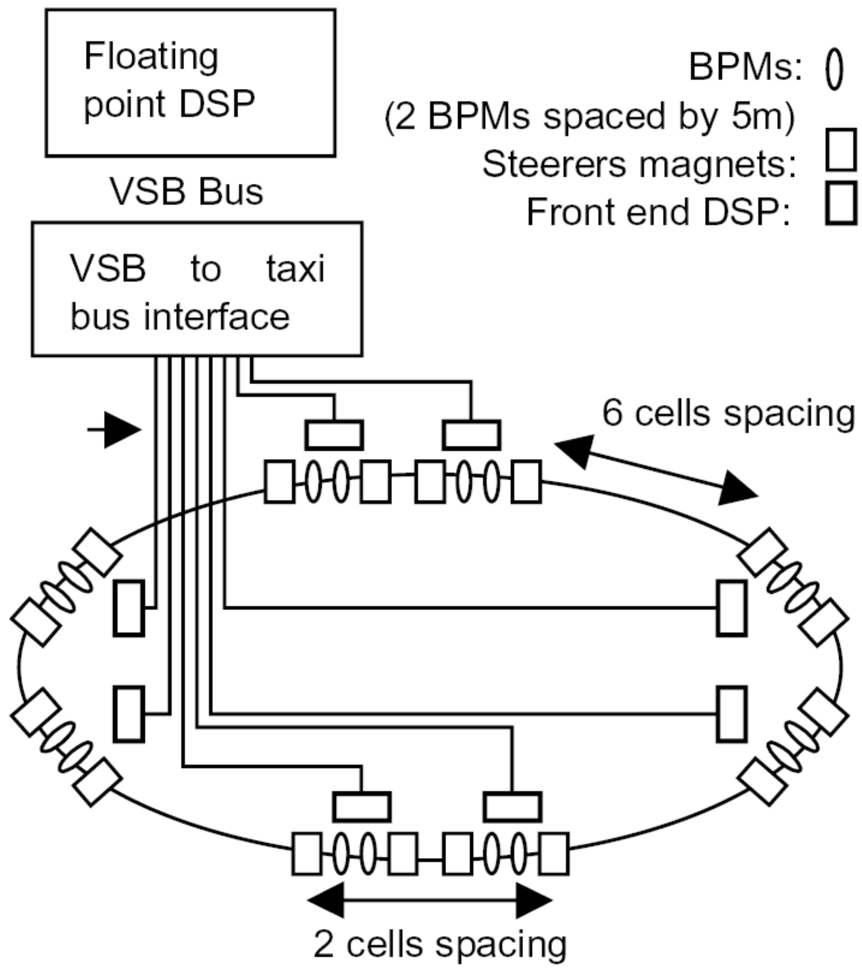
Distributed

- BPM processing can be performed close to the source of data.
- Corrector errors can be computed in parallel.
- Have to synchronize the processors so all corrections are applied at same time from same orbit data.
- No one processor has access to all the information.

