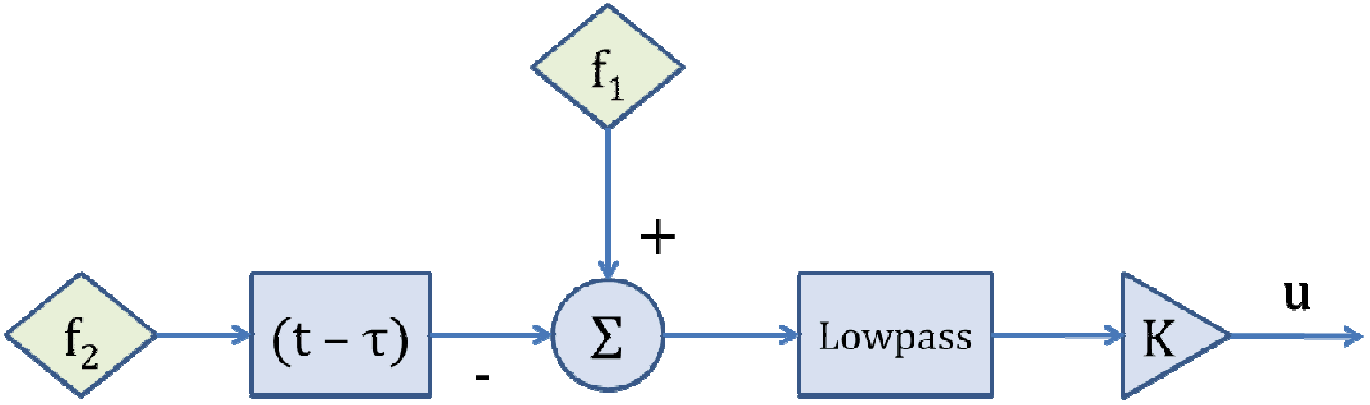
SAND2013-2223P

PSLF Simulations

- Closed-loop PDCI control
  - Feedback: Celilo, Sylmar frequency
  - Gain sensitivity analysis
  - Time delay sensitivity analysis
  - Monitored reactive power
- Open-loop PDCI transfer functions
  - Logarithmic chirp signal
  - Compared PSLF to PDCI probe test results
  - Evaluated: Celilo-Sylmar, BE50-Malin,BE50, CJ-PV

