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What is a Bode Plot?

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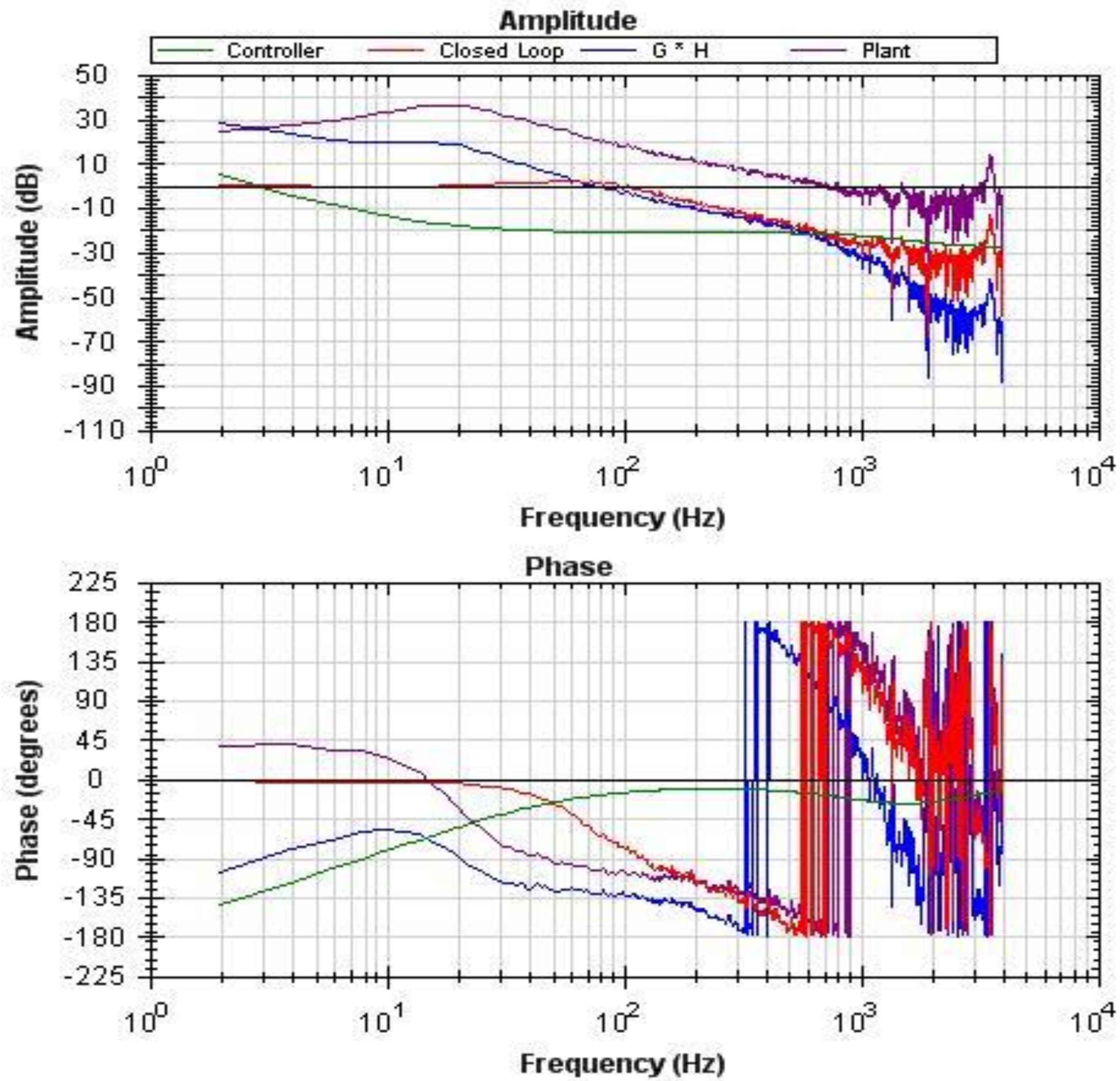
- A frequency domain analysis of a control system using a graphic technique from LaPlace transforms.
- It can be used to determine gain and phase relationships from input to the output as the frequency changes.
- It helps in characterizing the system for load inertia, friction, resonance, and interaction of a feedback system.

Measurements

- Plant
- Open Loop
- Closed Loop
- Controller



Plant, Open Loop, Closed Loop Basics

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- A Plant measurement is an open loop type measurement used to discover the load information
- The Open Loop transfer function will yield gain and phase margin information, anti-resonance and resonance data for interpreting stability by separating the forward and feedback loops.
- The Closed Loop measurement shows the bandwidth as well as the resonant affects. You can see the closed loop stability by comparing the resonant characteristics with 0-dB and -180 degree phase lag.

What Can Be Determined by a Bode?