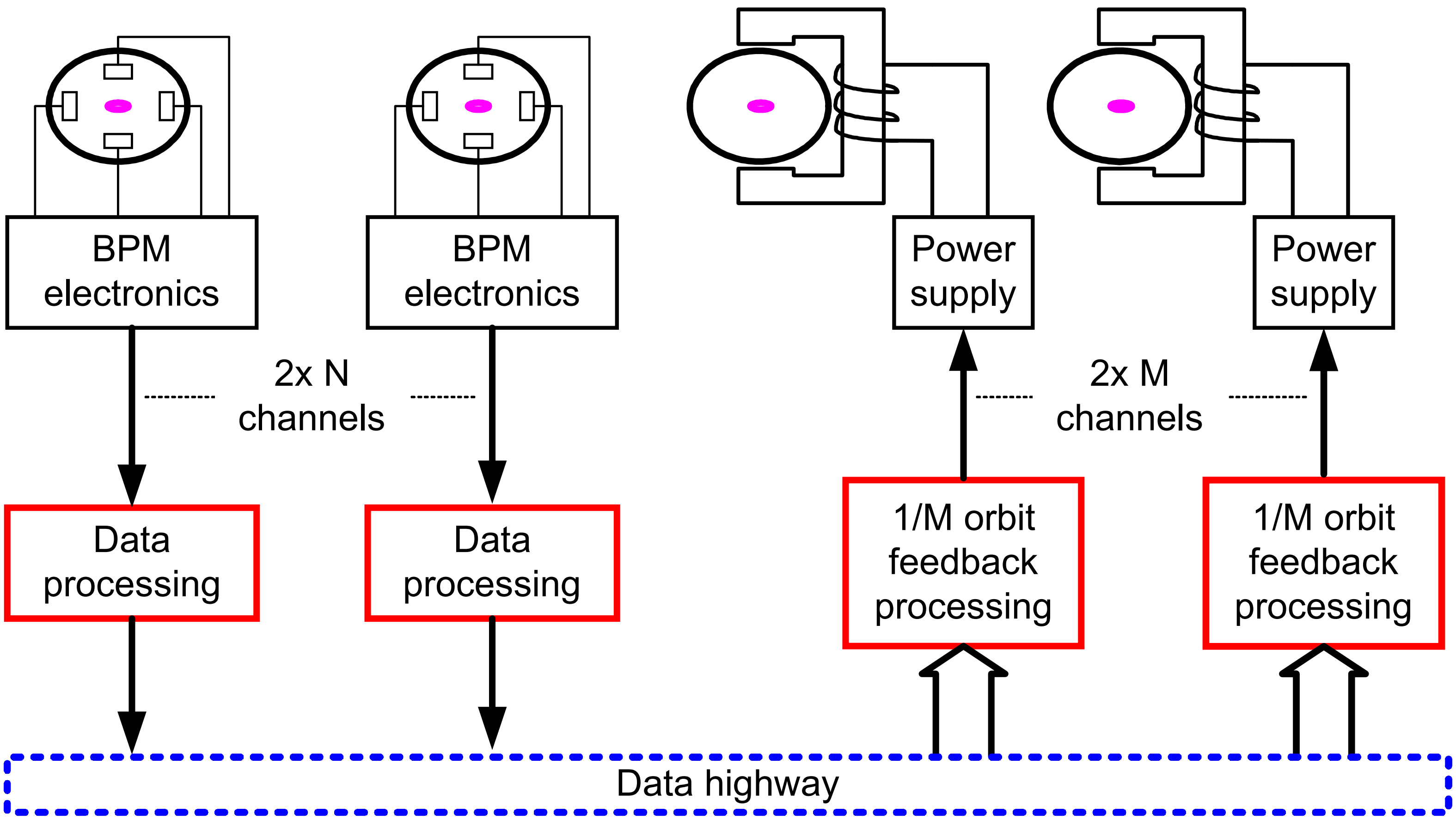
Centralized processing model



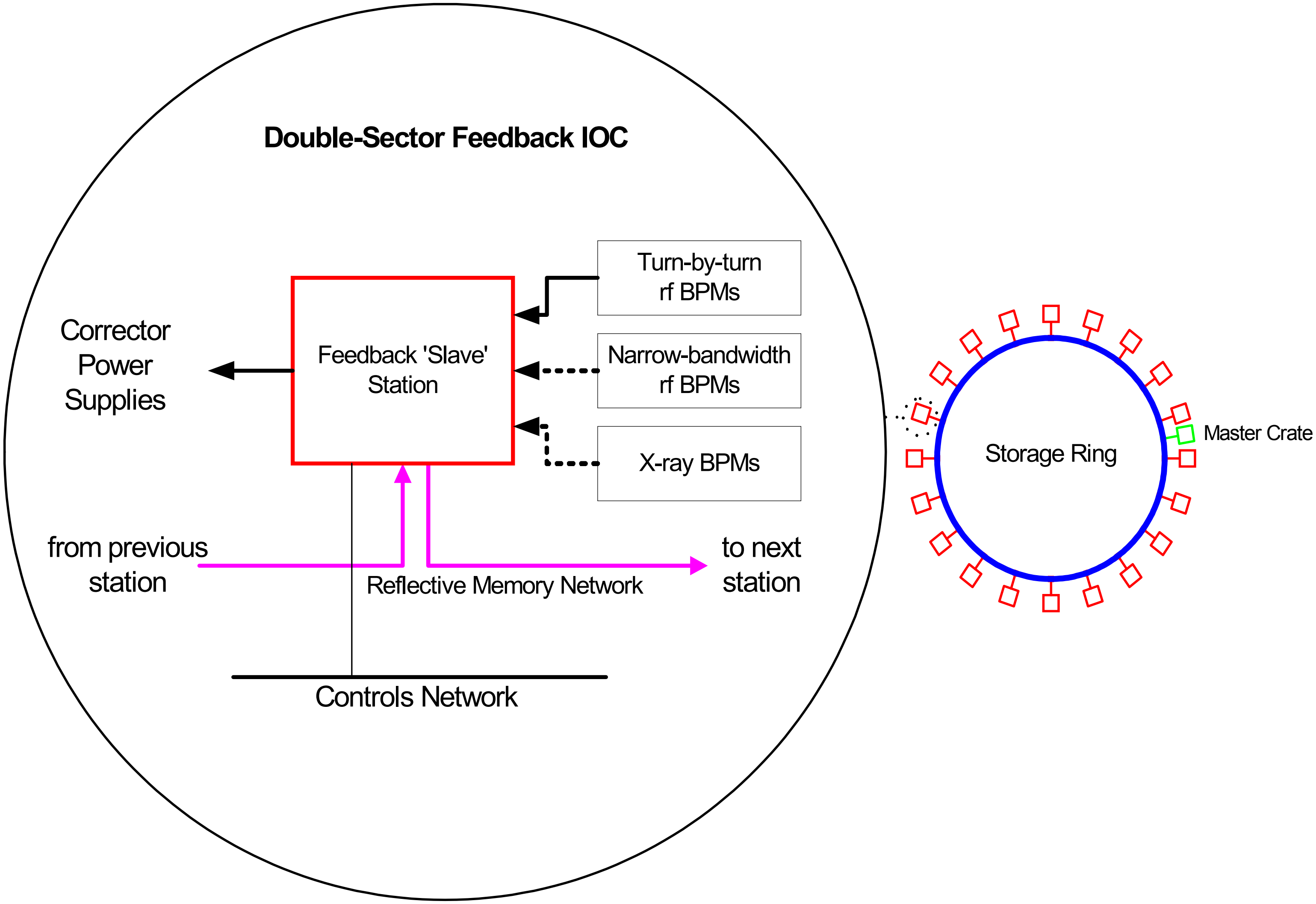
ESRF Global orbit feedback



Distributed processing model



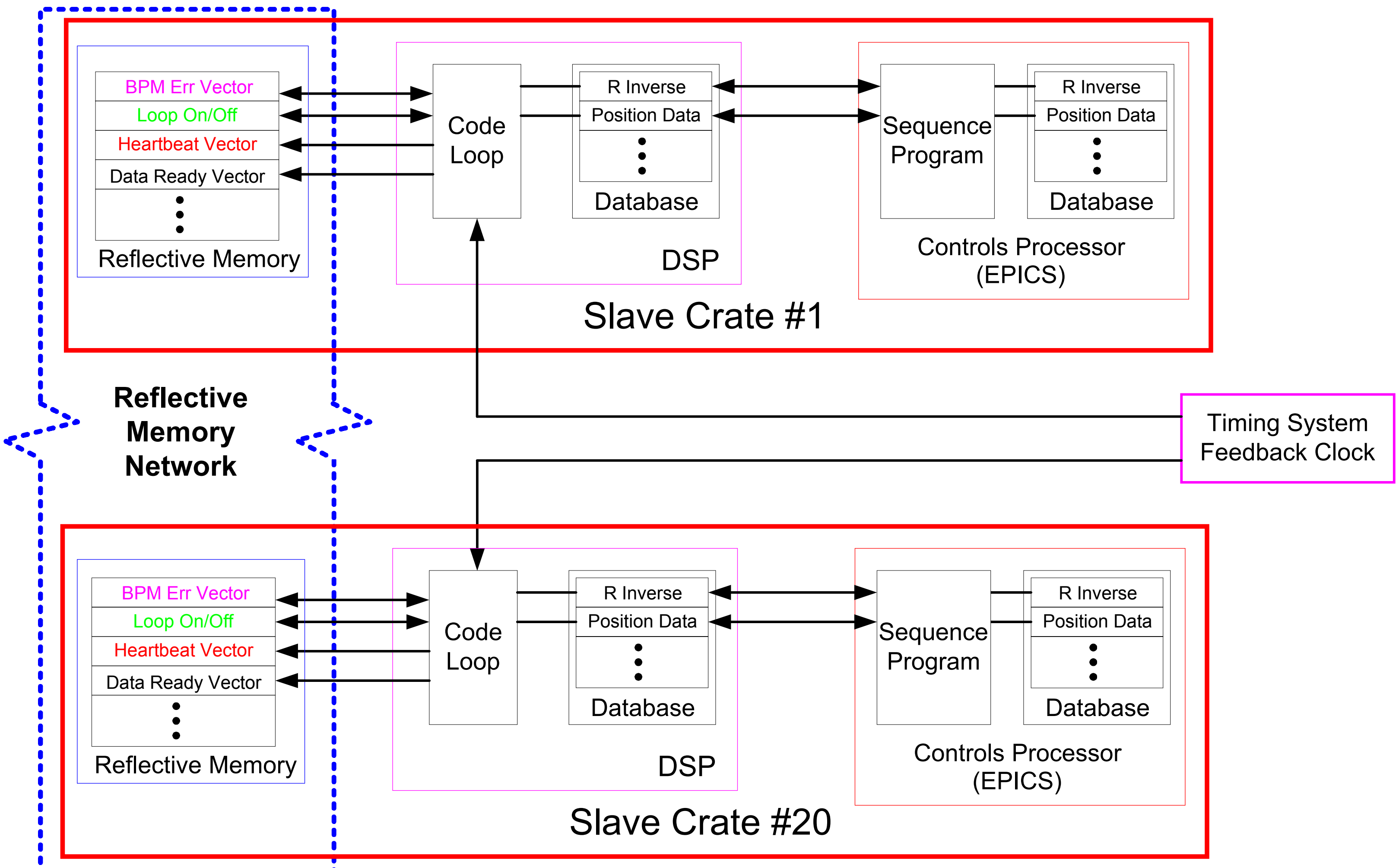
APS global feedback architecture



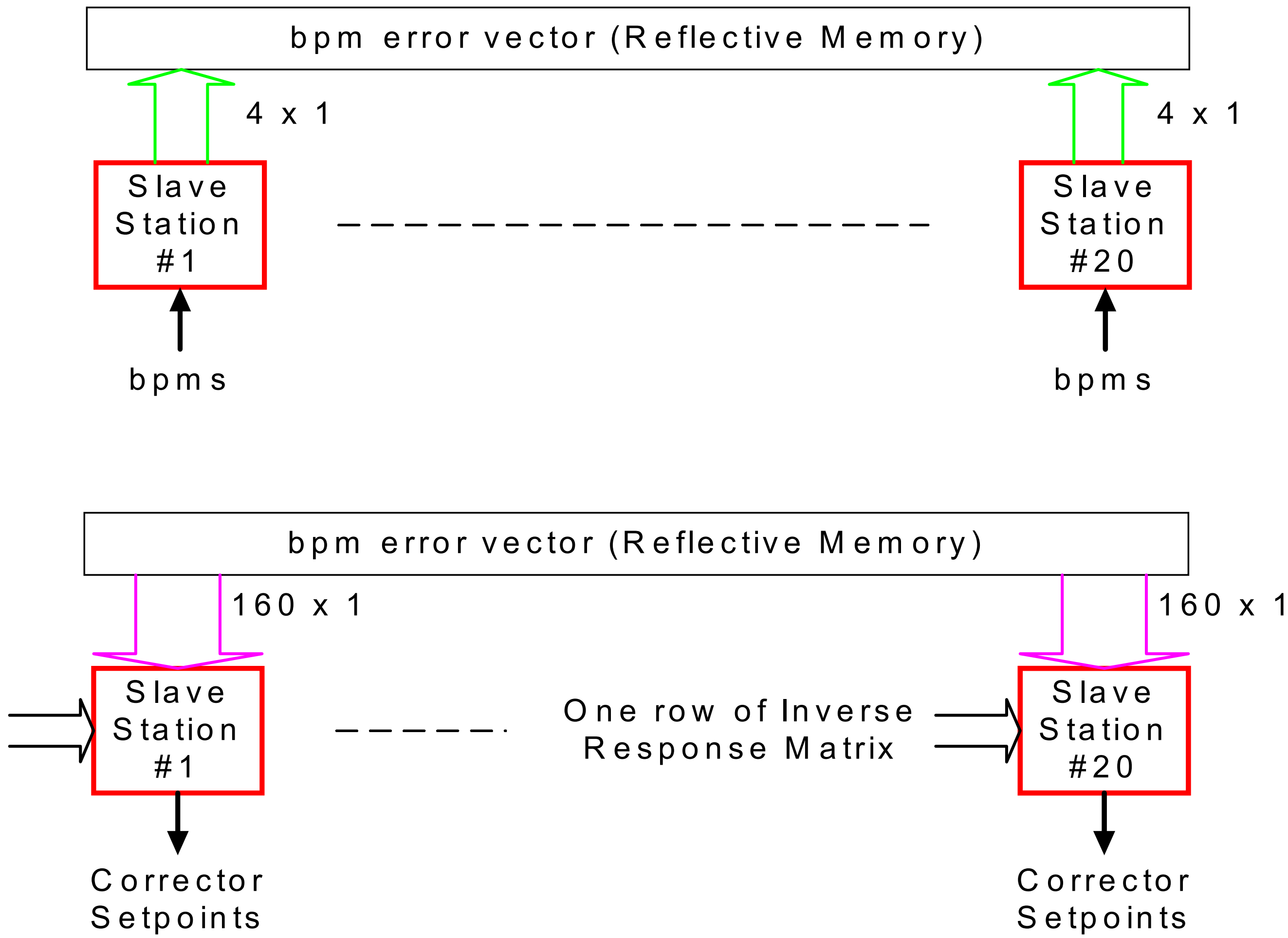
Reflective Memory

- Also known as Replicated Memory
- Each participant in the reflective memory network has a reflective memory module.
- Each module can be written and read as simple memory
- ***Property:***
  - Anything written to a location in one reflective memory module appears (after a loop transit time) appears in the same location in all attached modules.
  - Transfer rate 29.5 Mbytes/second
  - VME backplane transfer rate: ~700nS per 32-bit word