Time Domain Simulation Approach

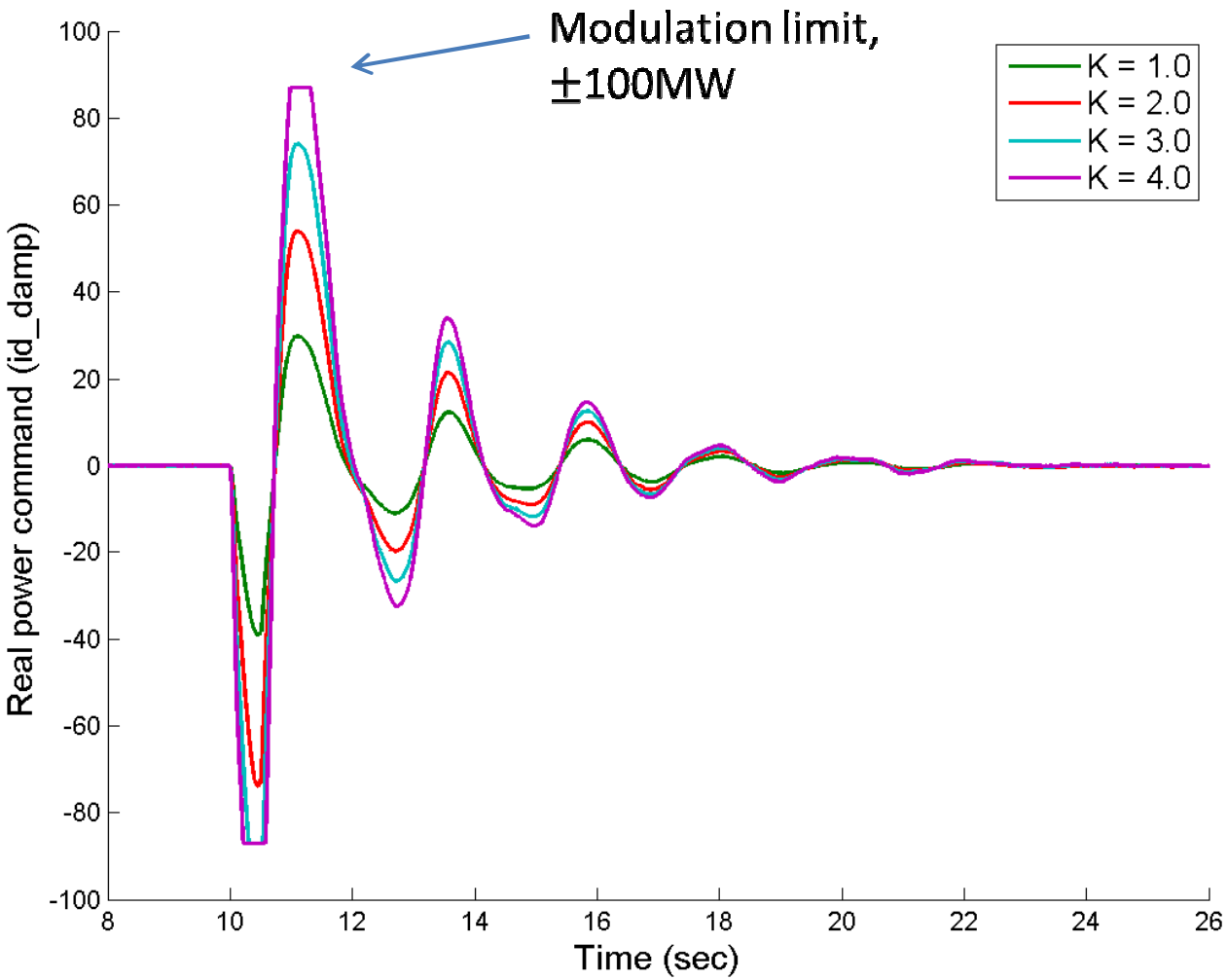


- Simulation test bed
  - 2022 Light Spring WECC base case
  - Chief Joseph brake insertion lasting 0.5 seconds
  - PSLF frequency measurements (time derivative of voltage angle)
  - Frequency difference measured between Celilo and Sylmar
  - Feedback signal passed through a 1st order low pass filter with a 2 Hz corner frequency (actual filter would be more sophisticated)