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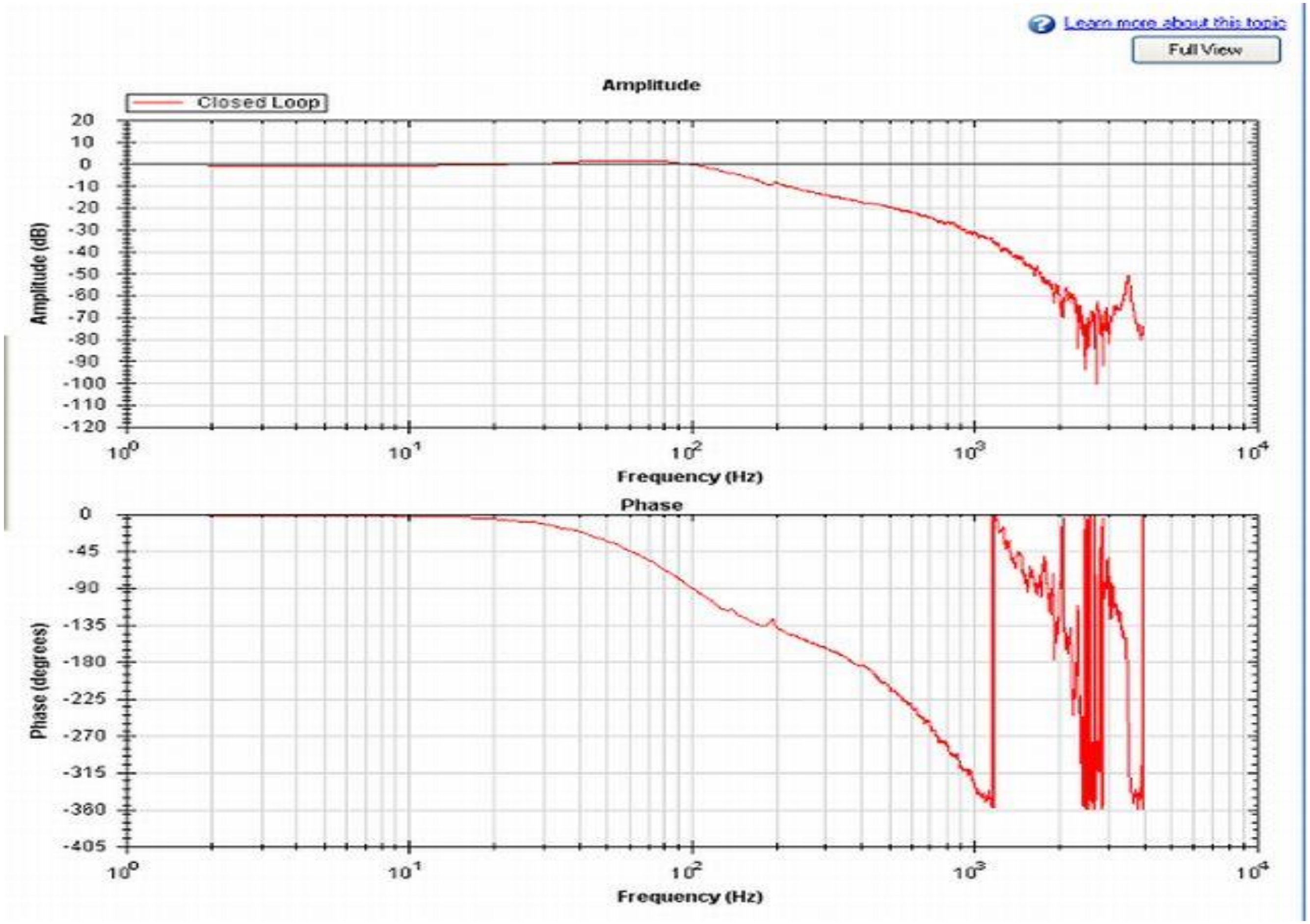
- Bandwidth
- Phase Margin
- Gain Margin
- Stiffness
- Friction
- Stability

Bandwidth

- In the closed loop domain, the point where the gain is –3dB and/or the phase is –45°.



Phase/Gain Margin

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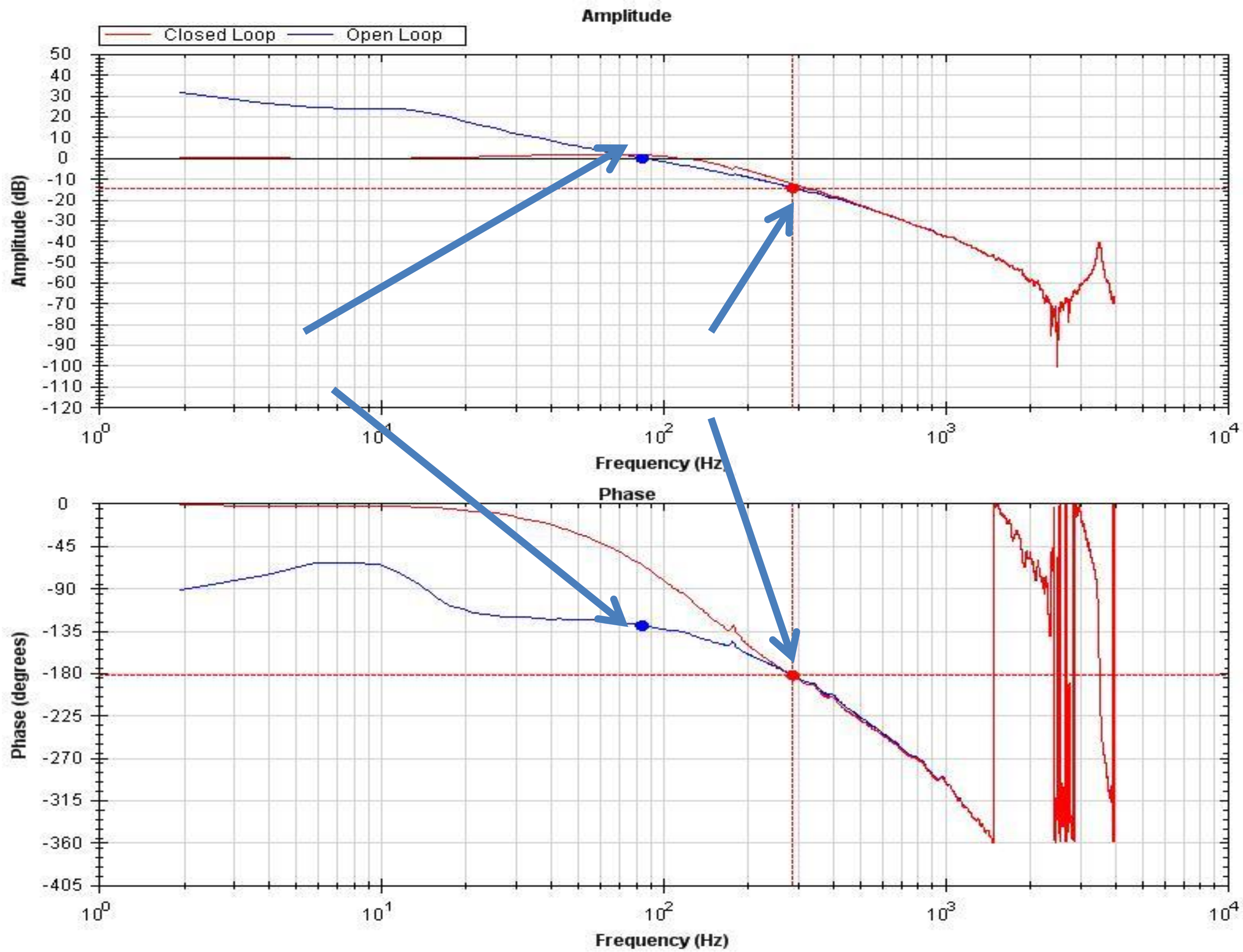
- Using the open loop gain and phase plots from the AKD, determine what the phase is at 0 dB. In most cases, where is starts from –90, if the moving to the right at the highest frequency where the gain is still on 0-dB, record the phase. The distance from –180 degrees is then the phase margin of a system.
- Gain Margin is defined as the distance away from 0-dB when the phase of the open loop is –180 degrees.
- **Why is this important?**

