Measurements for the PES Pareto Method of Identifying Contributors to Disk Drive Servo System Errors in Disk Drives

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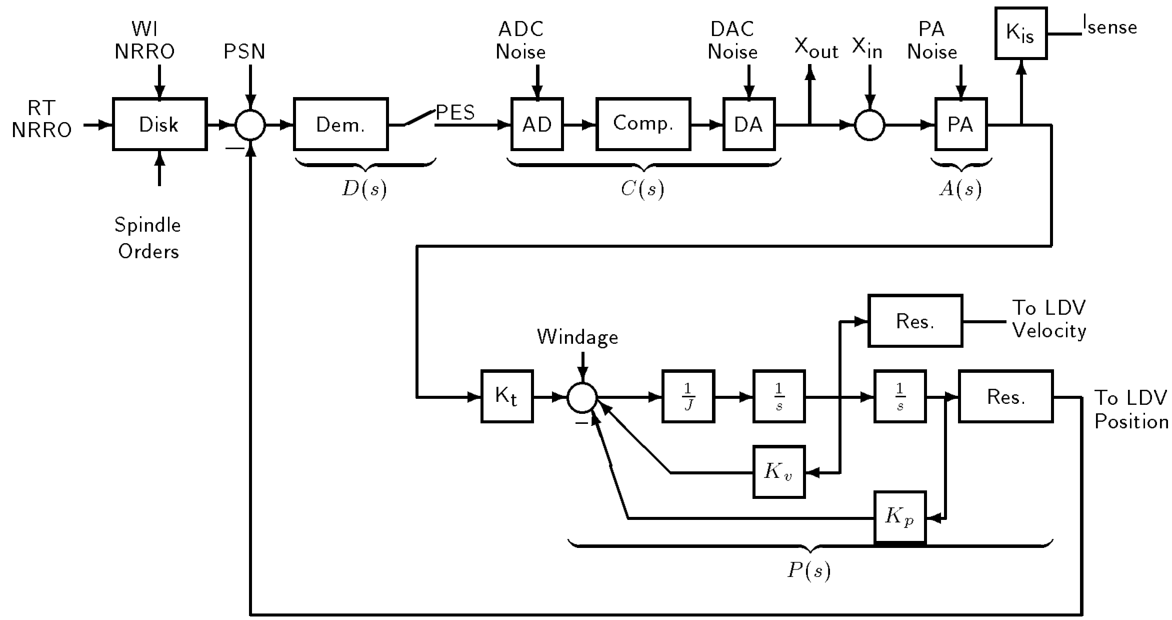
Outline

- Introduction/Overview/Measurement Goals
- Primary Tools/Capabilities Used
- Measurement Results
  - Frequency Response Functions
  - Power Spectra
  - Position Sensing Noise (ANOVA)
- Summary

System Model and Measurement Goals

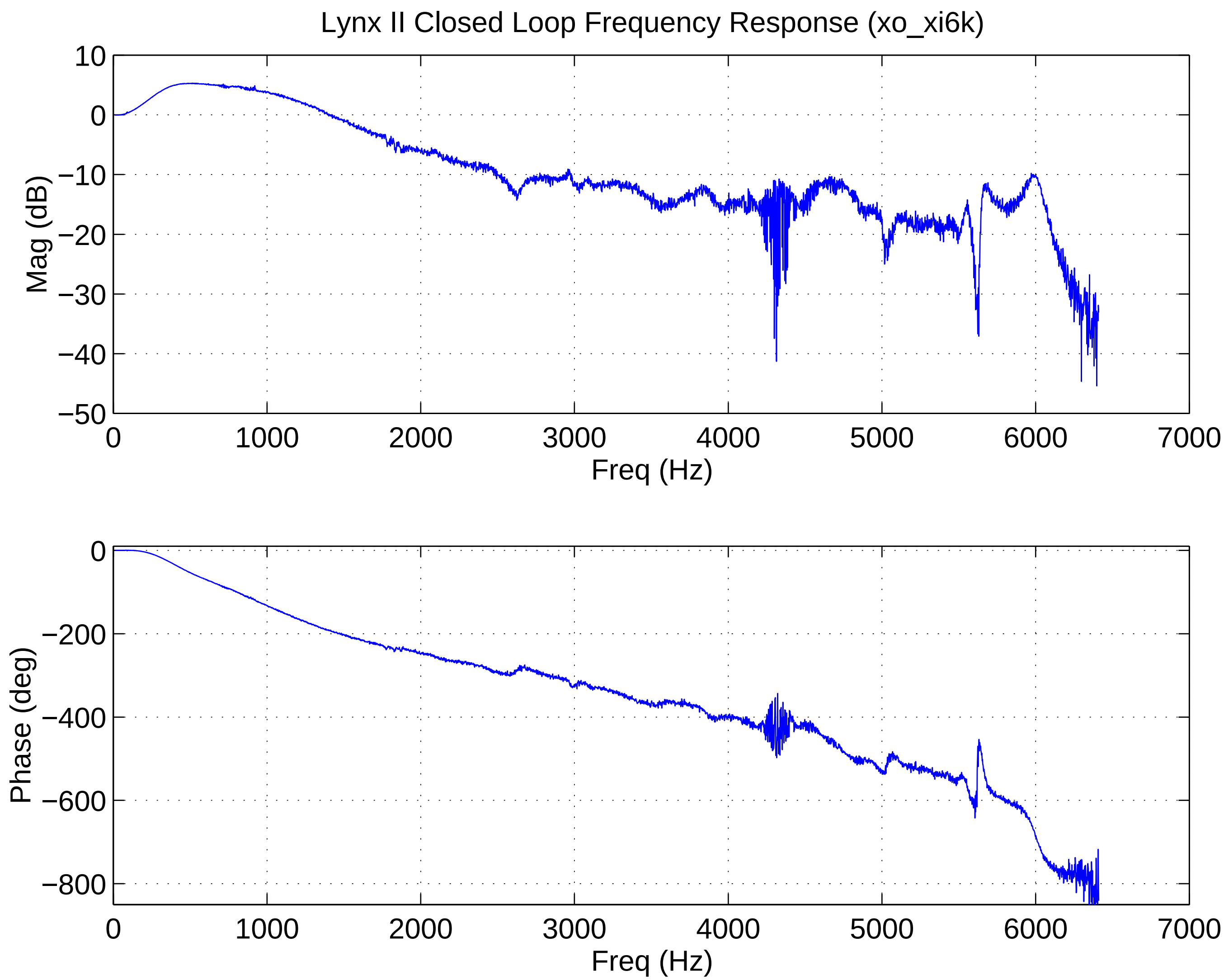


- Obtain Frequency Response Functions (10-6410Hz; 2-Hz resolution)
- Obtain Power Spectral Density Responses (same bandwidth/resolution as FRF's)