APS distributed architecture data interconnection

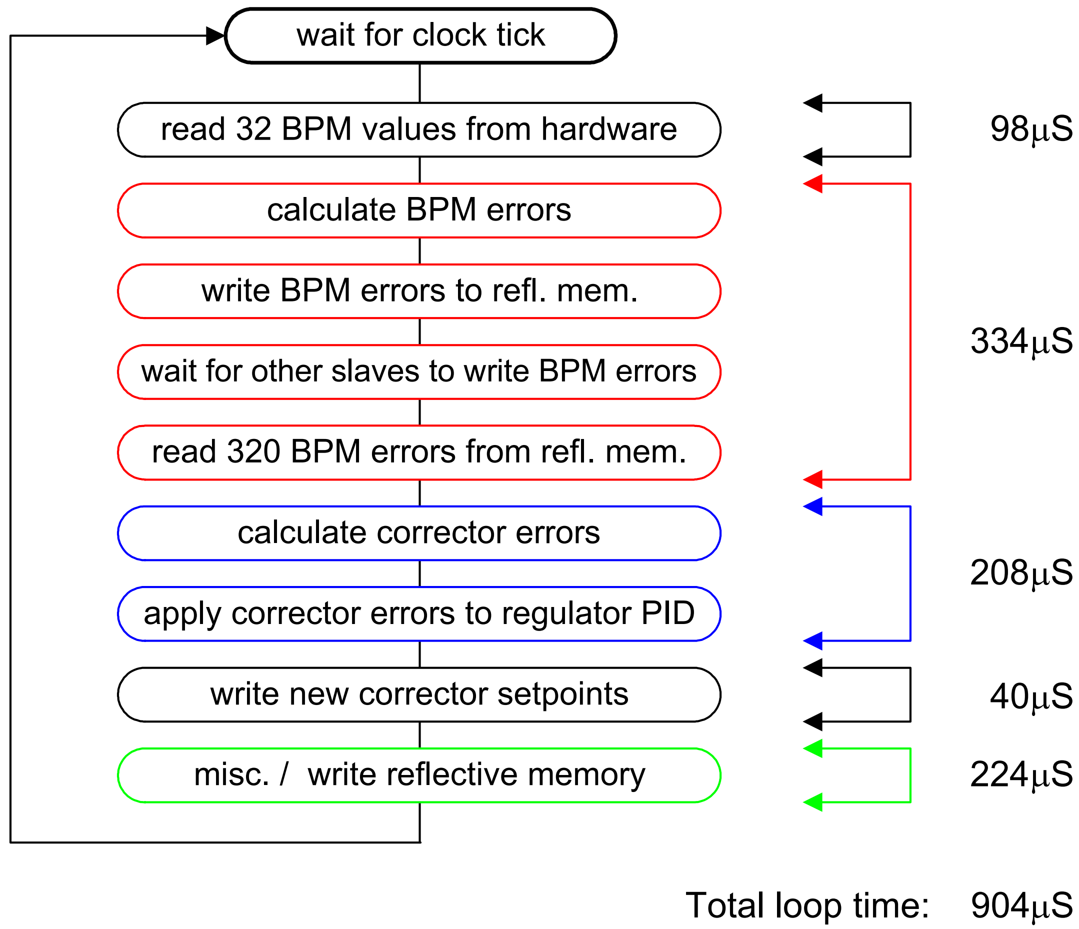


Distributed architecture reflective memory data read/write



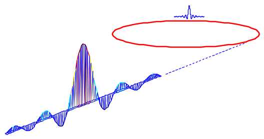
Transfer rates are ~700nS/word

APS real-time feedback slave station loop timing



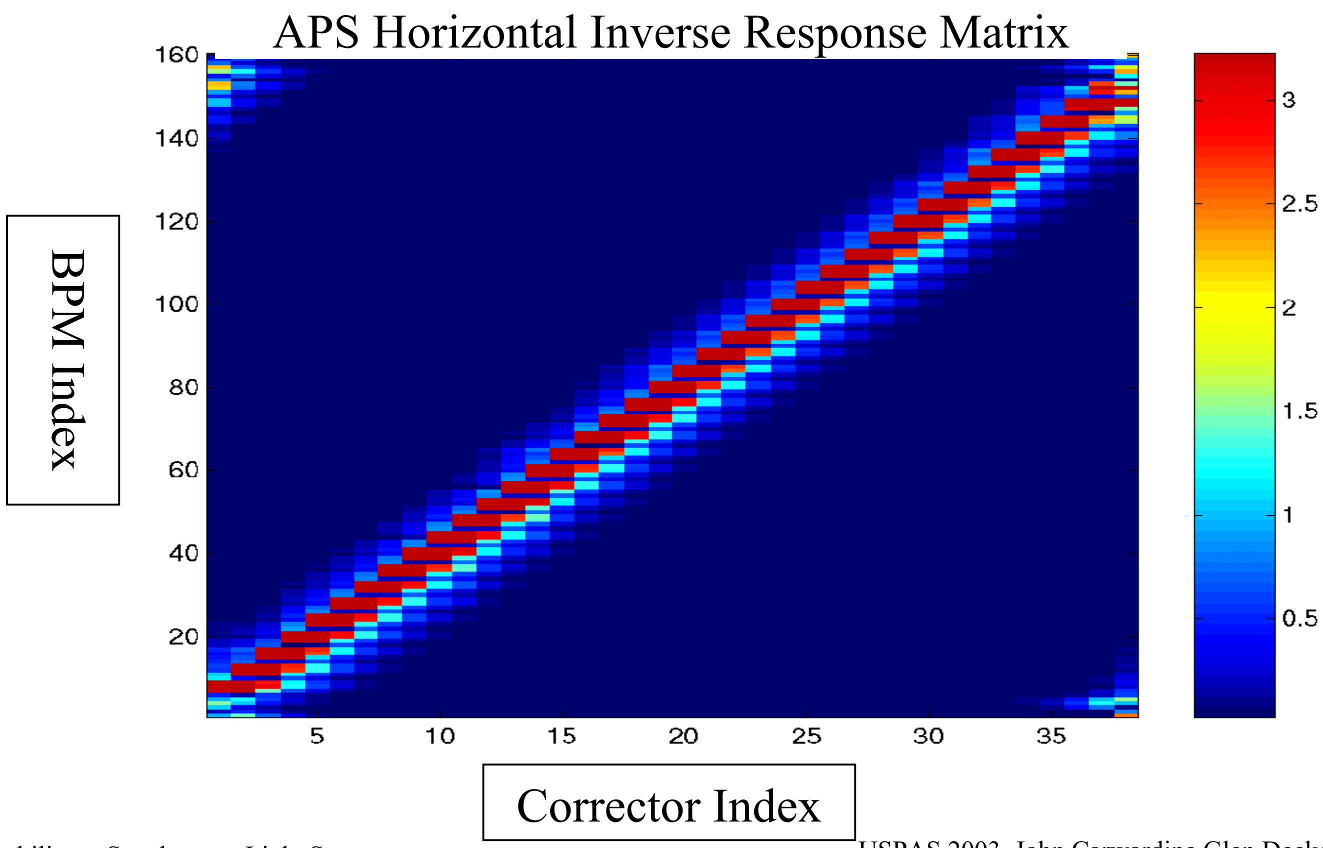
Reflective Memory Contents

- 460 X and 530 Y bpm position values
  - 320 monopulse RF BPMs
  - 70 narrow-band BPMs
    - More on the way
  - 70 ID x-ray BPMs
    - Not all physically installed
  - 70 BM x-ray BPMs (Y only)
    - Not all physically installed
- 320 Horizontal plane and 320 Vertical plane corrector set points
  - Actually only 317 physically exist in each plane
- 160 Real-Time feedback x and y bpm set points

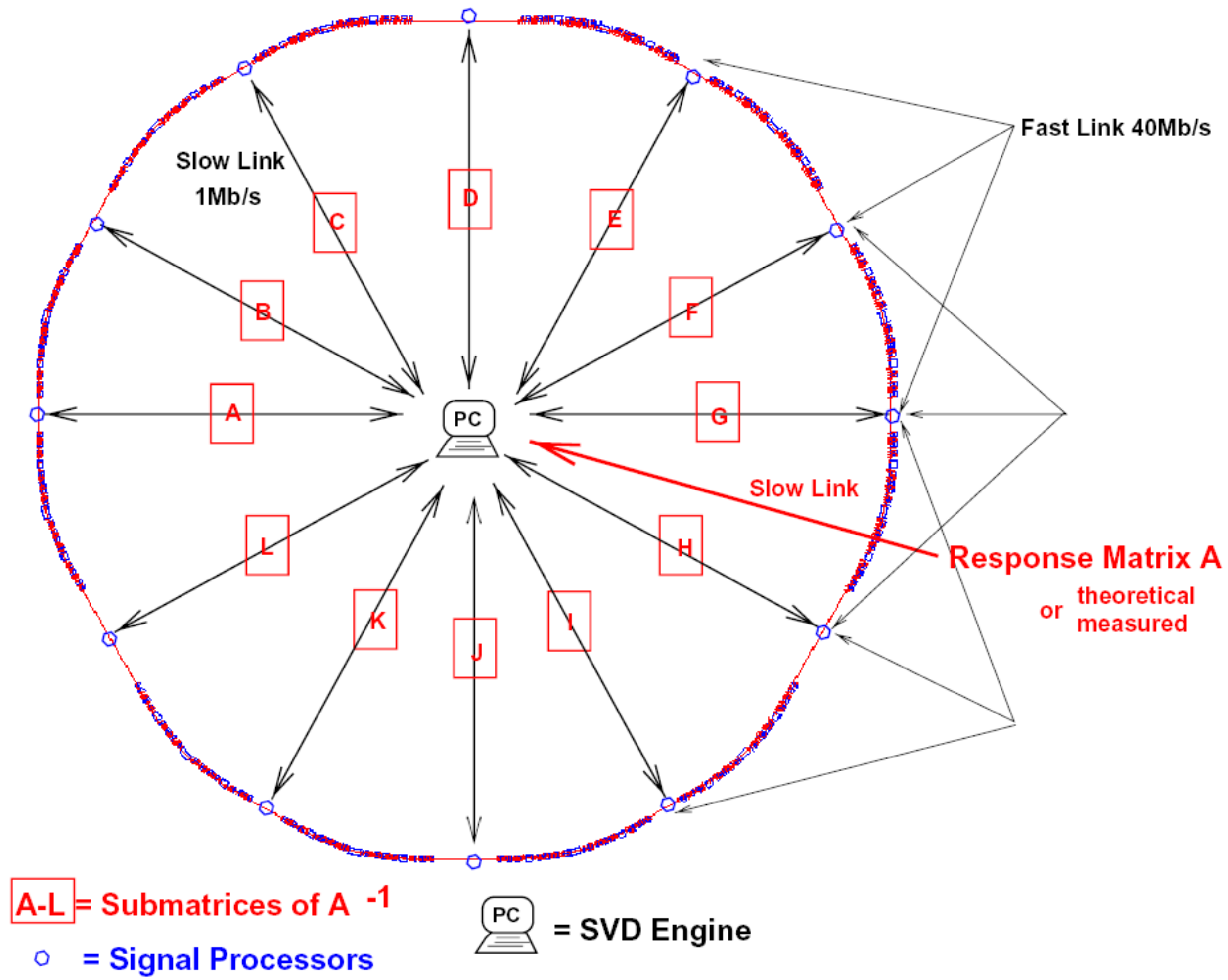


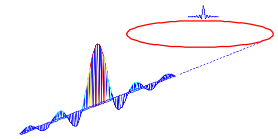
Reducing global algorithm to many local algorithms

- The band-diagonal nature of the inverse response matrix implies that computing a given corrector error only needs information from local bpms.
- This significantly reduces the requirement to distribute global bpm error vector to all corrector/regulator DSPs.

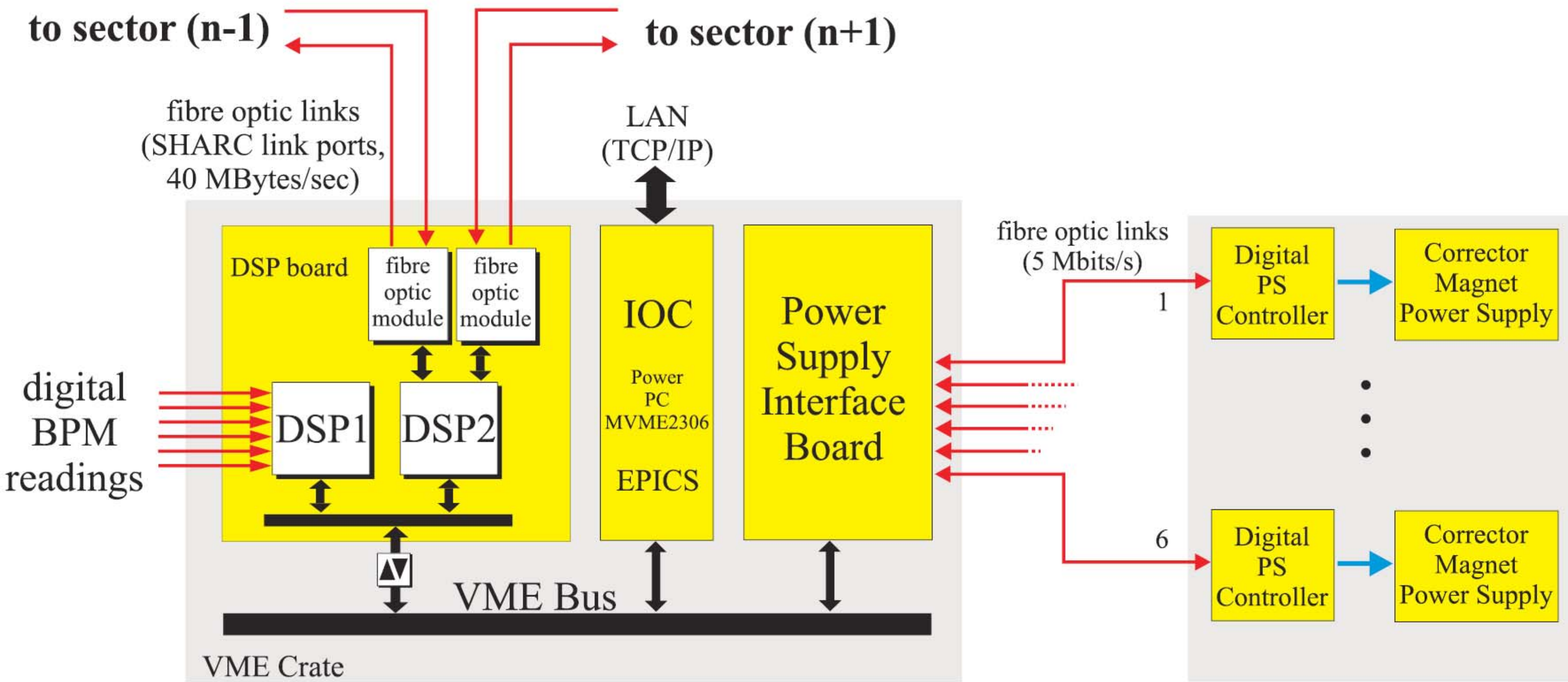


Swiss Light Source global feedback system layout





Swiss Light Source Global orbit feedback slave crate



APS "DATAPOOL" DC ORBIT CORRECTION SYSTEM IMPLEMENTATION

APS Datapool implementation

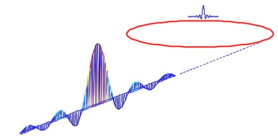
- APS uses two feedback systems operating in parallel to correct the transverse orbit:
  - Real-Time feedback
    - AC Coupled
      - Correction Bandwidth down to 0.02 Hz
    - 160 bpms and 38 correctors per plane
      - Limited by processing achievable at sampling rate (1.5 kHz)
  - DC Orbit Control (originally workstation based)
    - More bpms and correctors (80 correctors typically)
    - Bandwidth limited by iteration rate (0.025 Hz at 2.5 second iteration interval)
    - Time to complete an iteration varied significantly

Motivation for moving to a separate 'Datapool' processor.