Phase/Gain Margin



Phase / Gain Continued

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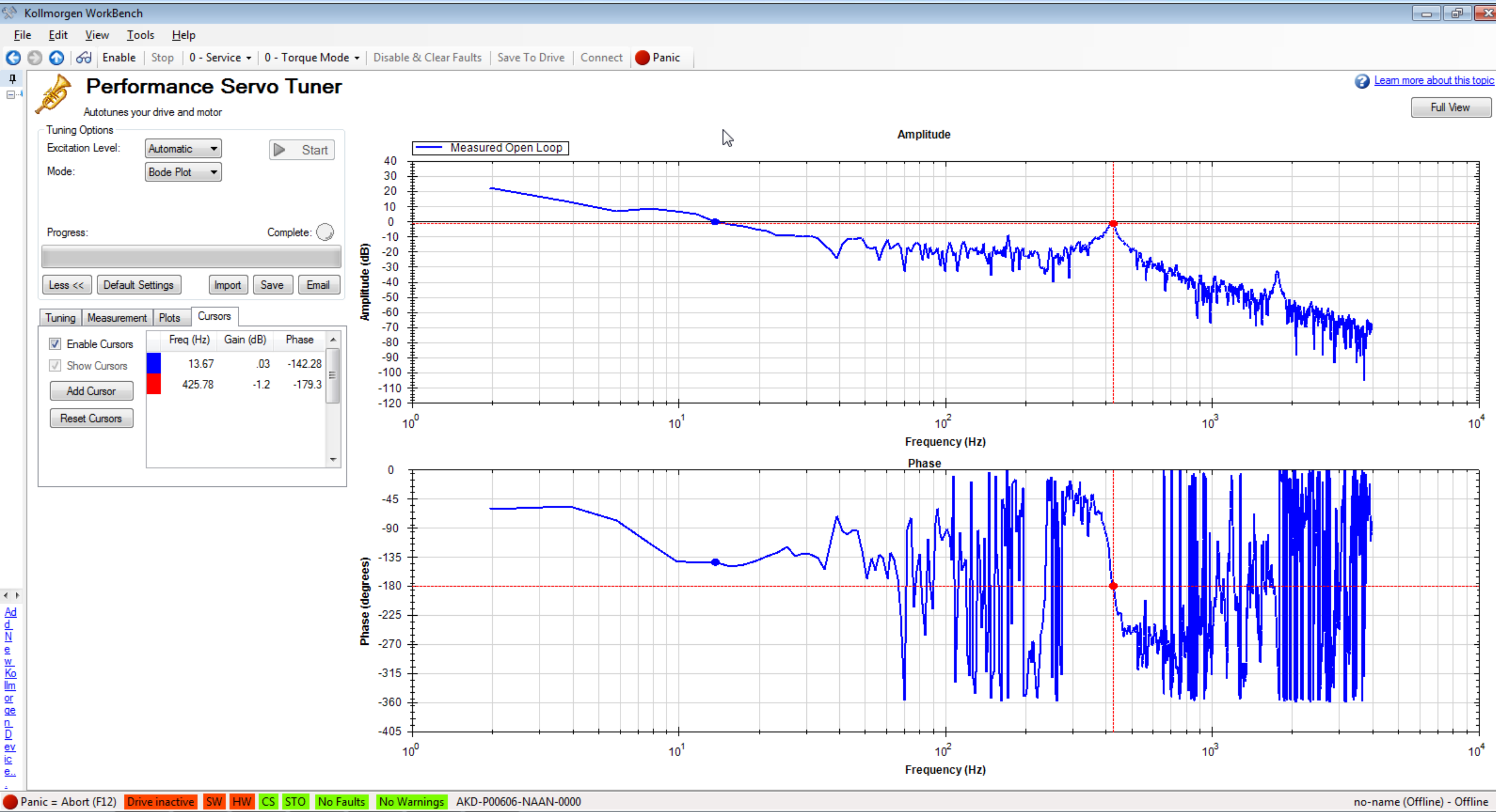

Two Body System

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- A Two Body system will have one frequency of Anti-Resonance F_{AR} and one frequency of Resonance F_R.
- These points are critical in understanding the system.
- Stiffness (K), load inertia, and the parallel combination of the load and motor inertia can be determined with a good plot. These are the critical factors in determining a stable system either visually or with calculations.