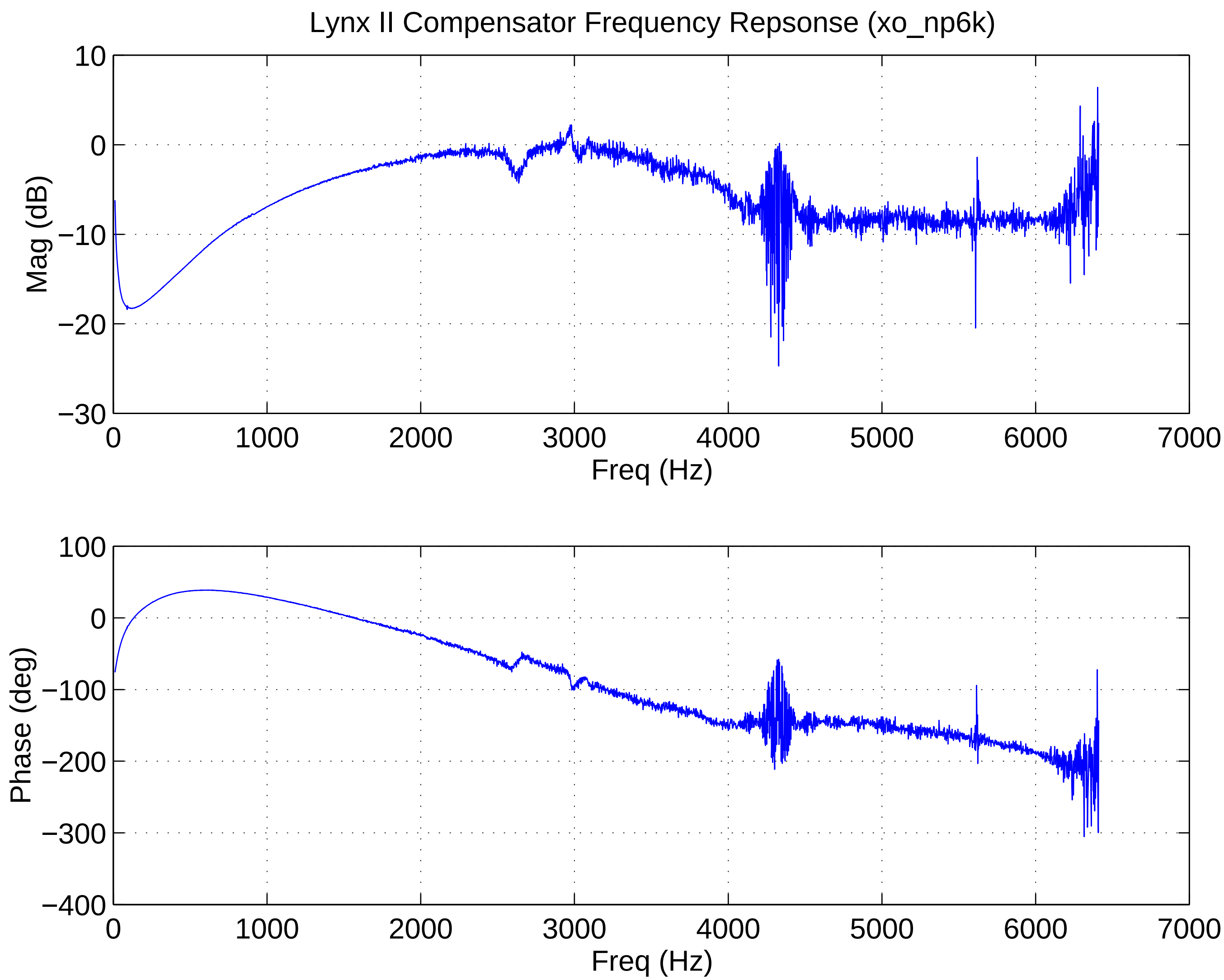
Primary Tools/Capabilities

- Lynx-2 disk drive and exerciser
  - Set loop parameters
  - Measure and compare key signals
- Polytec Laser Doppler Vibrometer (LDV)
- HP3567A 5-channel Digital Signal Analyzer
- HP54720D Digital Storage Oscilloscope
- The Network (including Web)
- Matlab