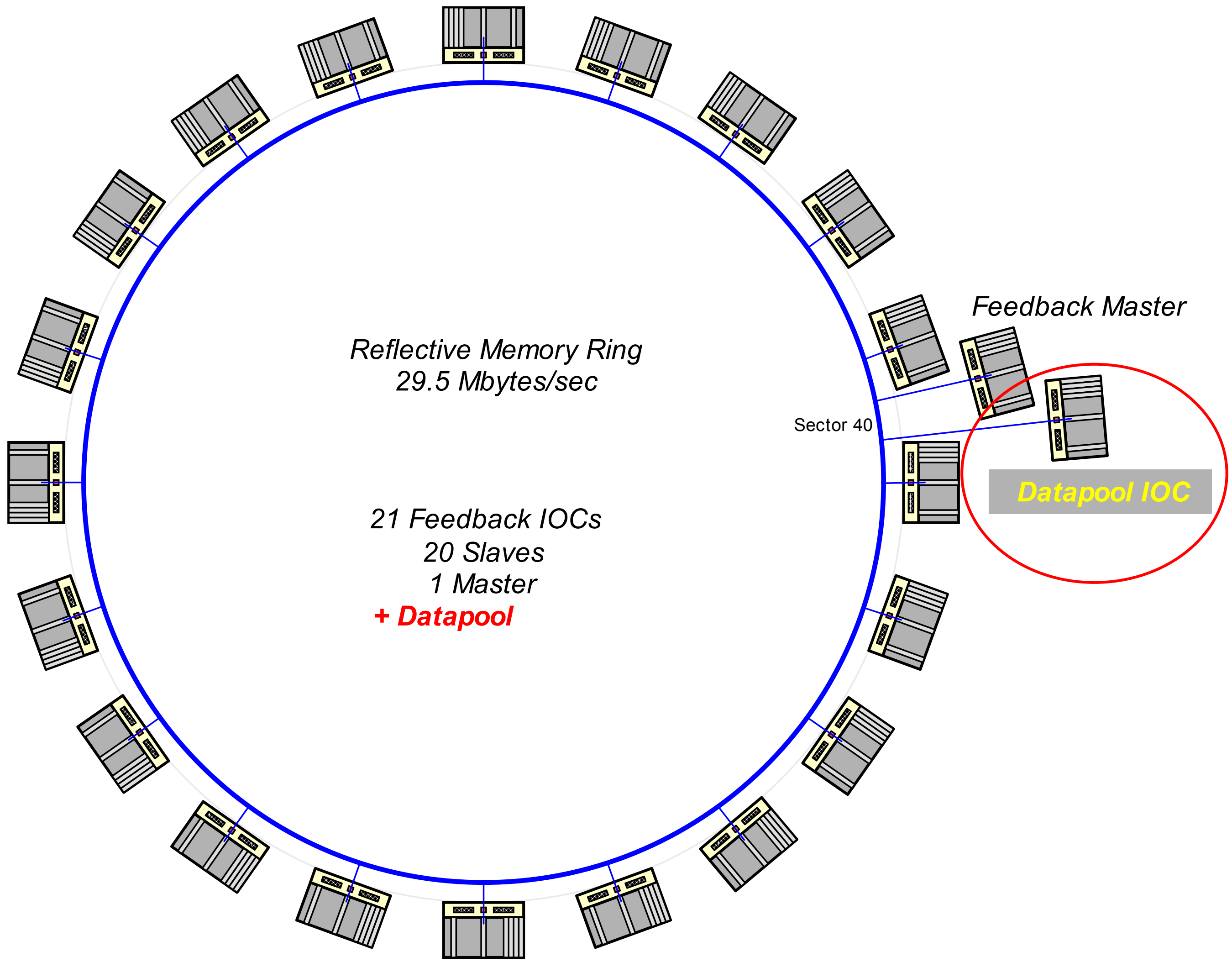
- Insertion Device gap changes near minimum gap cause orbit perturbations in the band below 1 Hz
  - Real-Time feedback only partially compensates for these perturbations.
  - DC Orbit Control at 2.5 second iteration interval only corrects the "DC" perturbation

- Goal: Reduce orbit perturbations due to insertion device gap changes near minimum gap.

- Strategy: Increase correction bandwidth of Orbit Control
  - Move orbit control to an EPICS IOC with "direct" access to all bpms and correctors



APS orbit feedback data-pool crate

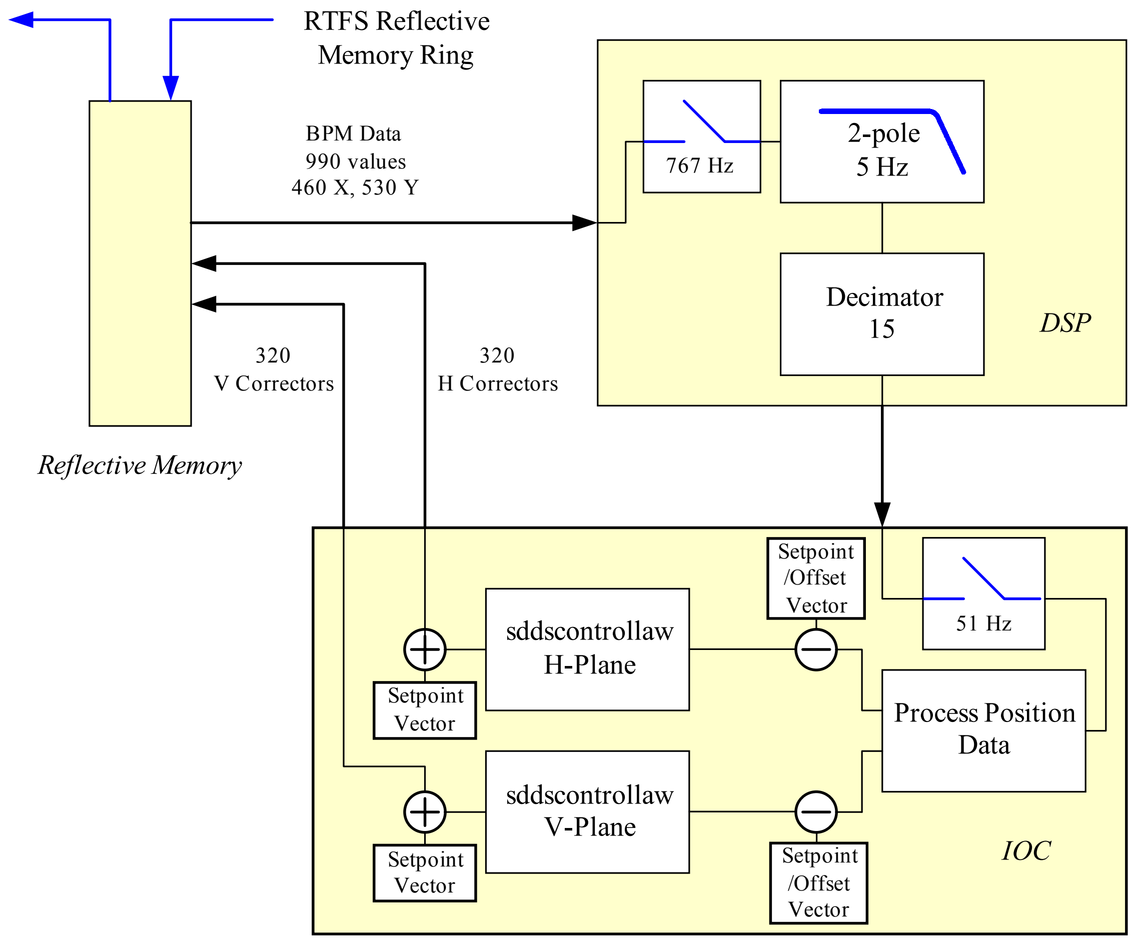


Evolution of the Datapool IOC

- Initially, workstation version of the orbit control program:
  - Fetched BPM positions from 43 BPM and Feedback IOCs
  - Wrote corrector values to 20 power supply IOCs
  - Iteration intervals of 2.5 – 4 seconds

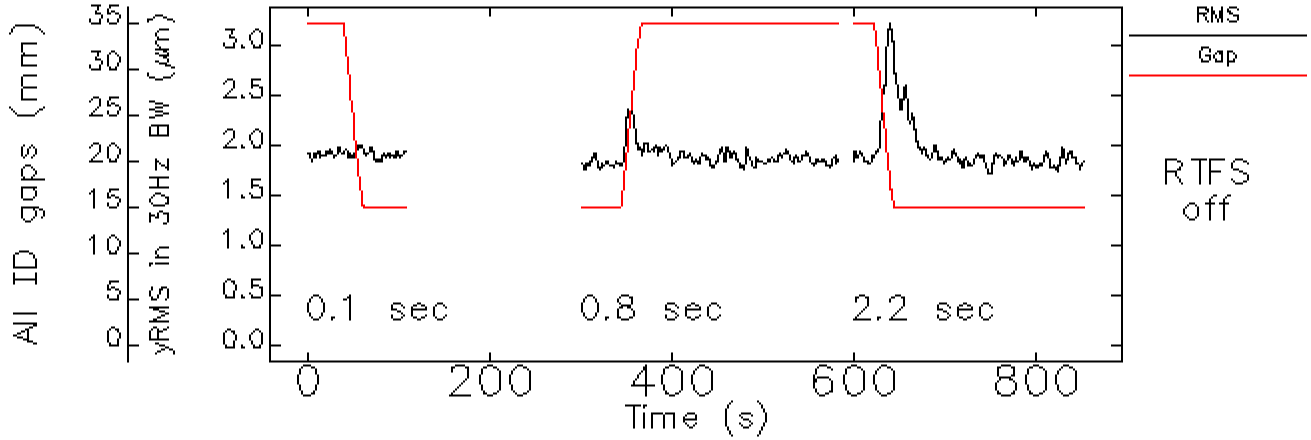
- Real-Time Feedback system's reflective memory provides access to all BPMs and all correctors
  - Adding Datapool IOC to Real-Time Feedback system's reflective memory network provides "direct" access
- Phase 1: Datapool provided vectors of bpm positions as EPICS waveform records but corrector values were still written to 20 power supply IOCs
  - Iteration interval 0.5 seconds (2 Hz)
- Phase 2: Orbit control code (***sddscontrollaw***) was ported to VxWorks
  - Iteration rate – 10 to 20 Hz.
    - Both H and V planes simultaneously on one IOC
    - Motorola MVME2700 (366 MHz).