Two Body System Mockup

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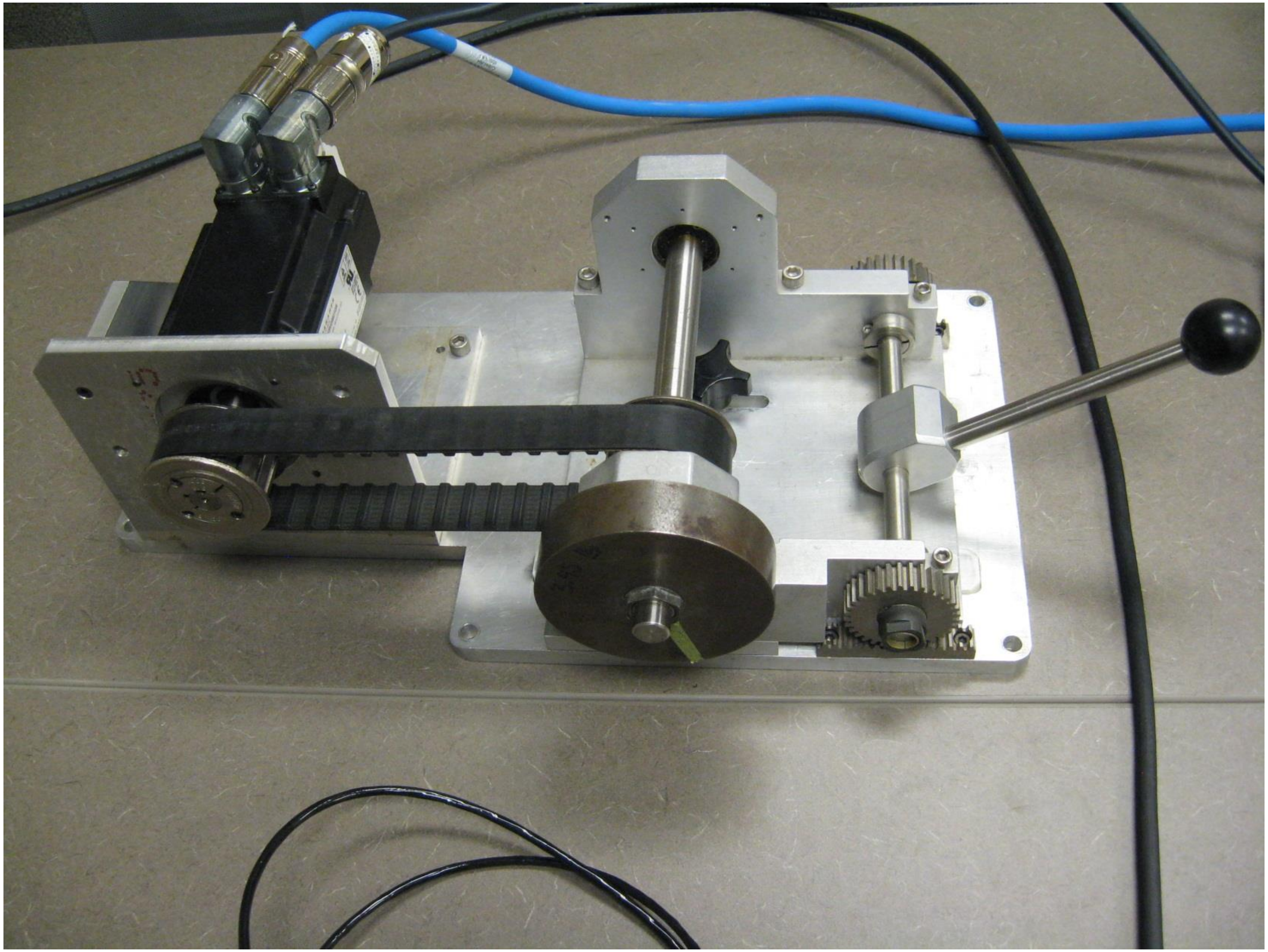
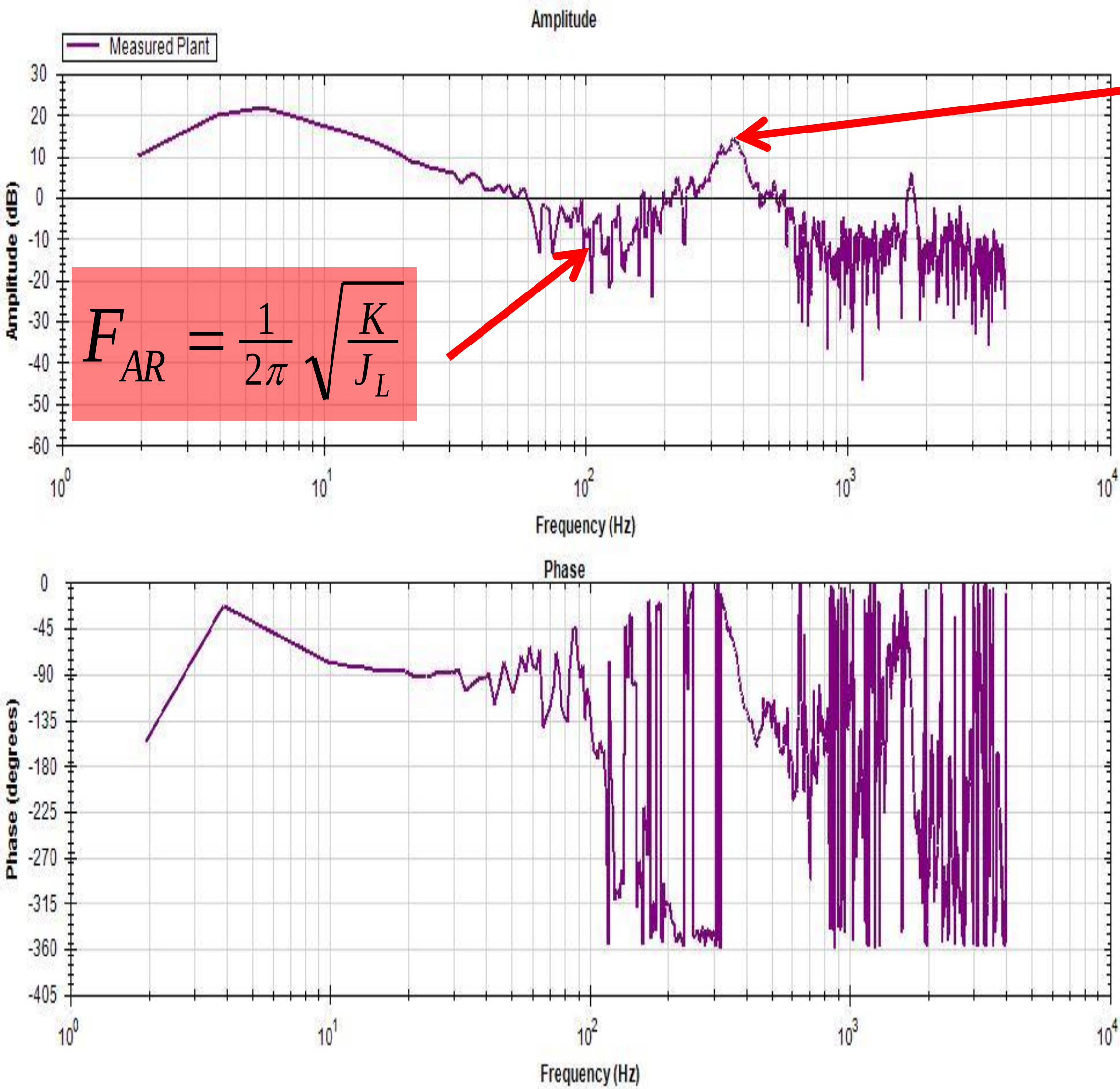