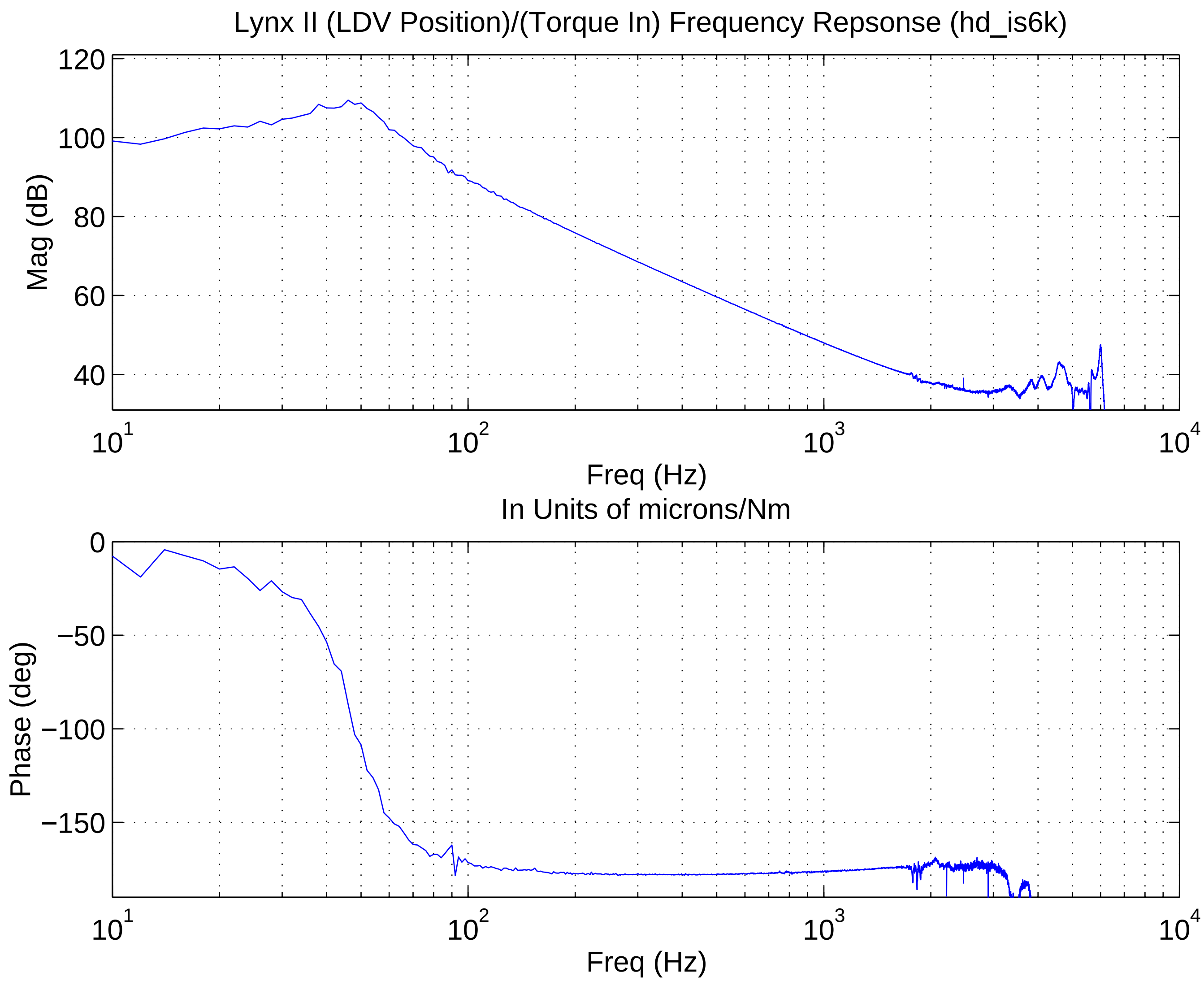
Closed Loop Transfer Function: Xout/Xin



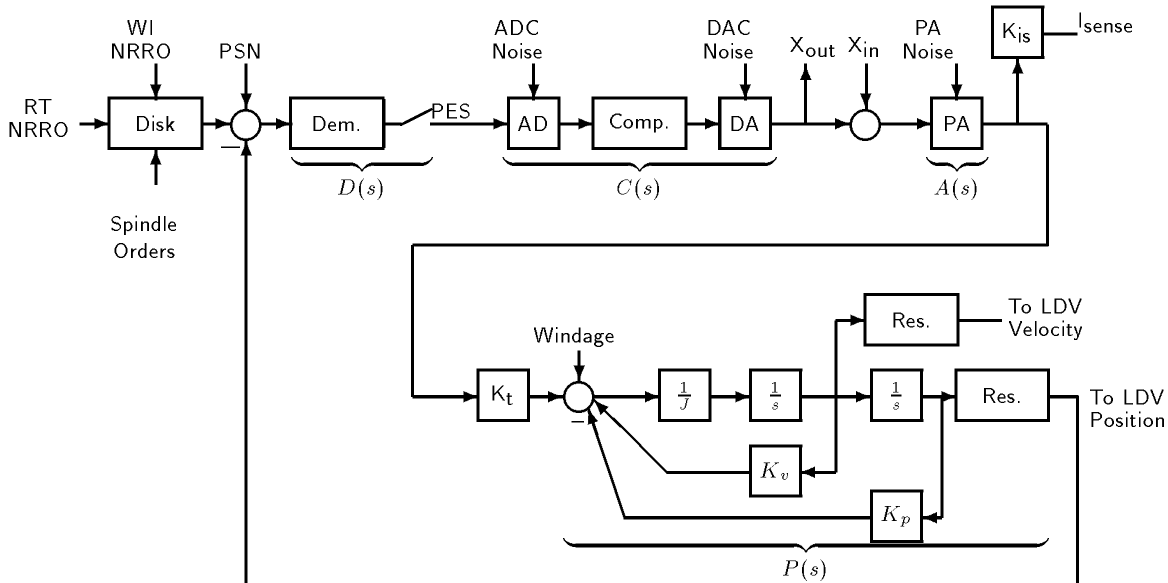
Compensator Transfer Function: Xout/NPES



Mechanics Transfer Function: LDV/Torque–In

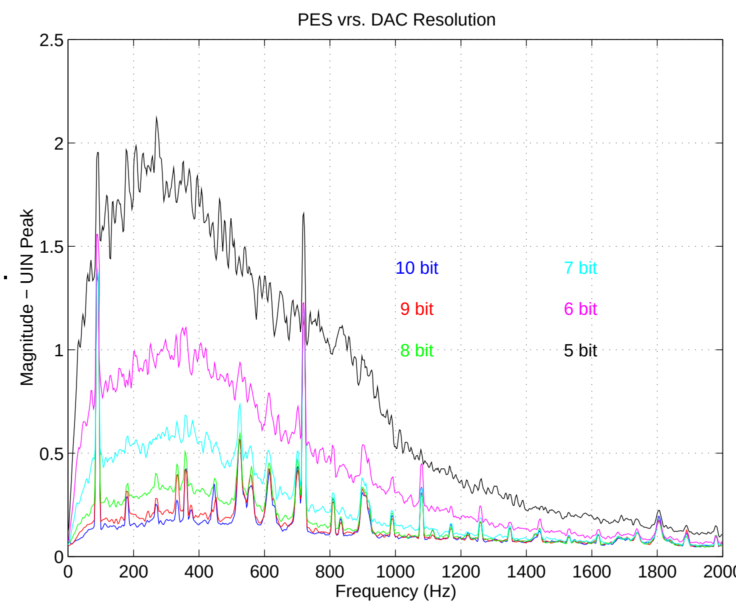


DAC Noise (From Greg Hofer/DMD)