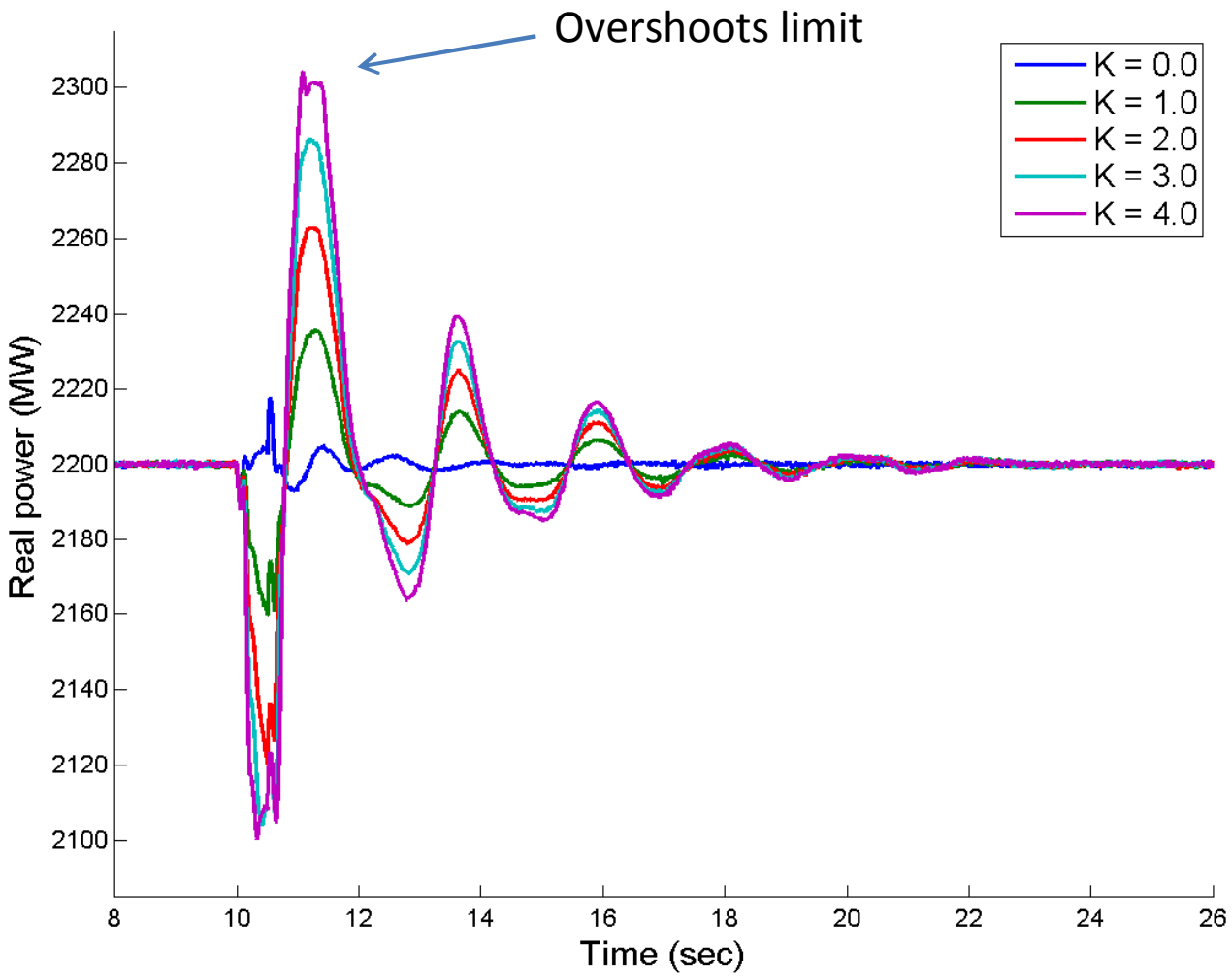
Performance Sensitivities

- Sweep control gain holding transport delay fixed
  - Transport delay of 70 ms from remote measurement
  - Vary control gain between 0 – 4 MW/mHz
  - Low pass filter with a 2 Hz corner frequency
- Sweep transport delay holding control gain fixed
  - Control gain of 2 MW/mHz held constant
  - Vary transport delay between 0 – 400 ms
  - Low pass filter with a 2 Hz corner frequency
- Transport delay, control gain, and command signal filtering all have an impact on performance