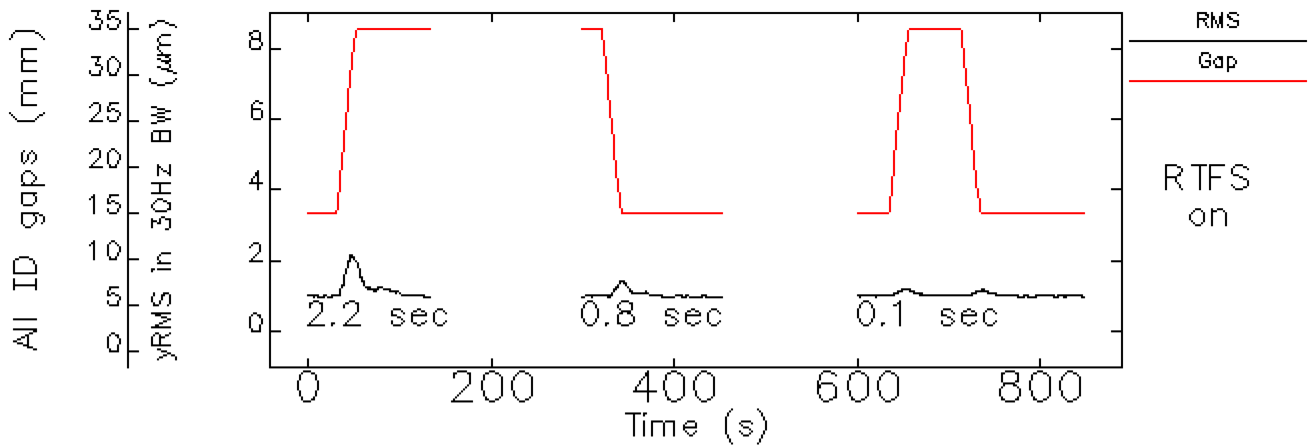
Data Acquisition and Processing



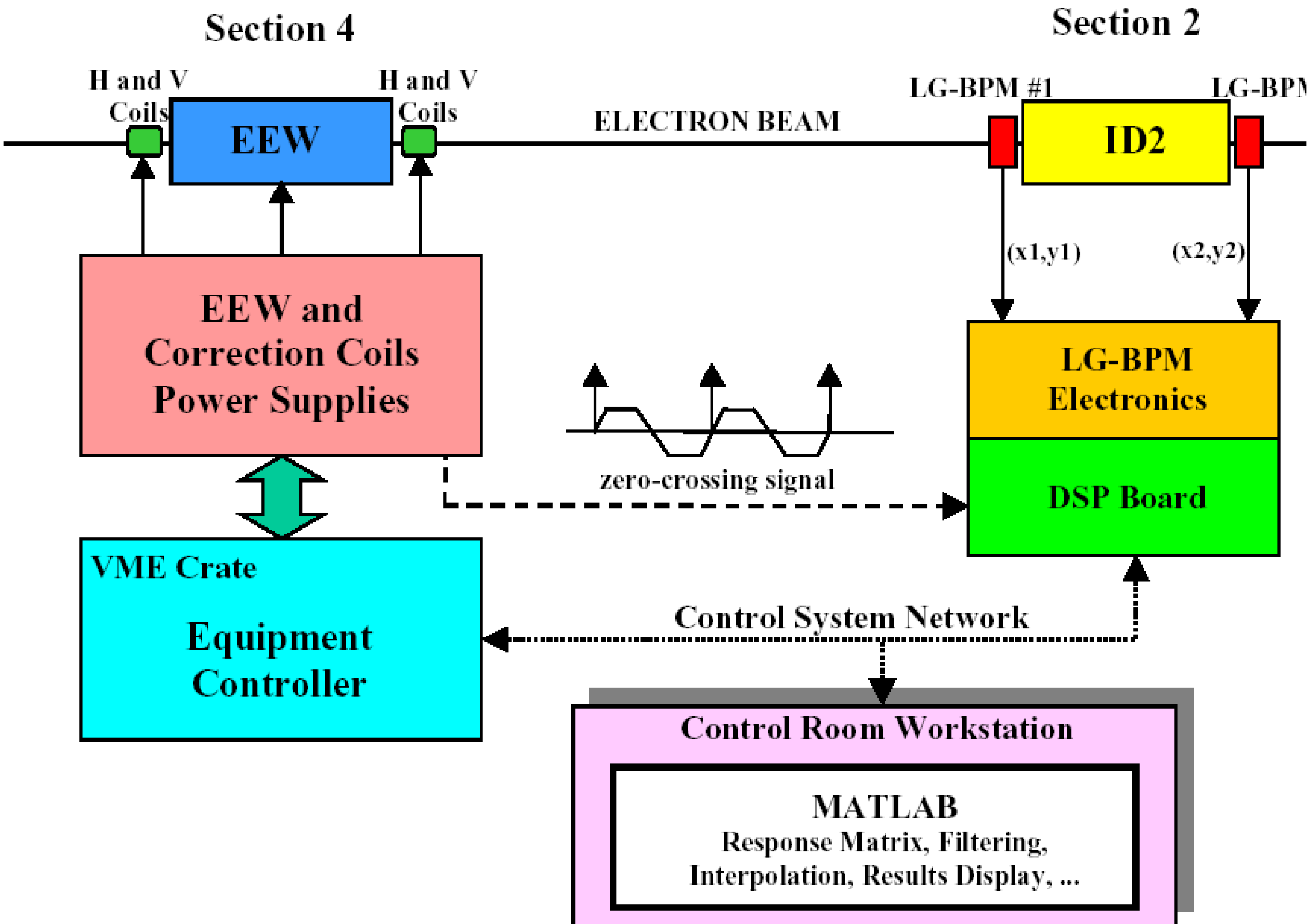
INSERTION DEVICE GAP FEED-FORWARD

ID Gap Changes (Vertical Axis)





ELETTRA EMW compensation system



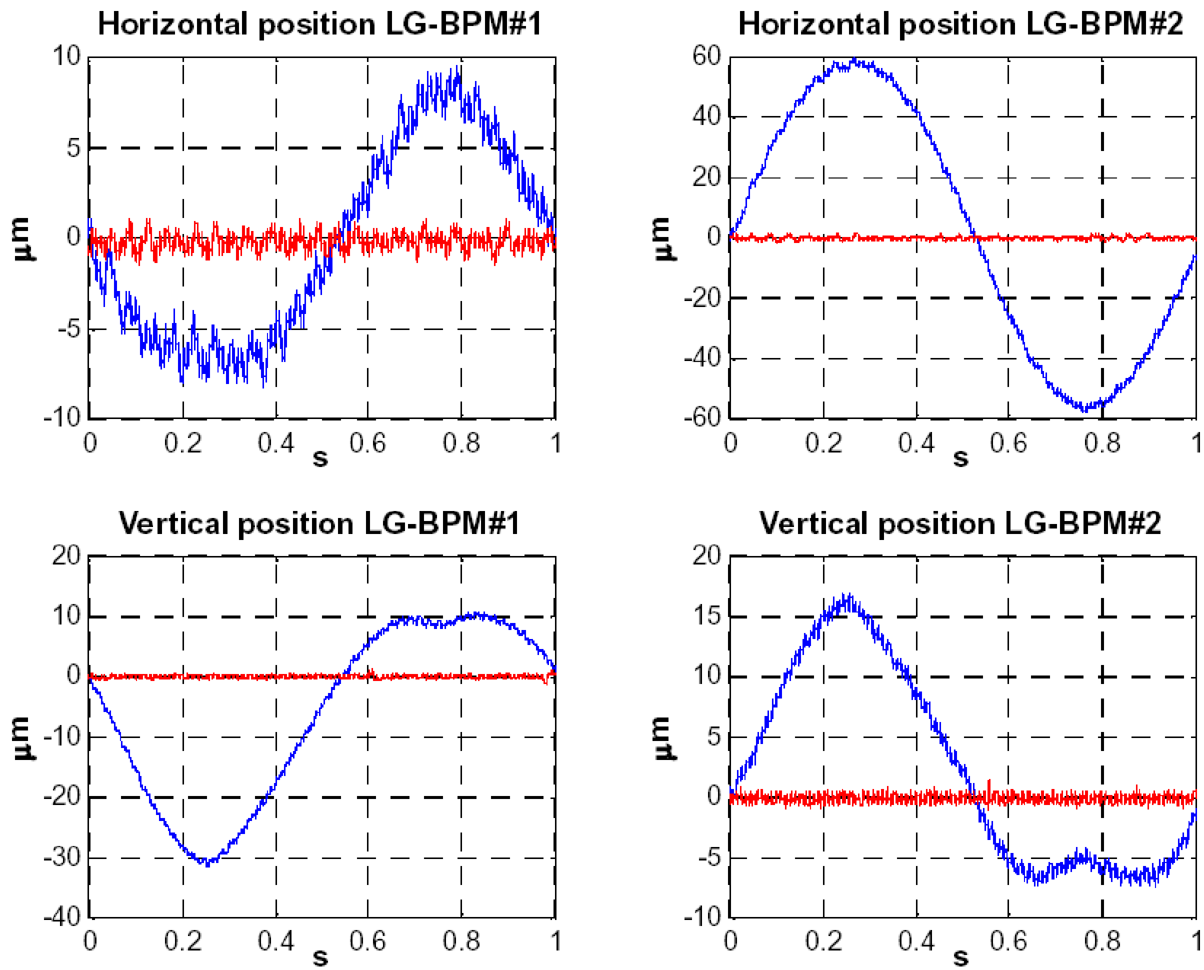
Lonza – EPAC'02

ELETTRA EMW Compensation algorithm

- Variation on conventional local orbit feedback.
- Assume orbit is corrected globally if it is corrected at two locations some phase advance apart (measured at second ID).
- Measured response matrix provides relationship between two bpms and two compensation magnets.

- Combination feed-forward/feed-back scheme.
- Generate correction waveforms for two correction magnets that are synchronized to the EMW main coil wave forms
- Incrementally modify the correction waveforms based on measured orbit distortions at bpm locations around second ID and using standard obit correction algorithm.

Performance of ELETTRA EMW compensator



Blue – open loop
Red – closed loop

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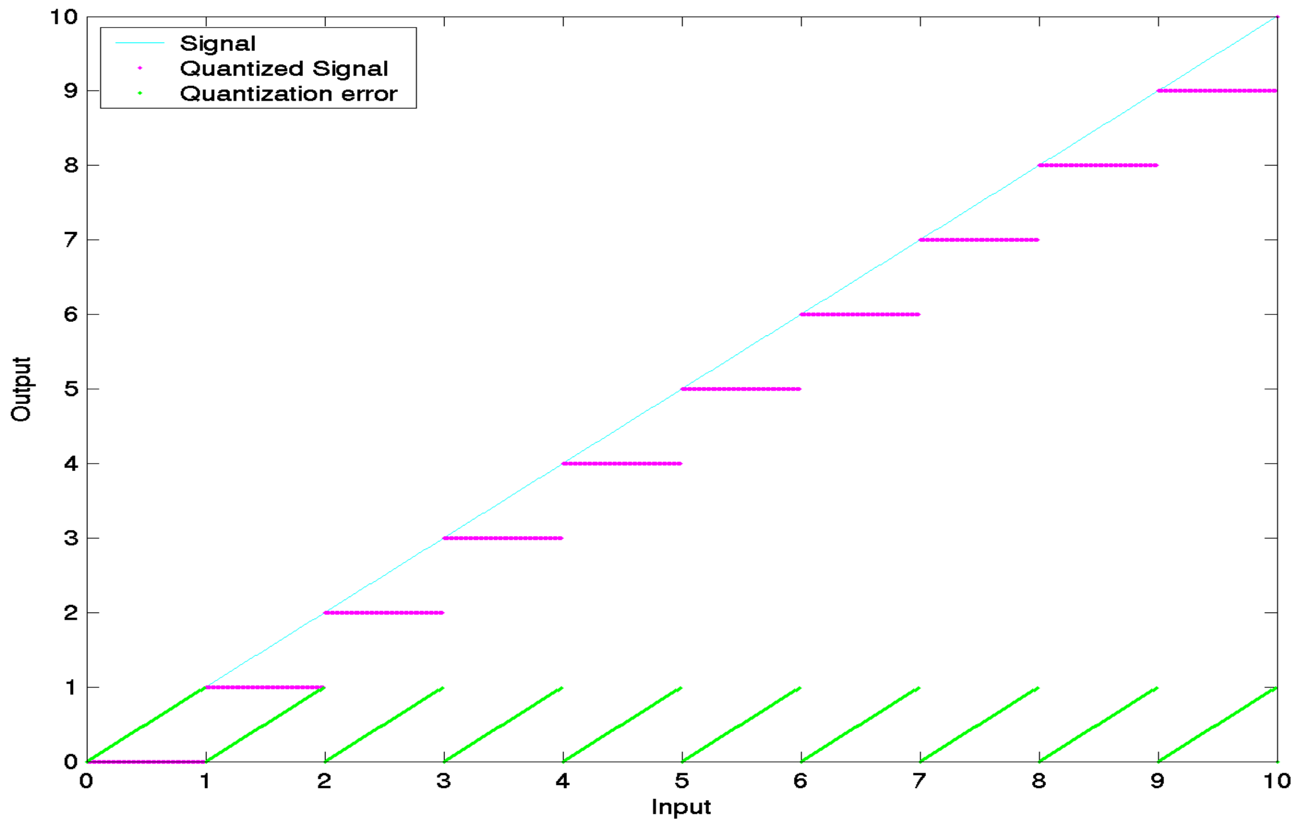
WORDLENGTH AND QUANTIZATION EFFECTS

Quantization of analog signal

- Bpm measurement quantization and corrector setpoint quantization (resolution) can be considered as sources of noise, and be assessed in statistical terms.