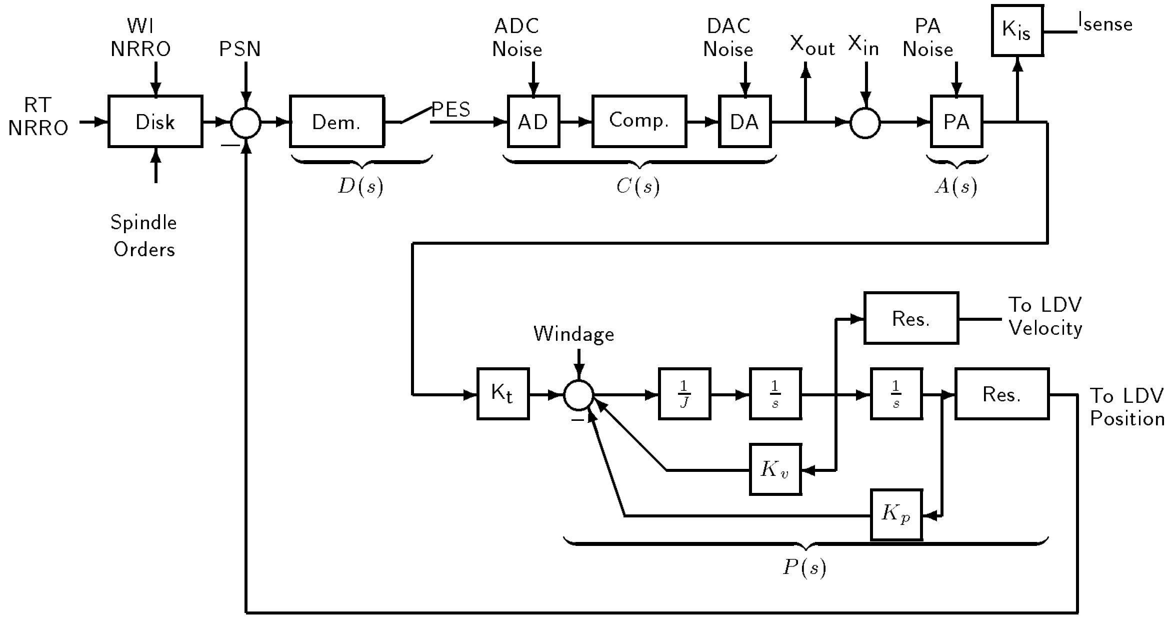


Procedure:

- Mask off DAC LSB's (alter DSP firmware);
- Send result to VCMDAC;
- Losing even 1 bit results in noticeable difference in PSD.

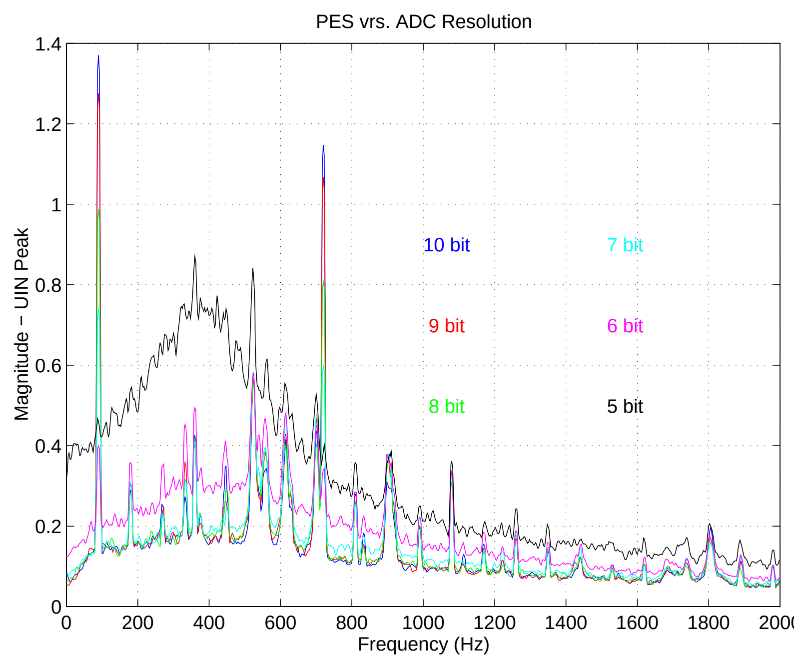


ADC Noise

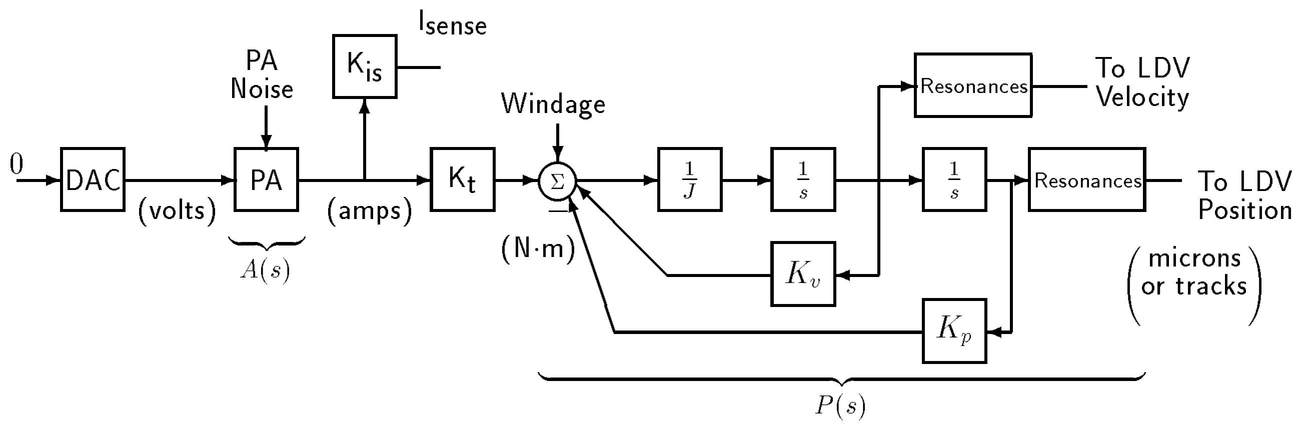


Procedure:

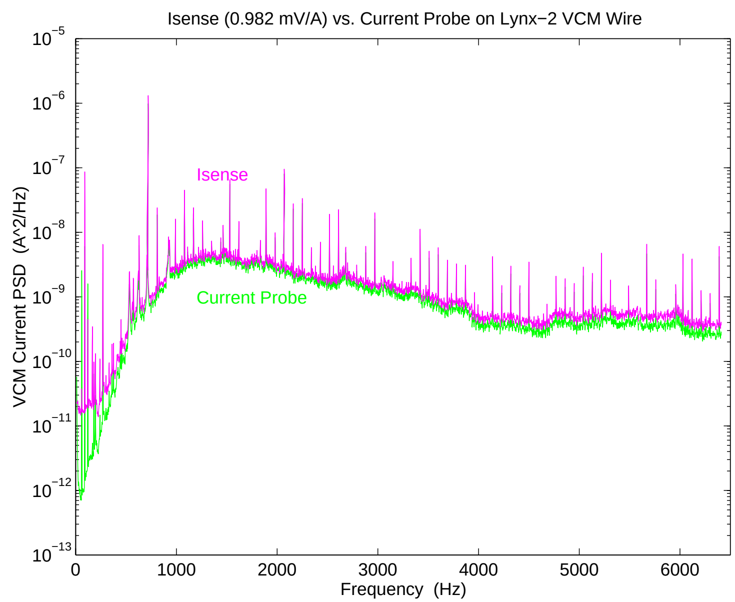
- Read ADC value and Mask off LSB's;
- Measure PSD of altered ADC value;
- Losing 2-3 bits results in minimal effect.



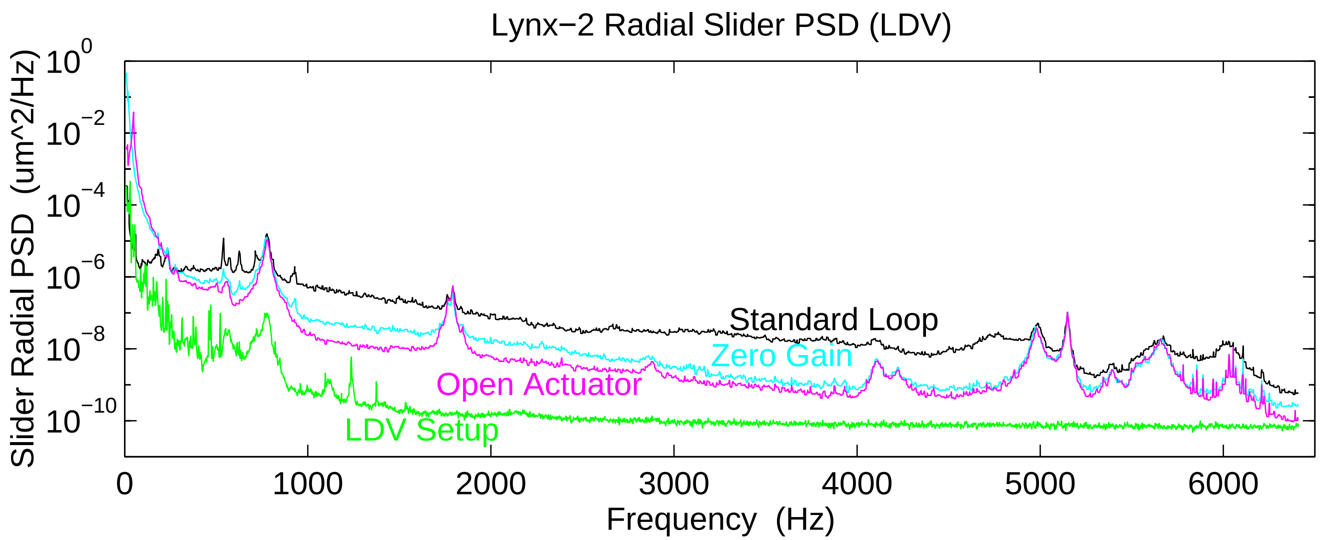
Power Amplifier Noise: Isense vs. Current Probe

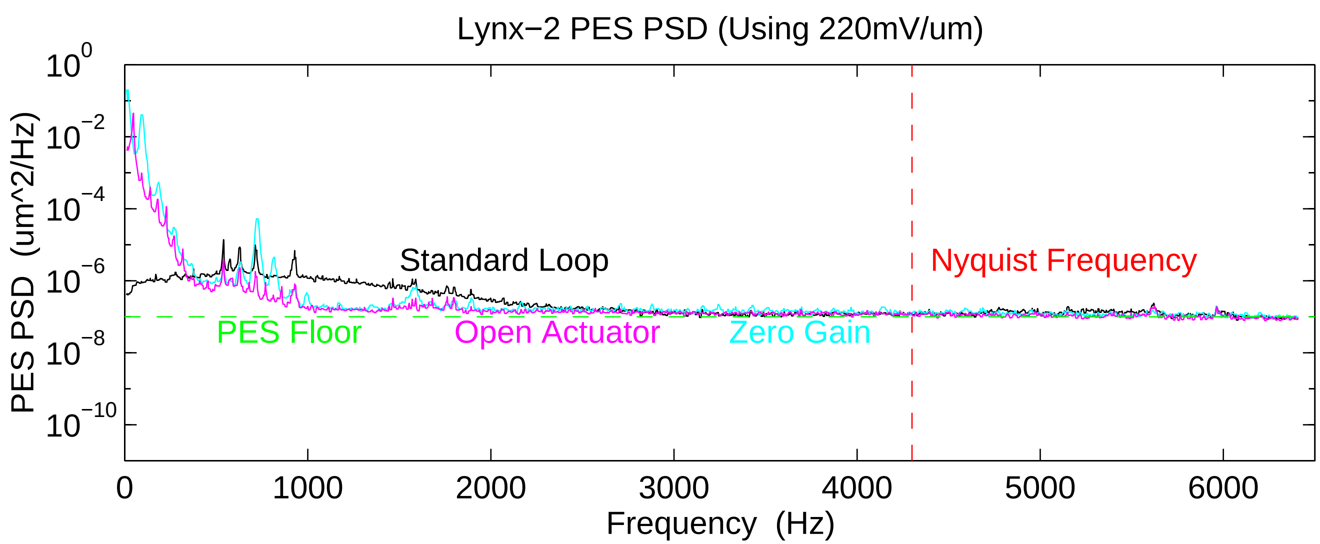


– Isense was verified using current probe on actuator leads.
– Zero value at DAC isolates power amplifier.
– Disconnect actuator wires to isolate actuator.