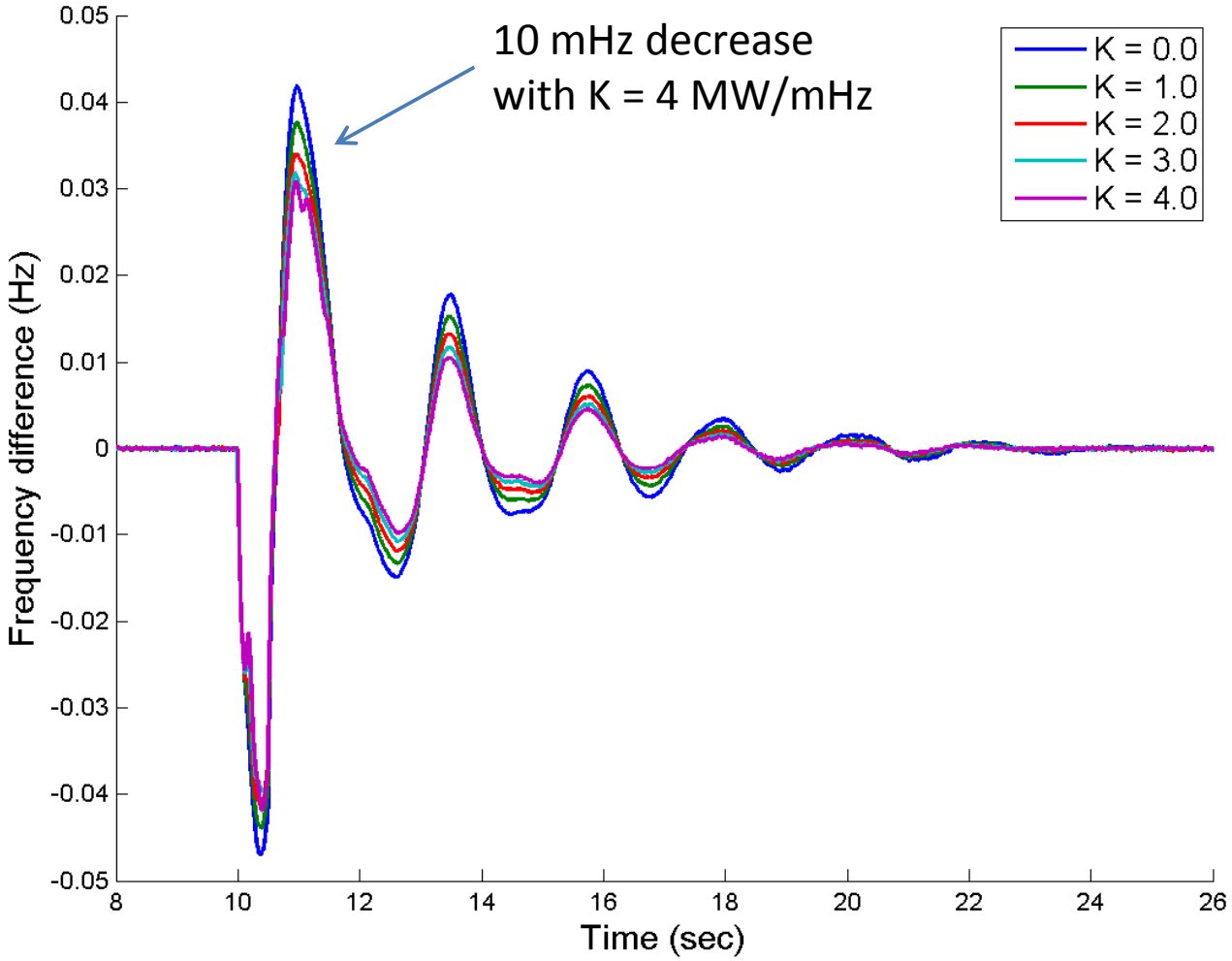
PDCI Real Power Command



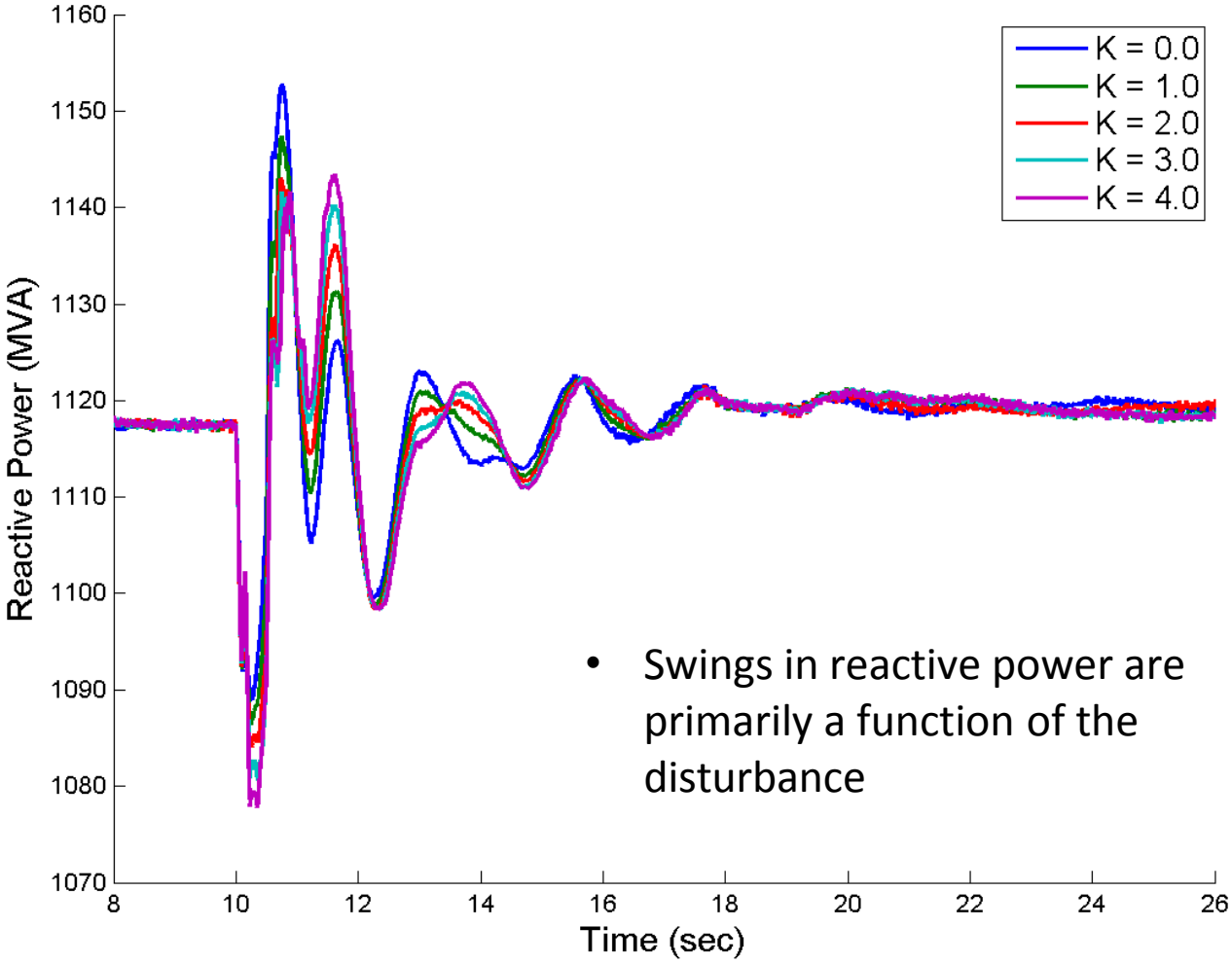
PDCI Real Power (ac)