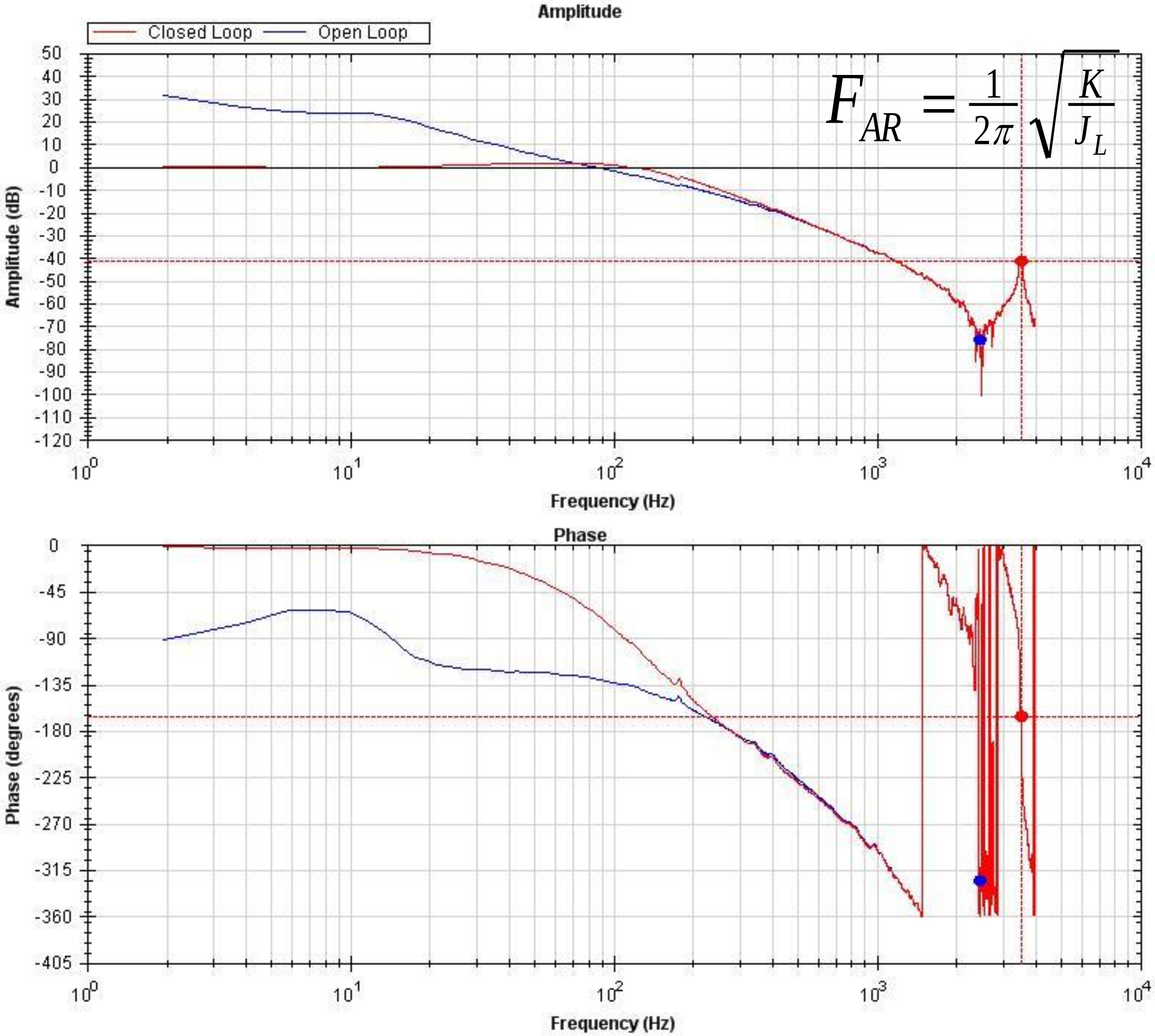
Resonance /Anti-Resonance

$$F_R = \frac{1}{2\pi}\sqrt{\frac{K}{J_L \| J_M}}$$



$$F_{AR} = \frac{1}{2\pi}\sqrt{\frac{K}{J_L}}$$

Resonance /Anti-Resonance



$$F_{AR} = \frac{1}{2\pi}\sqrt{\frac{K}{J_L}}$$

$$F_R = \frac{1}{2\pi}\sqrt{\frac{K}{J_L \| J_M}}$$

Stiffness “K”

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- With the information of the resonance and anti-resonance, you can determine the stiffness of the system.
- This is algebraically determined from the each of the points on the chart and the known motor inertia. Thus, JL and K can be determined from the two equations and two unknowns.

Algebraic Calculations

Resonant Node

$$\omega_r := \left[\left[K_p \cdot \left(\frac{1}{J_m} + \frac{1}{J_{L2}}\right)\right]^{.5}\right]$$

$$\omega_r = 703.012$$

$$f_r := \frac{\omega_r}{2 \cdot \pi}$$

Calculated Frequency $f_r = 111.888$

Anti-Resonant Node

$$\omega_{ar} := \left(K_p \cdot \frac{1}{J_{L2}}\right)^{.5}$$

$$\omega_{ar} = 36.995$$

$$f_{ar} := \frac{\omega_{ar}}{2 \cdot \pi}$$

Calculated Frequency $f_{ar} = 5.888$

Calculating the Forward Loop Gain of the Load $G2(s) := s \cdot \theta_L(s)$

Stability

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- Going Back to the Phase Gain plots, there are a few rules and assumptions that must be made.
- Using Controls Theory, if you have 60 degrees phase margin and 18 dB of gain margin, you are stable. The problem with using this as an absolute is that the system will result in some cases of being too conservative to operate with the customer requirements. Usually, this will be noted in excessive damping for the customer settle requirements.
- The stability rules can be compromised by systems with consistent mechanics. Can you think of any?

Evaluating a System

- Measure the current and acceleration of a move to be used in the calculation of load inertia ($\tau = j\alpha$)
- Measure a constant velocity move to determine the approximate static friction. Keep the velocity below an area where viscous friction may hinder your measurement.
- Using the formula of the resonant and anti-resonant frequencies, determine the stiffness K.