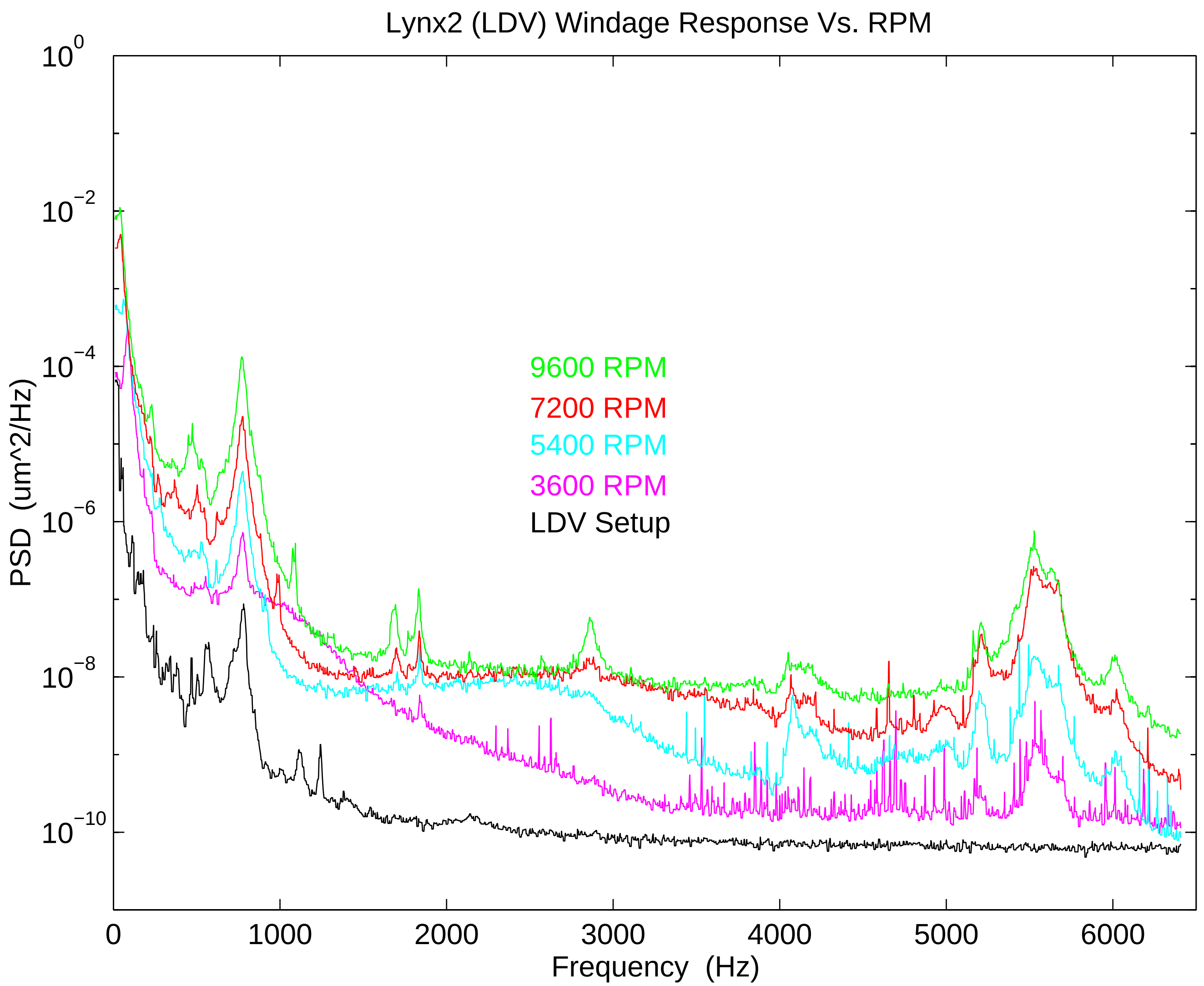
LDV vs. PES for Various Loop Conditions



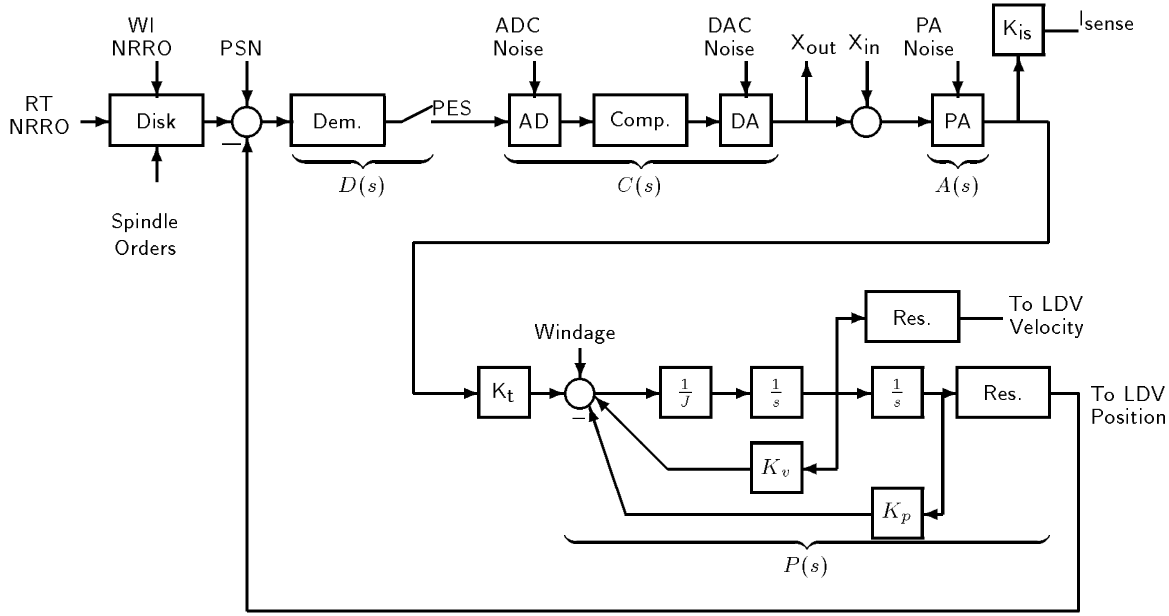


– First PSN estimate: $\sqrt{1.2 \times 10^{-7} \mu m^2/Hz \times 6400 Hz} \;=\; 0.028 \mu m \;\Rightarrow\; 3\sigma_{PSN} \;=\; 1.34\%$ of track pitch.