Celilo – Sylmar Frequency Difference

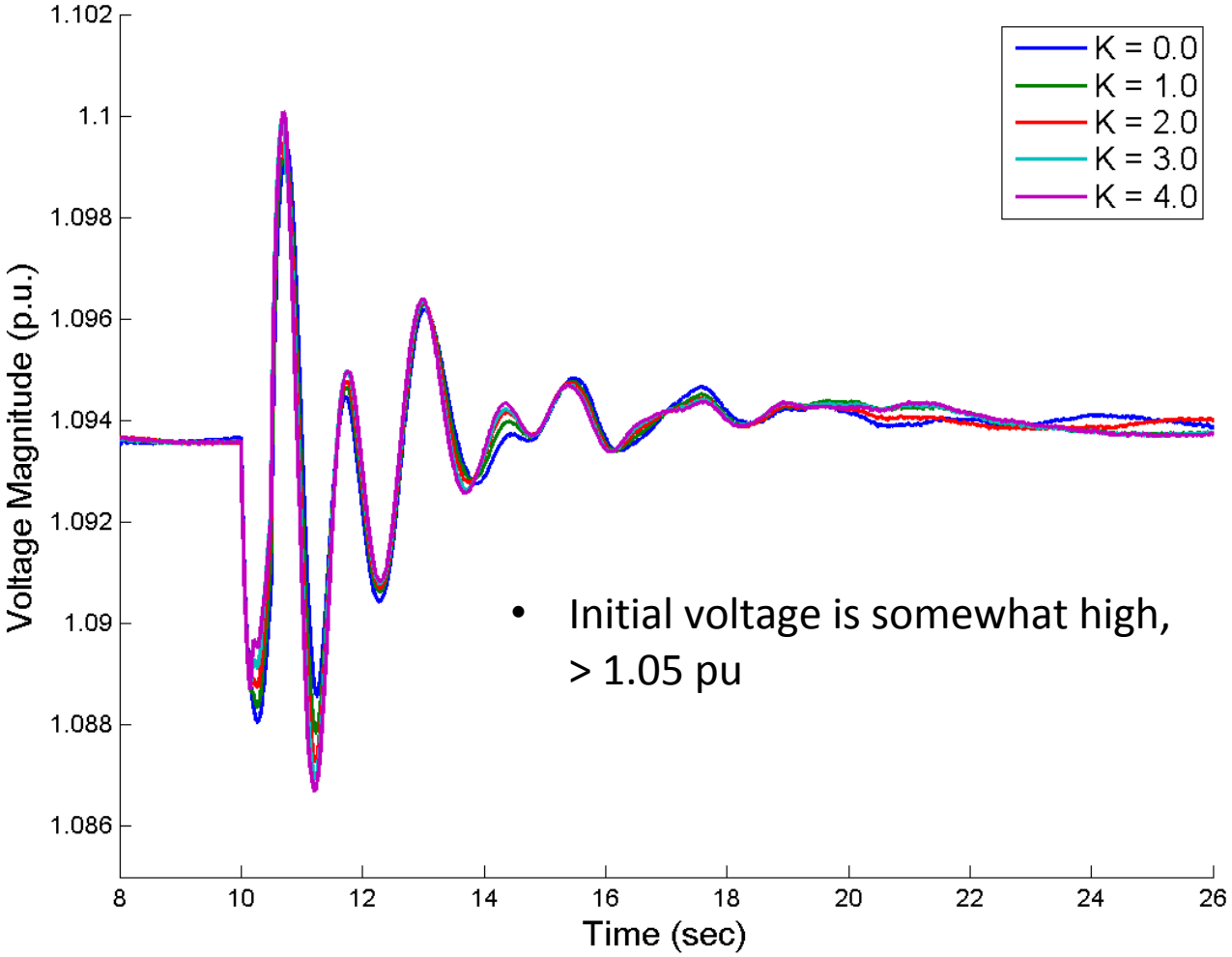


Reactive Power at Celilo