Impact of corrector setpoint quantization for 'DC' correction

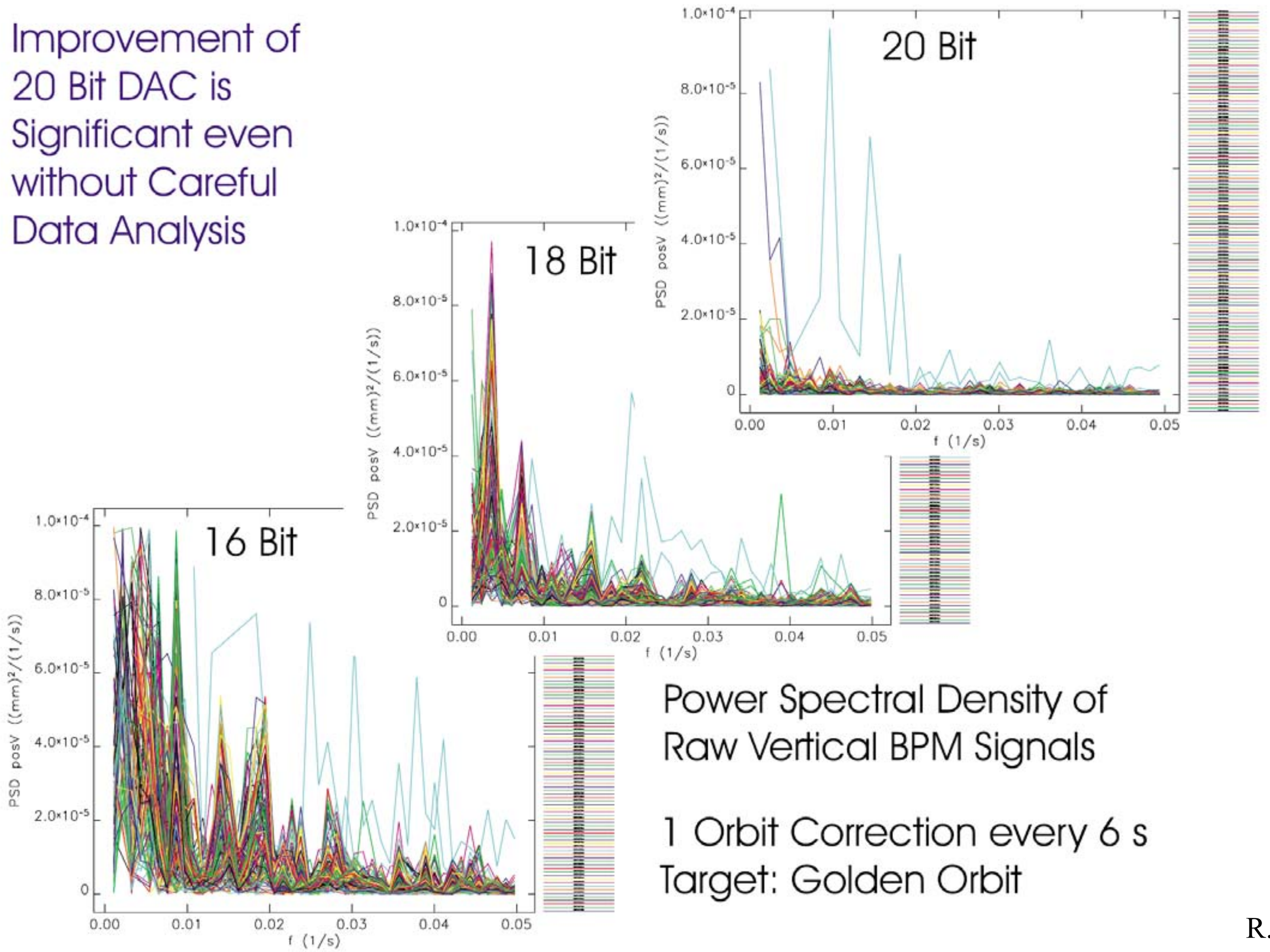
- Equates to quantization of angular kicks possible for steering through each photon source point.

- Mis-steering of electron beam through photon source point.
- Local bump closure error, giving global orbit error.

- Impact depends on
  - Full-scale range of corrector kick.
  - Beta function at the kick.
  - Magnitude of local bump coefficients.
  - Sensitivity of experiment beamline to angular deviations at the source point.

Orbit motion improvements from increasing corrector resolution at BESSY

Improvement of 20 Bit DAC is Significant even without Careful Data Analysis



Power Spectral Density of Raw Vertical BPM Signals

1 Orbit Correction every 6 s
Target: Golden Orbit

R.Mueller, PAC 2001

Corrector quantization effects for dynamical orbit feedback

- Assuming time varying control signals to the correctors, quantization errors can be viewed as yet another orbit motion noise source.
- Quantization errors are random, varying in the range 0 to 1 LSB.
- The rms value of a uniform distribution 0.2887, meaning that the rms error for any single quantization event is 0.2887 LSBs.
- The rms noise power is spread equally over the frequency spectrum from DC to half the update rate of the corrector setpoints.

Corrector quantization dynamic effects example

APS “fast” correctors

- Orbit deviation from a single AH3 corrector: 43.6μm rms / Amp.
- Corrector setpoint resolution: 300A / 65535 = 4.5mA / bit.

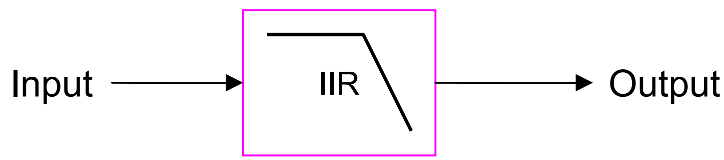
- Orbit deviation per bit from a single corrector is 0.2886 * 0.0045 * 43.6 = 0.056μm rms.

- We assume the quantization noise sources from the many correctors are uncorrelated.
- Then the orbit deviation per bit from 38 correctors is 0.056μm * sqrt(38) = 0.35μm rms.

- The impact of the rms quantization noise is therefore a function of the number of correctors, the orbit correction rate, and the frequency range of interest.

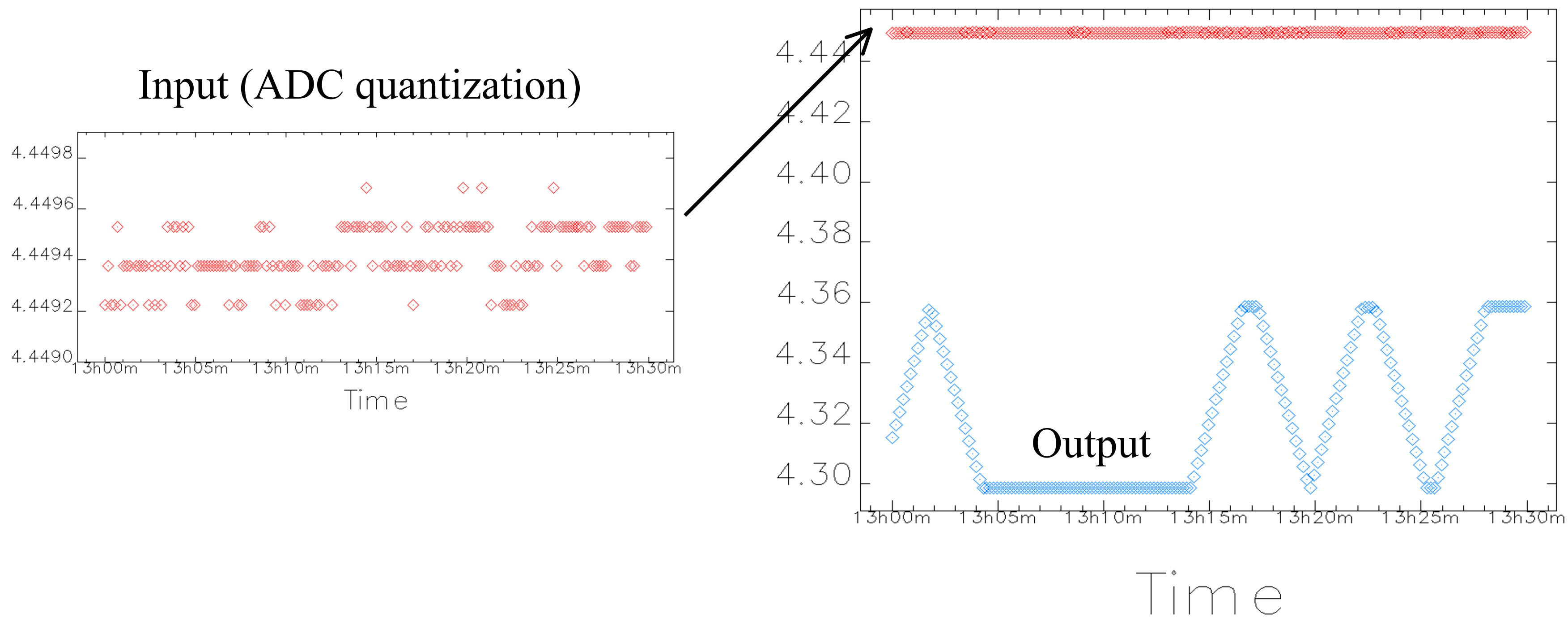
Processor word-length Effects

2-pole ‘biquad’