Slider/Arm Movement vs. Spindle RPM

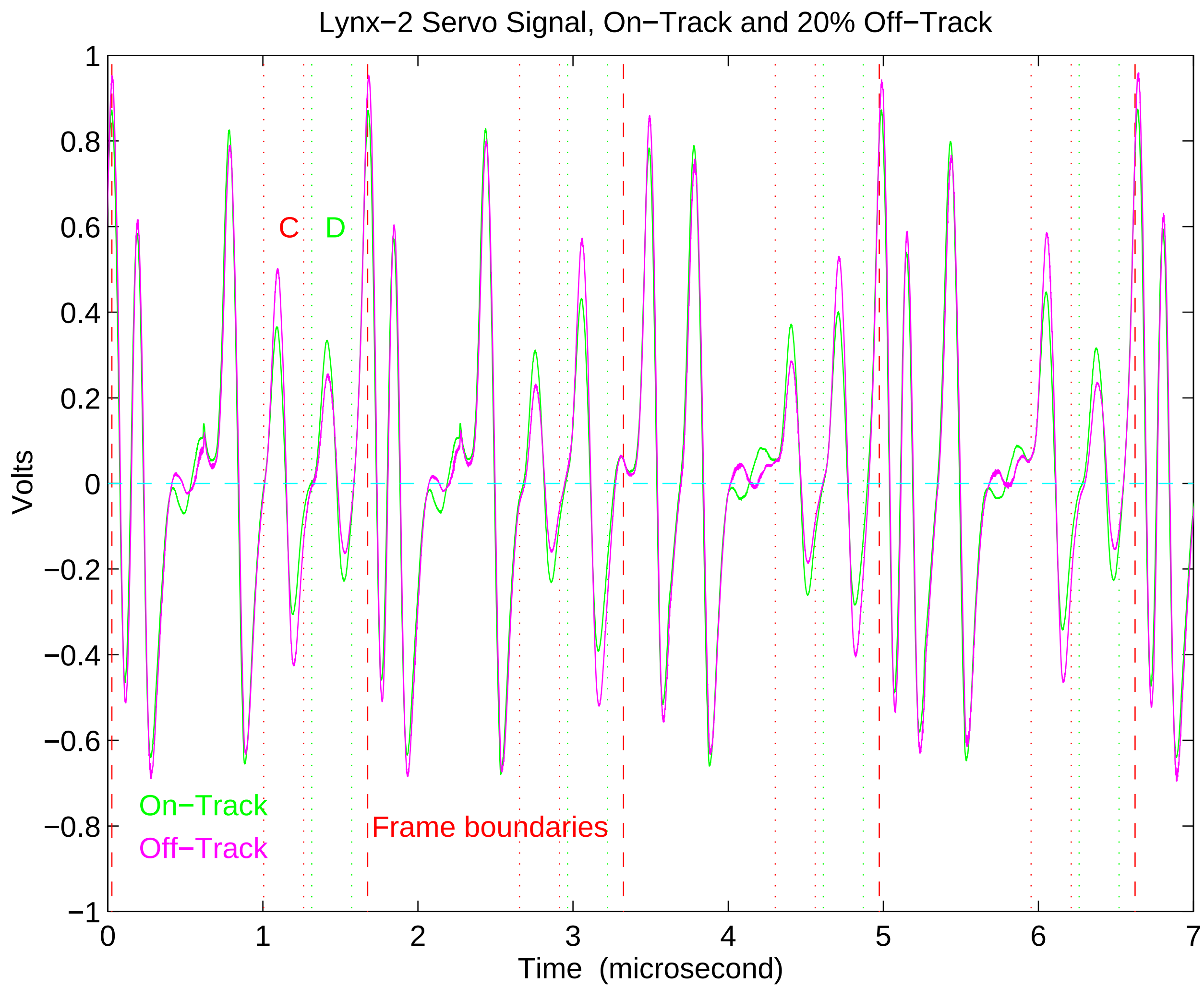


Measuring Position Sensing Noise (PSN)



- Enters system directly via reference summing junction (difficult to isolate).
- Seek an independent estimate of PSN besides low–gain measurement.
- Can then compare "forward–path" estimate with "what's left" value.

Lynx-2 Servo Signal and Frame Format



- Question: How much of signal is from PSN vs. actual off-track?

Statistical Two–Way Analysis of Variance (ANOVA)