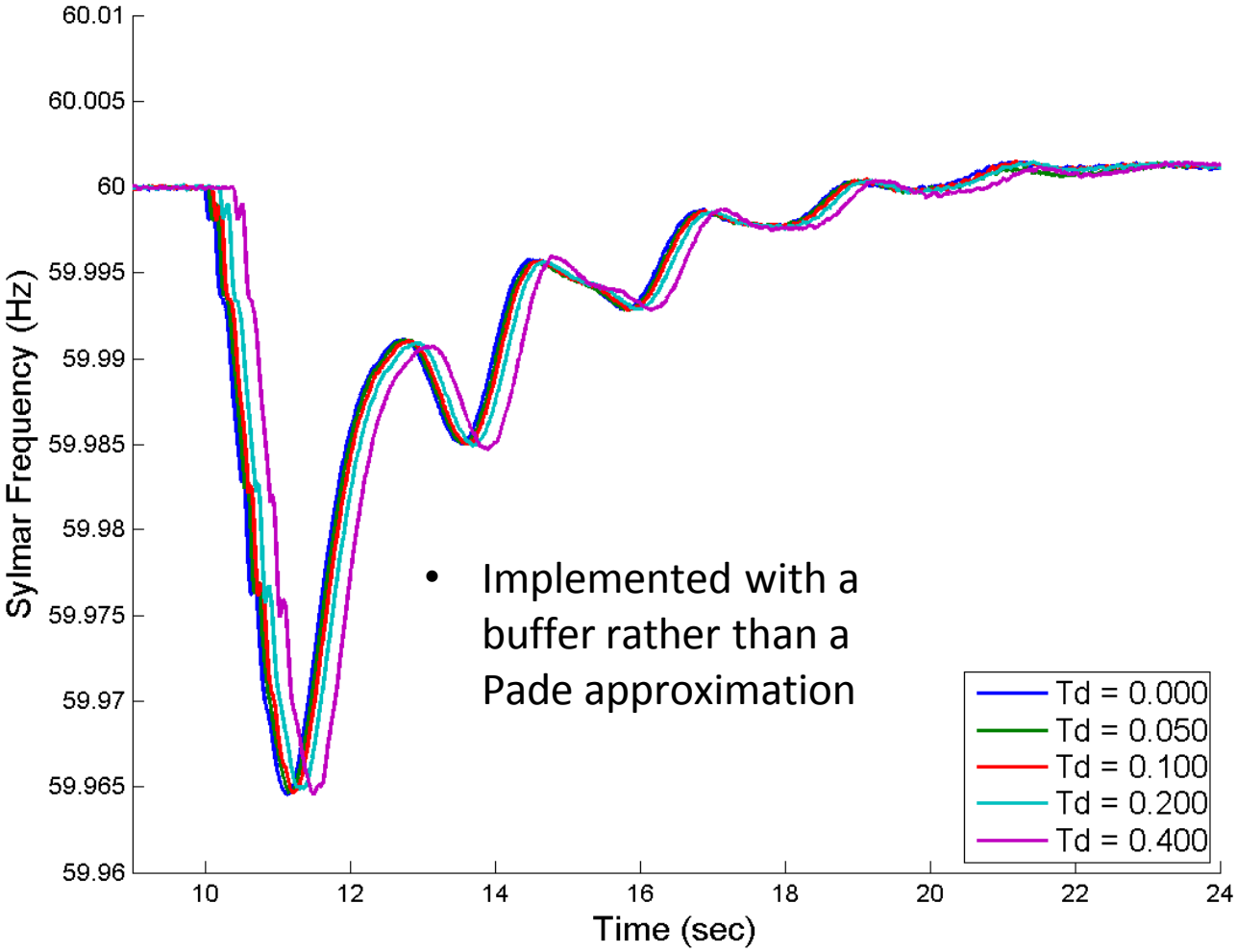
- Swings in reactive power are primarily a function of the disturbance