0.5Hz cutoff

Sampling rate = 1500Hz



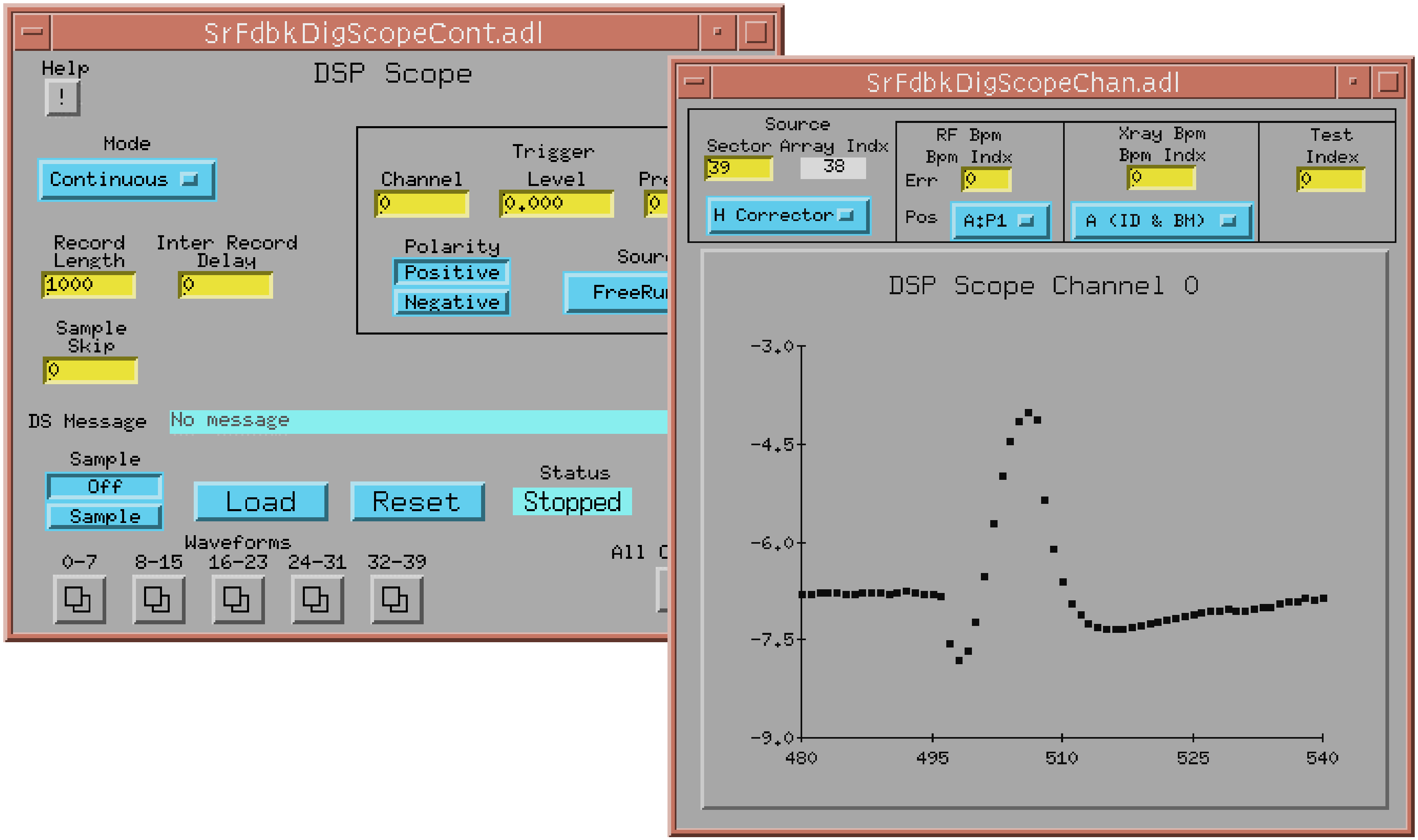
REAL-TIME DATA ANALYSIS

Data available at each step of orbit feedback

- The value of every bpm used in the orbit correction algorithm.
- Every corrector error signal.
- Every corrector drive signal.

- Information of value
  – Evolution of signals with time.
  – Frequency spectrum of signals (as a function of time).
  – RMS orbit motion as a function of time.
  – Snapshot of signals just before a beam dump (whether or not the orbit feedback system dumped the beam).

Waveform capture using 'DSP-scope'

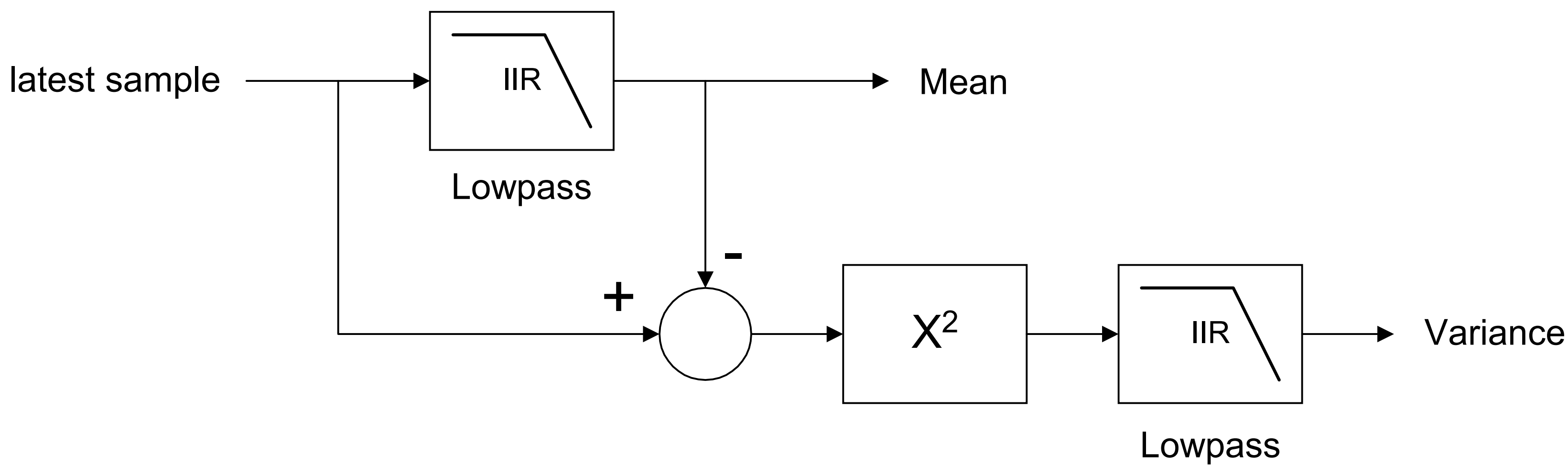


Sliding (Real-time) Algorithms

Mean: $$\mu_n = E\{x_n\} \approx \frac{1}{N}\sum_{k=1}^{N} x_k$$

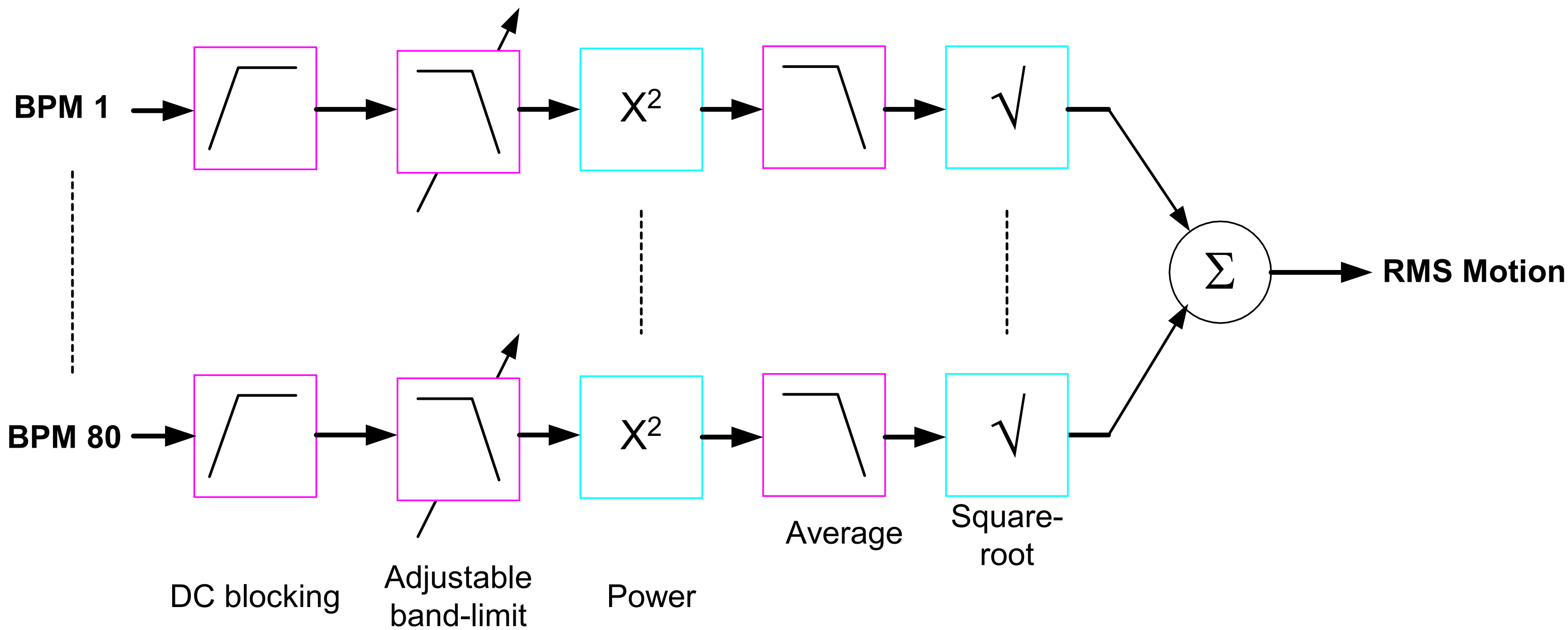
Variance: $$\sigma_n^2 = E\left\{(x_n - \mu_n)^2\right\} \approx \frac{1}{N}\sum_{k=1}^{N}(x_k - \mu_n)^2$$

- Statistical estimates of the mean and variance of a signal can be easily computed in real time, sample-by-sample.



Real-time RMS orbit motion calculations

- New real-time measurement of the APS orbit motion



Sliding Fourier Transform

- Discrete Fourier Transform

$$X[k] = \sum_{k=0}^{N-1} x[n].W_N^{kn} \qquad W_N = e^{-j\frac{2\pi}{N}}$$

- Computationally, it is very inefficient to implement this equation directly (use the Fast Fourier Transform algorithm instead).

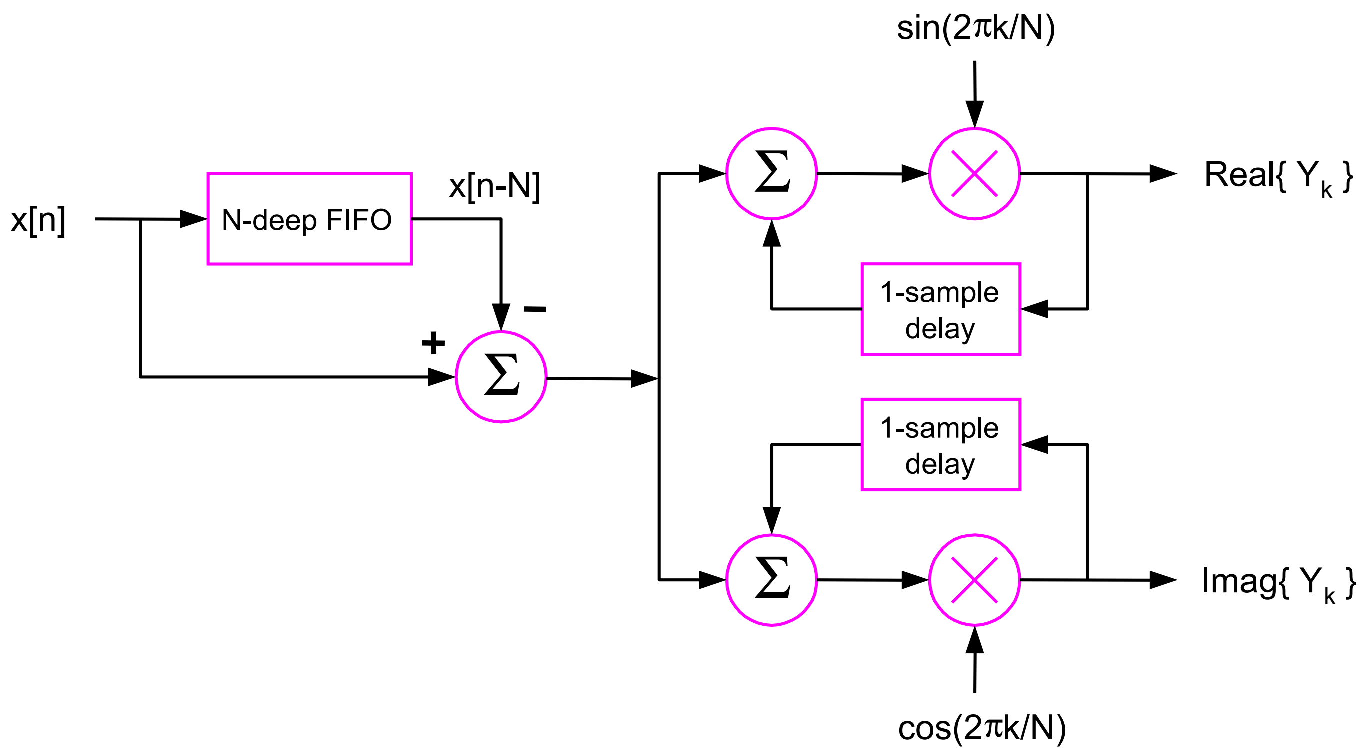
- Sliding *N*-point Fourier Transform
  - Updates a previous estimate using only the difference between the latest sample and the sample *N* points ago

$$Y_k[n] = \left[Y_k[n-1] + x[n] - x[n-N]\right].e^{-j2\pi\frac{k}{N}}$$

- Over *N* samples, this implements the *full* Discrete Fourier Transform equation, but is very efficient on a sample-by-sample basis.