Do the Math Upfront

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Constant Values

	CH063B
Motor Torque Contant (N*m/Amp)	$K_t := 3$
Motor Armature Resistance (Ohms)	$Rt := 0.47$
Motor Armature Inductance (Henries)	$L_a := 7.1 \cdot 10^{-3}$
Rotor Inertia (Kg*m²)	$J_m := 0.0157$
Load Inertia (Kg*m²)	$J_L := 6.119$
Stiffness Factor (N*m/rad	$K_p := 189197$
Current Gain(amps/volt)	$I := 48$
Total Inertia(Kg*cm²)	$J_t := J_L + J_m$
Equivalent Parallel Inertia	$J_E := \frac{J_m \cdot J_L}{J_m + J_L}$

Do the Math Upfront - continued

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Transfer Function

Motor Position Transfer Function

$$\theta_m(s) := \frac{K_t \cdot I \cdot \left(s^2 \cdot J_L + K_p\right)}{s^2 \cdot J_t \cdot \left(s^2 \cdot J_E + K_p\right)}$$

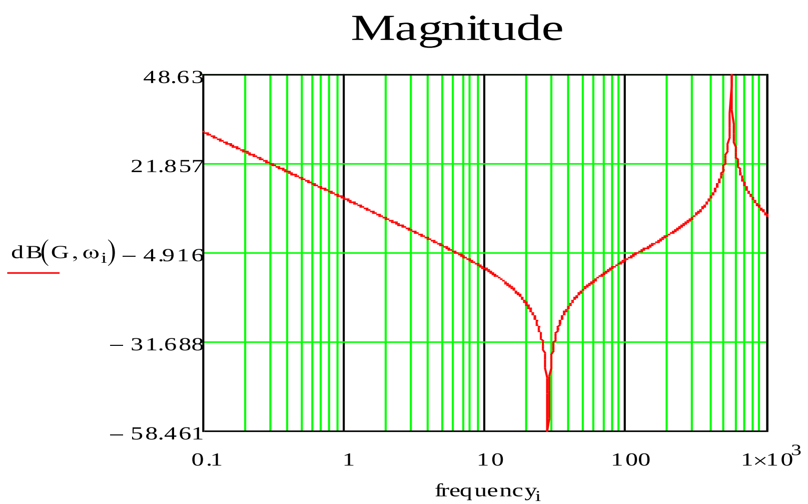
Load Position Transfer Function

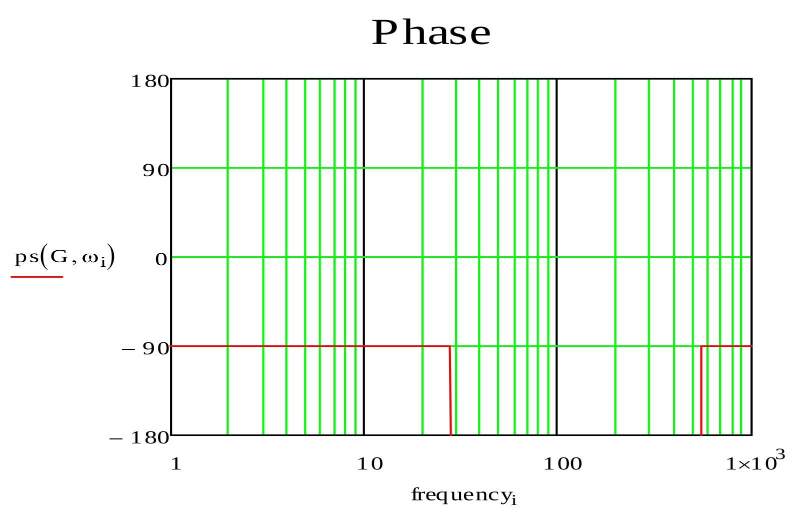
$$\theta_L(s) := \frac{K_t \cdot I}{s^2 \cdot J_t} \cdot \frac{K_p}{s^2 \cdot J_E + K_p}$$

Calculating the Motor Velocity Transfer Function

$$G(s) := s \cdot \theta_m(s)$$

Doing the Math - Results





Ensuring a Good Plot

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- The Phase Relationship is a very good indicator of the quality of the data in a bode plot. Friction and backlash are usually hard terms to deal with when attempting to evaluate a system. Knowing some basic rules should help.
  - The phase of a torque system plant or open loop should start at –90 degrees for the one integrator of the motor.
  - If the source is input in the velocity and you look at the torque output, then you will start at –180 degrees.
  - Should you find that the starting point of the phase does not make sense, you may have a bad plot due to insufficient excitation, backlash or frictional component issues.