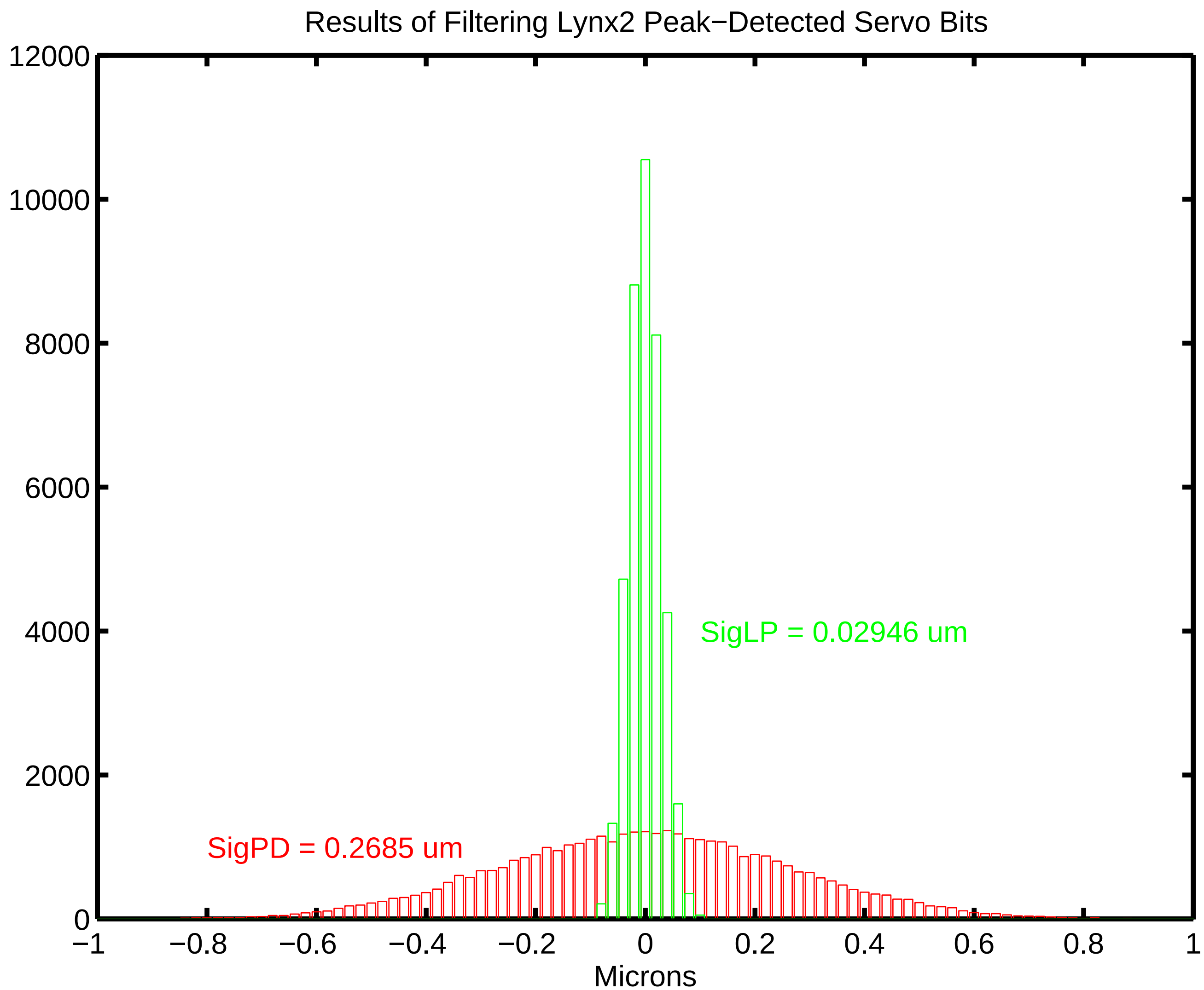
- Required Assumptions
  - Assume constant position during each of k servo bursts, each of length n servo bits.
  - Variations within each n-burst are uncorrelated.
  - Instrumentation measurement error is negligible.
- Model each servo bit, Y_{ij}, as a sum of displacement, Δ_i, and measurment, E_{ij}, errors, each normally distributed about zero mean: $Y_{ij} = \mu + \Delta_i + E_{ij}$; $i = 1, 2, \ldots k$, $j = 1, 2, \ldots n$
- Variances are given by Expected Values: $E(SSD) = \sigma^2 + n\sigma_\Delta^2$; $E(SSE) = \sigma^2$; $SSD = n \sum_{i=1}^{k} (\bar{Y}_{i\cdot} - \bar{Y}_{\cdot\cdot})^2$; $SSE = \sum_{i=1}^{k} \sum_{j=1}^{n} (Y_{ij} - \bar{Y}_{i\cdot})^2$.
- Variance of (sectored) PES Measurement Error (based on $Y \mid_A - Y \mid_B$): $\sigma_m^2 = \frac{\sigma_A^2}{n} + \frac{\sigma_B^2}{n}$.
- σ_m is an estimate of PSN.

ANOVA Comparison: Integrate vs. Peak-Detect; Kittyhawk, Lynx-3, and Lynx-2

Disk Drive and Track Pitch (μm)	Peak–Detect				Integrate			
	A/B Variance (μm^2)	Bits	Sample σ (μm)	3σ % of TrkPitch	A/B Variance Variance	Bits	Sample Sigma	3σ % of Trk Pitch
Kittyhawk (9.41)	0.086 / 0.046	5	0.16	5.18	0.085 / 0.047	5	0.16	5.18
Lynx-3 (4.43)	0.043 / 0.042	9	0.097	6.58	0.053 / 0.031	9	0.13	8.78
Lynx-2 (6.35)	0.070 / 0.076	N/A	0.029	1.39	0.111 / 0.114	N/A	0.034	1.61

- PES Sample Uncertainty, Kittyhawk and Lynx-3: $\sigma_m^2 = \frac{\sigma_A^2}{n} + \frac{\sigma_B^2}{n}$.
- Computing Lynx-2 (continuous servo) Sample Uncertainty:
  - Digitize PES waveform;
  - Matlab Peak–detect (or Integrate) and ANOVA $\Longrightarrow$ σ_{bit} ;
  - Generate Gaussian noise time sequence $X(t)$:
    $t \; = \; [0 : 200E - 9 : 12E - 3]\,' \, ; X(t) \; = \; \sigma_{bit} \; \times \; randn(\; size(t) \;) \; ;$
  - Low-pass filter $X(t)$ by model of Lynx-2 demodulation filter:
    $G(s) = \frac{10^{10}}{8.61\times10^{-7}s^3 \; + \; 3.95\times10^{-1}s^2 \; + \; 1.49\times10^5 s^5 \; + \; 10^{10}} \; ; \; Y(t) \; = \; lsim(\; G(s), X(t), t \;) \; ;$
  - Resultant σ_S of $Y(t)$ is estimate of Lynx-2 Position Sensing Noise (PSN).
- And the result is:

σ_S matches PES Pareto "What's Left" Value: $0.029\ \mu m$!



Measurement Summary

- In–drive characterization of Lynx–2 FRF's and PSD's was accomplished.
- ANOVA was adapted and used for Lynx–2 (continuous–servo vs. embedded).
- Measurements and PES Pareto estimates were cross-checked, e.g.:
  - LDV vs. PES at zero gain
  - PSN from ANOVA vs. "What's Left" from PES Pareto.
- Key work remains for more precise characterization and improvement:
  - CMU/DSSC work on optimal position signal generation (Sacks/Mathur/Messner).
  - NSIC: PSN and Windage thrusts.