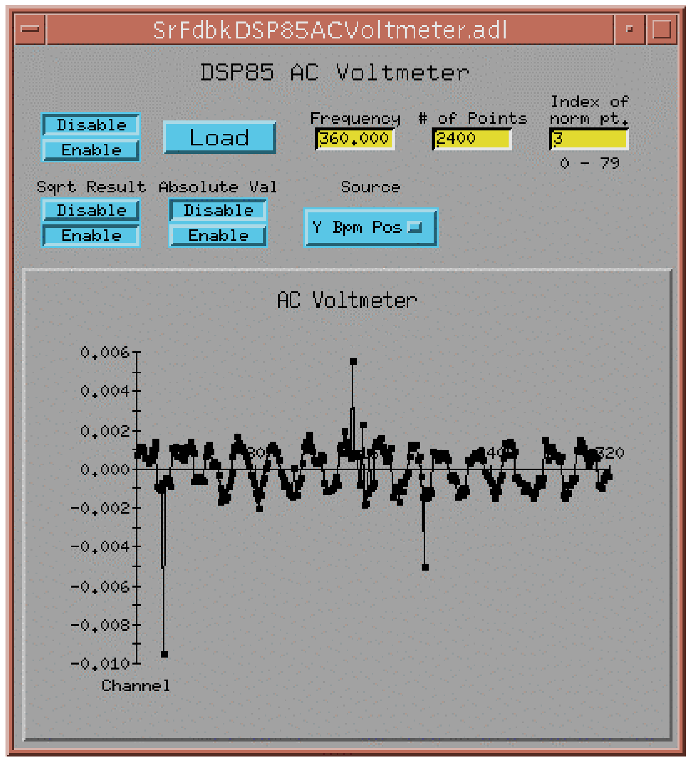
Sliding Fourier Transform (implementation)

- The structure for each frequency component *k* is as follows



Sliding Fourier Transform
('AC Voltmeter')

- 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.



How we got the 10-decade orbit motion plot

LOCATING SOURCES OF ORBIT MOTION

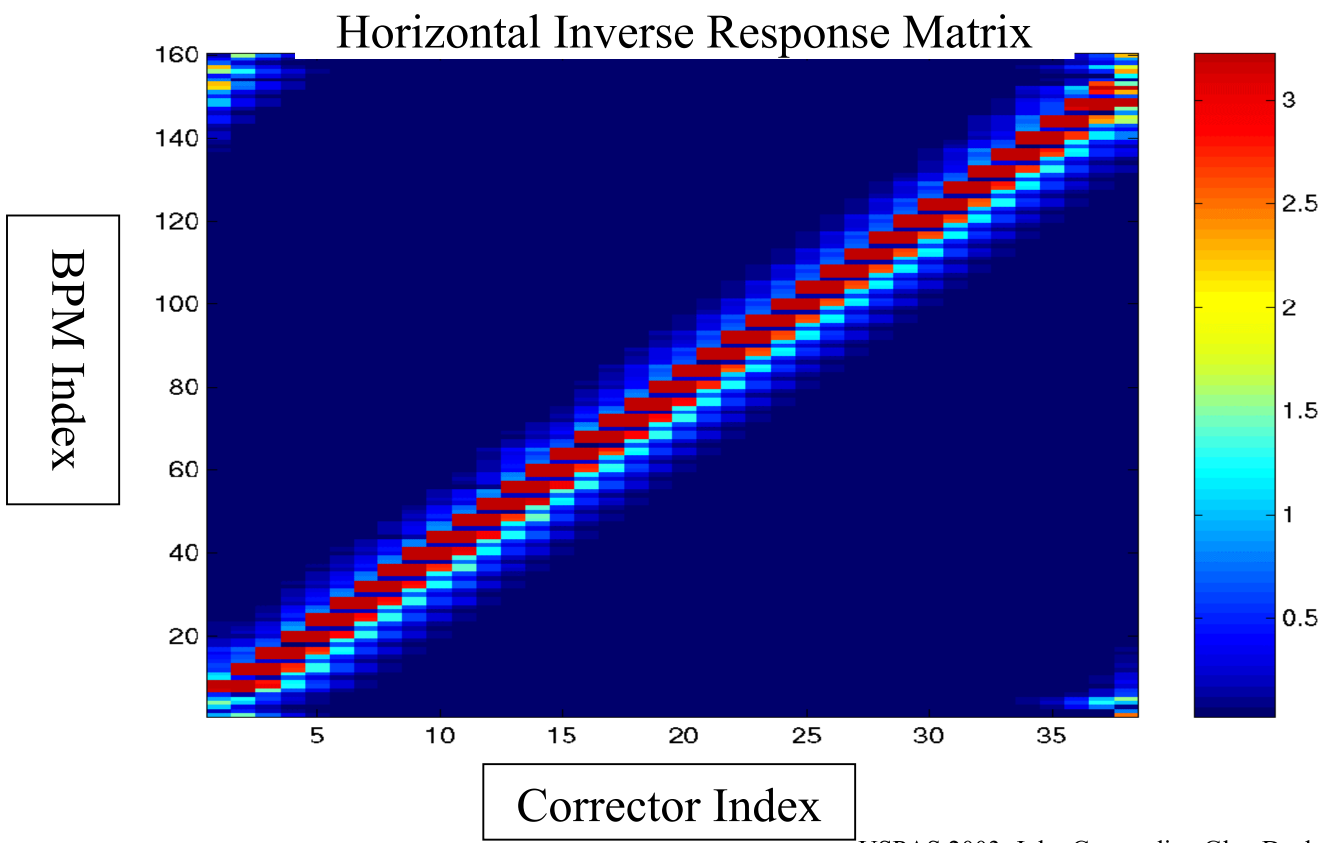
Orbit motion source identification

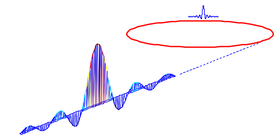
- The best way to correct orbit motion is to get rid of the original sources.
- Strong sources individual sources of motion do appear, eg when something is wrong
  - A bad magnet power supply that is oscillating.
  - A bad bpm that is injecting noise or disturbances into the correction algorithm.
  - Vibrating mechanical pumps.
  - etc.

  - Before we can get rid of such sources, we have to find them!

Using the inverse response matrix to localize sources

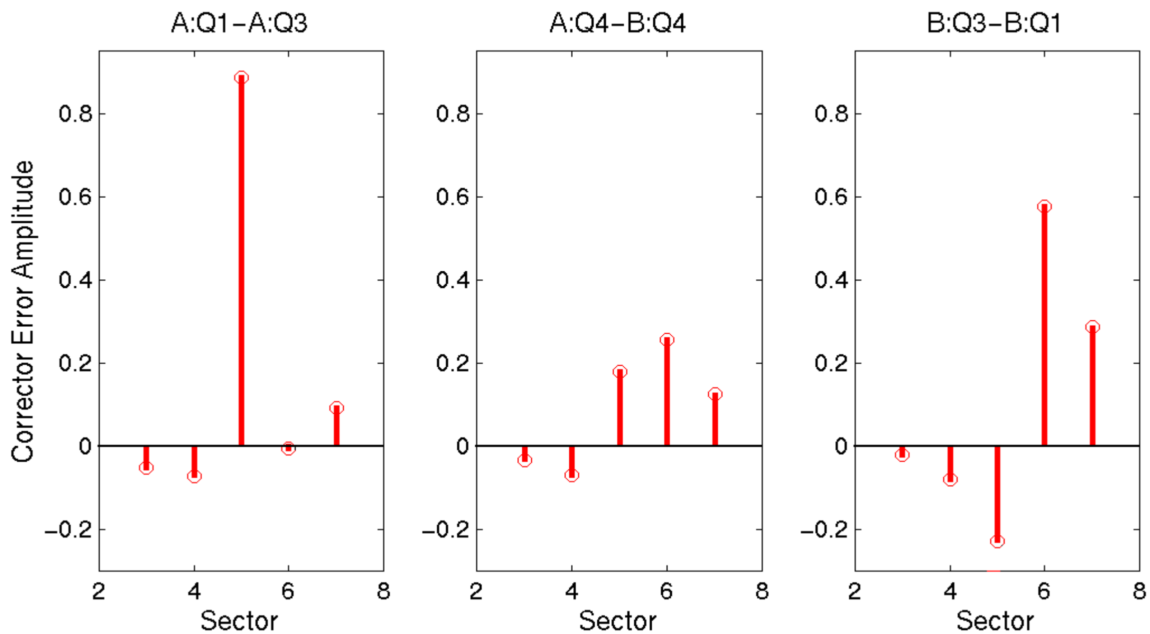
- The band-diagonal nature of the inverse response matrix gives us the possibility of finding sources using the measured orbit motion.
- The feedback system applies localized corrections to fix orbit motion, therefore any strong source of orbit motion will show up in the corrector control signals.





Corrector Error Signatures for Different Source Locations

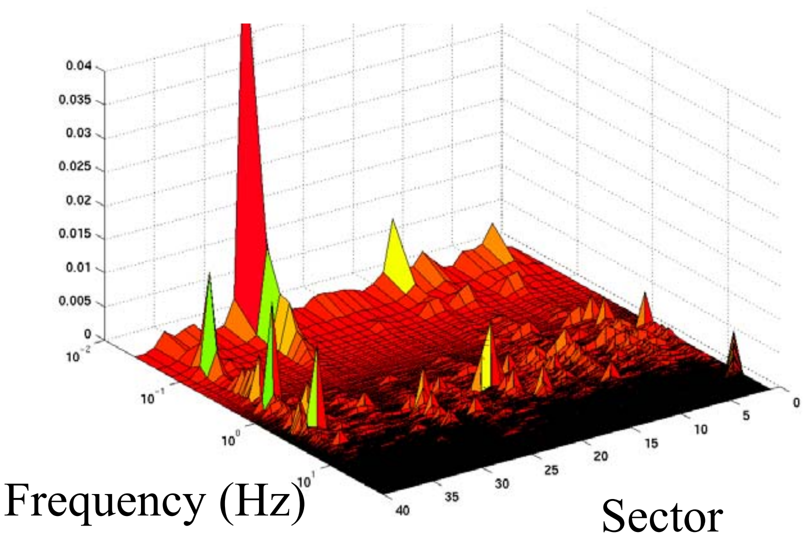
- Ten quadrupoles in one sector were excited with a small AC modulation.
- Relative changes in the derived corrector-error signals were monitored for each of the ten sources.
- Three distinct corrector-error signatures were identified.
- These same signatures allow real sources of motion to be located to within about one third of a sector (about 9 meters)



Frequency maps of orbit motion sources

- Plots of corrector error spectra as a function of corrector location can be used to identify and locate sources of orbit motion.
- It is much easier to analyze the frequency content of this data if it is taken with the orbit feedback open-loop.
- As shown, the data gives about 1 sector accuracy. Better spatial accuracy can be accomplished by taking additional data from bpms around the source.

Horizontal



Vertical