Closed Loop Plot of Large System

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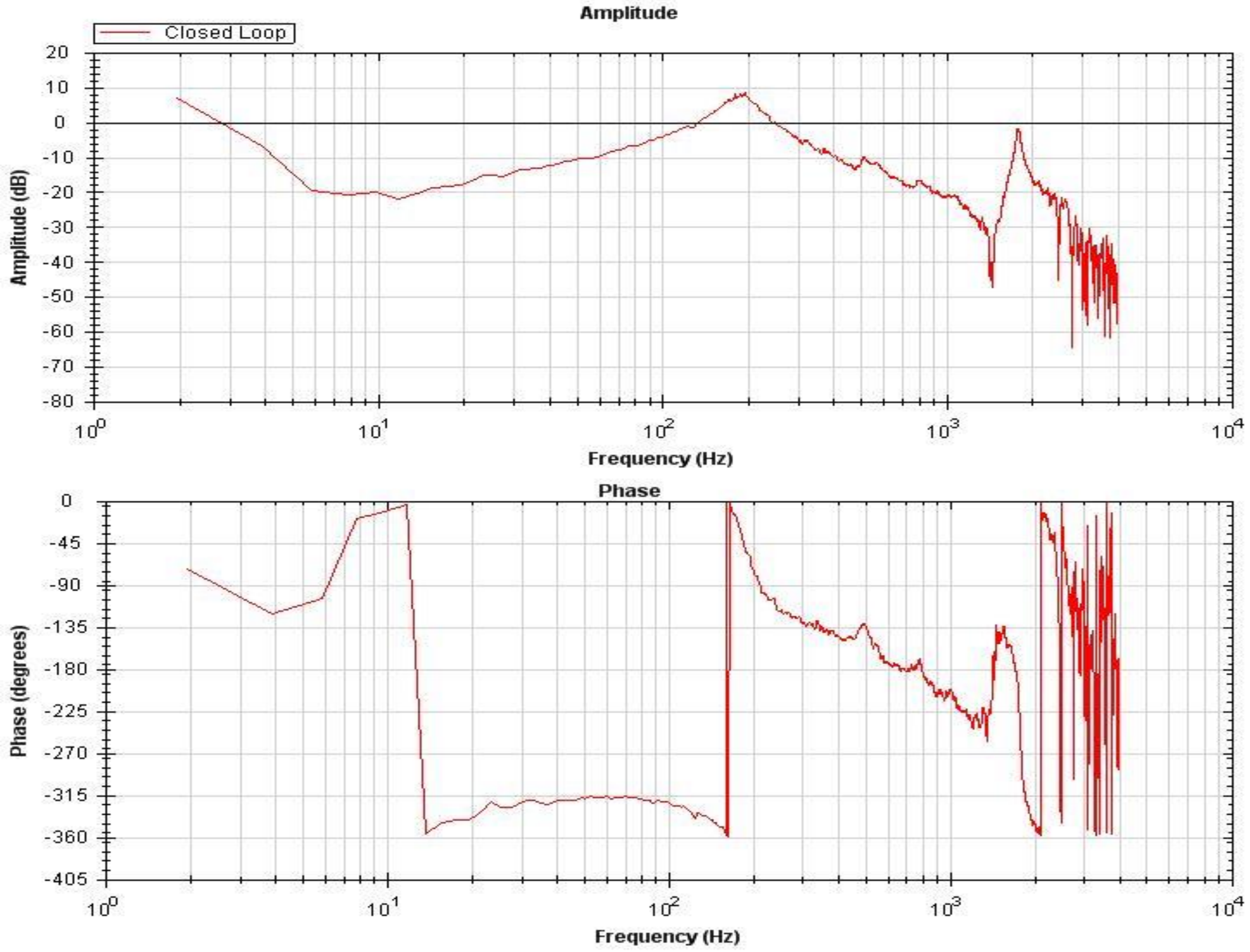
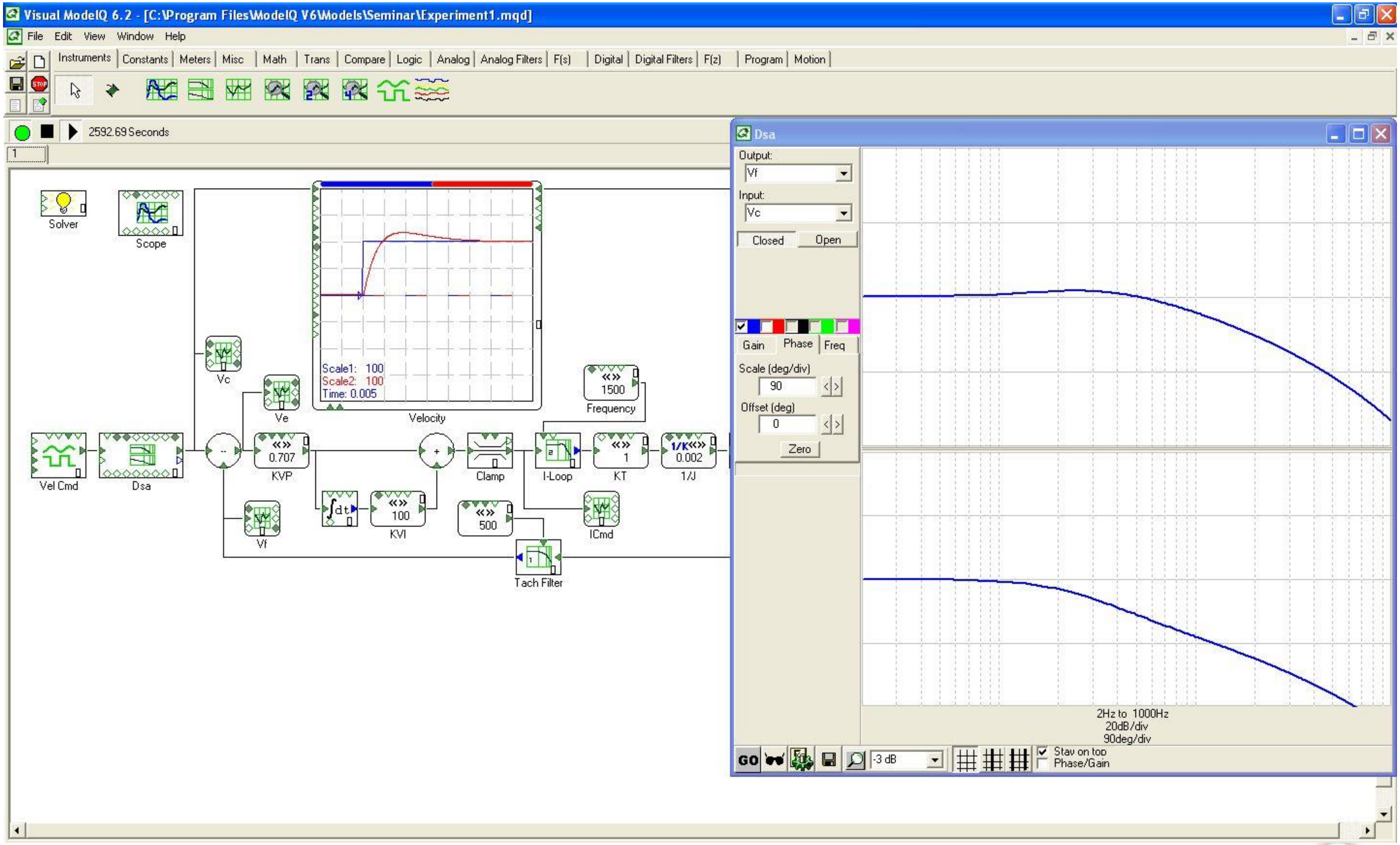


How Bandwidth Affects Tuning



Same Model With Increased Gain

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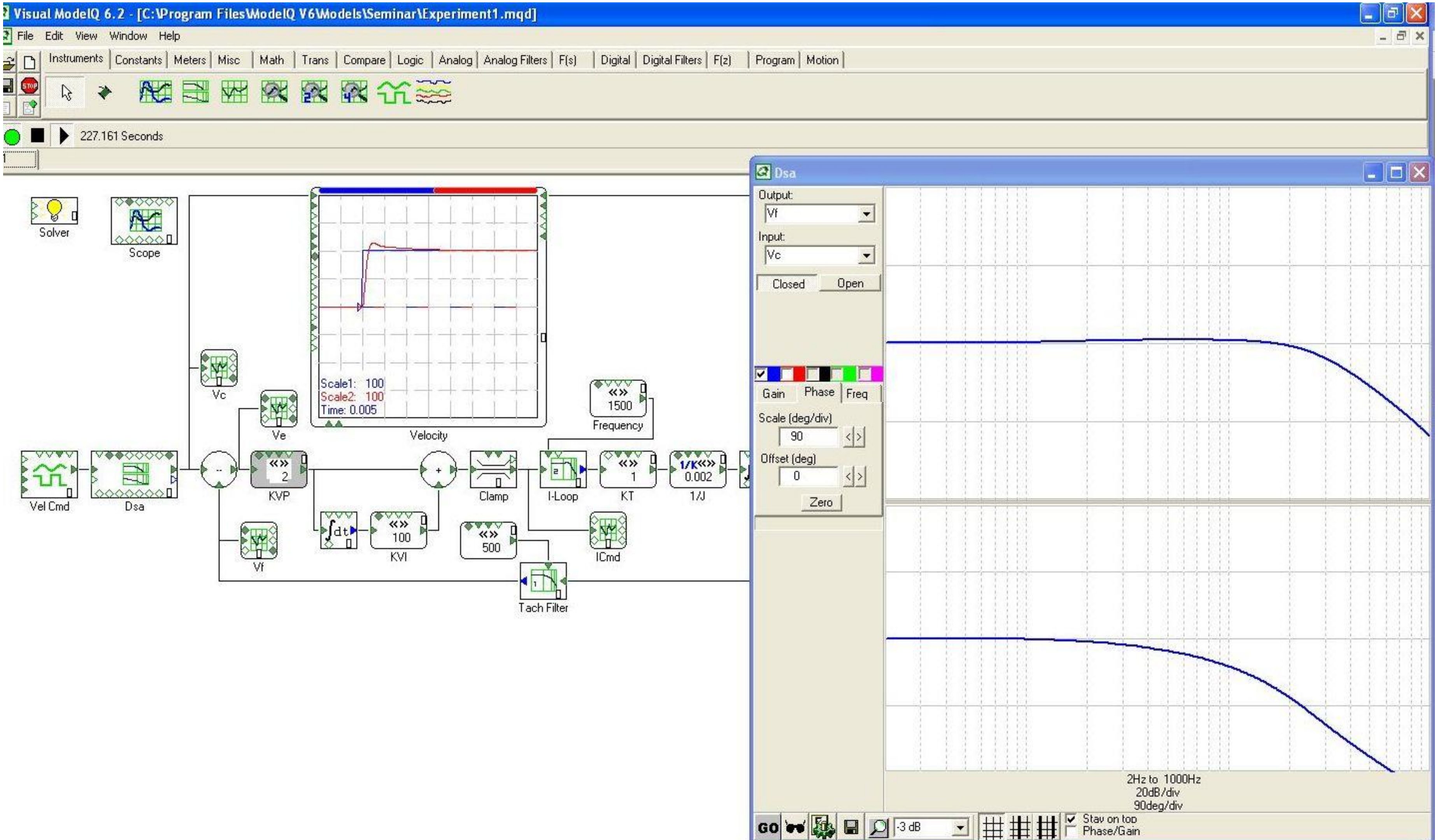
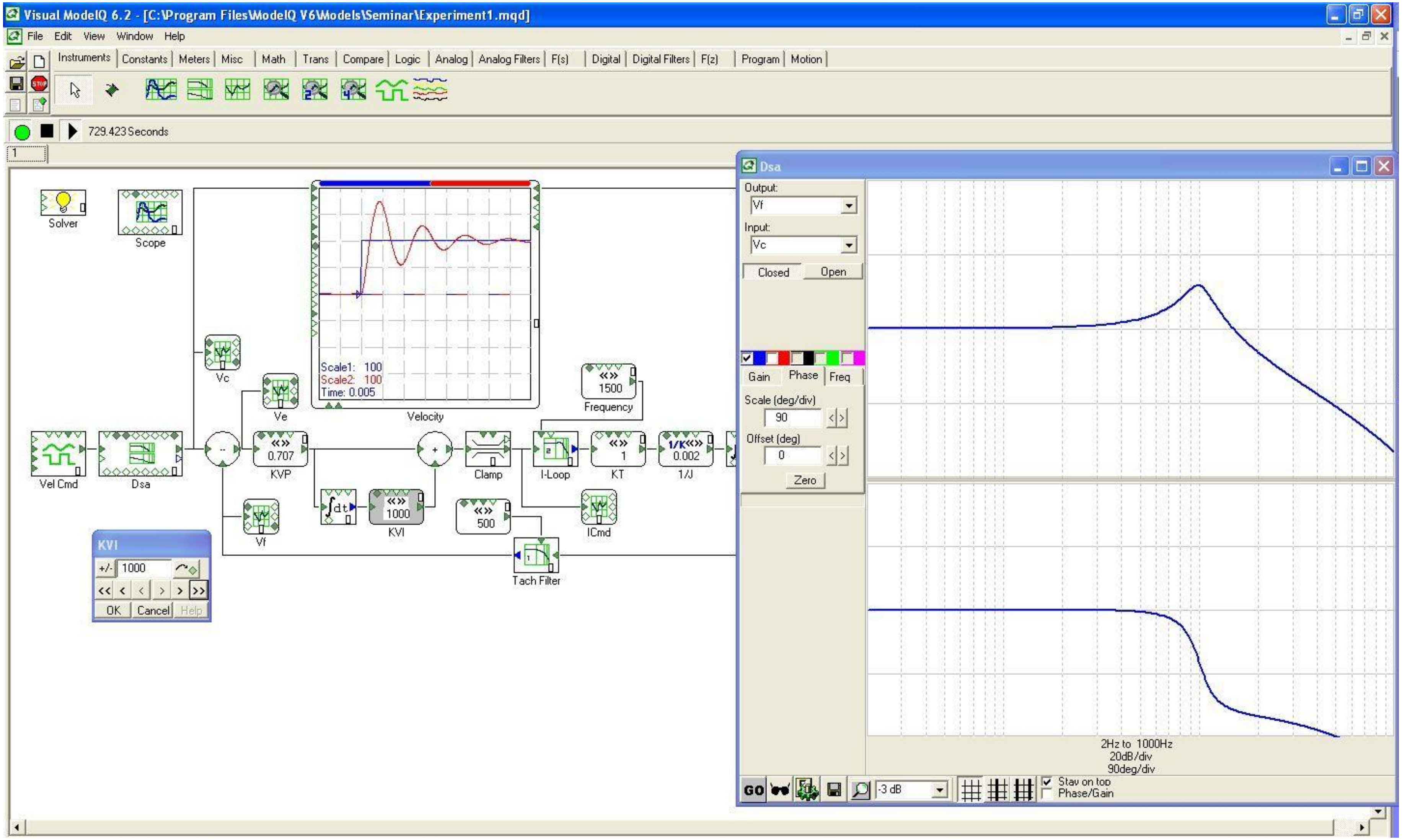


Excessive Gain In Model



Excessive Gain in Mockup

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