Voltage at Celilo



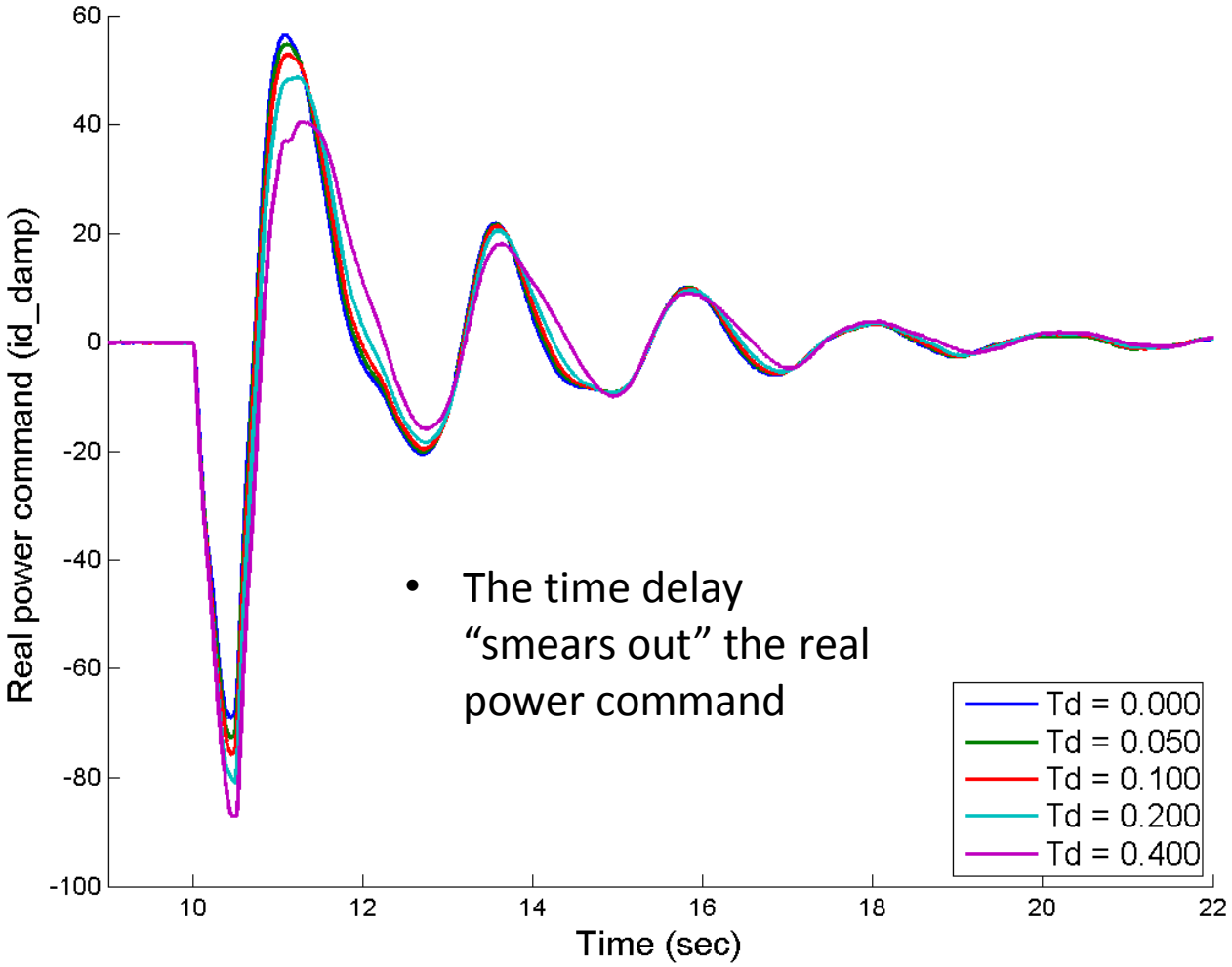
- Initial voltage is somewhat high, > 1.05 pu

Time Delay Sweep



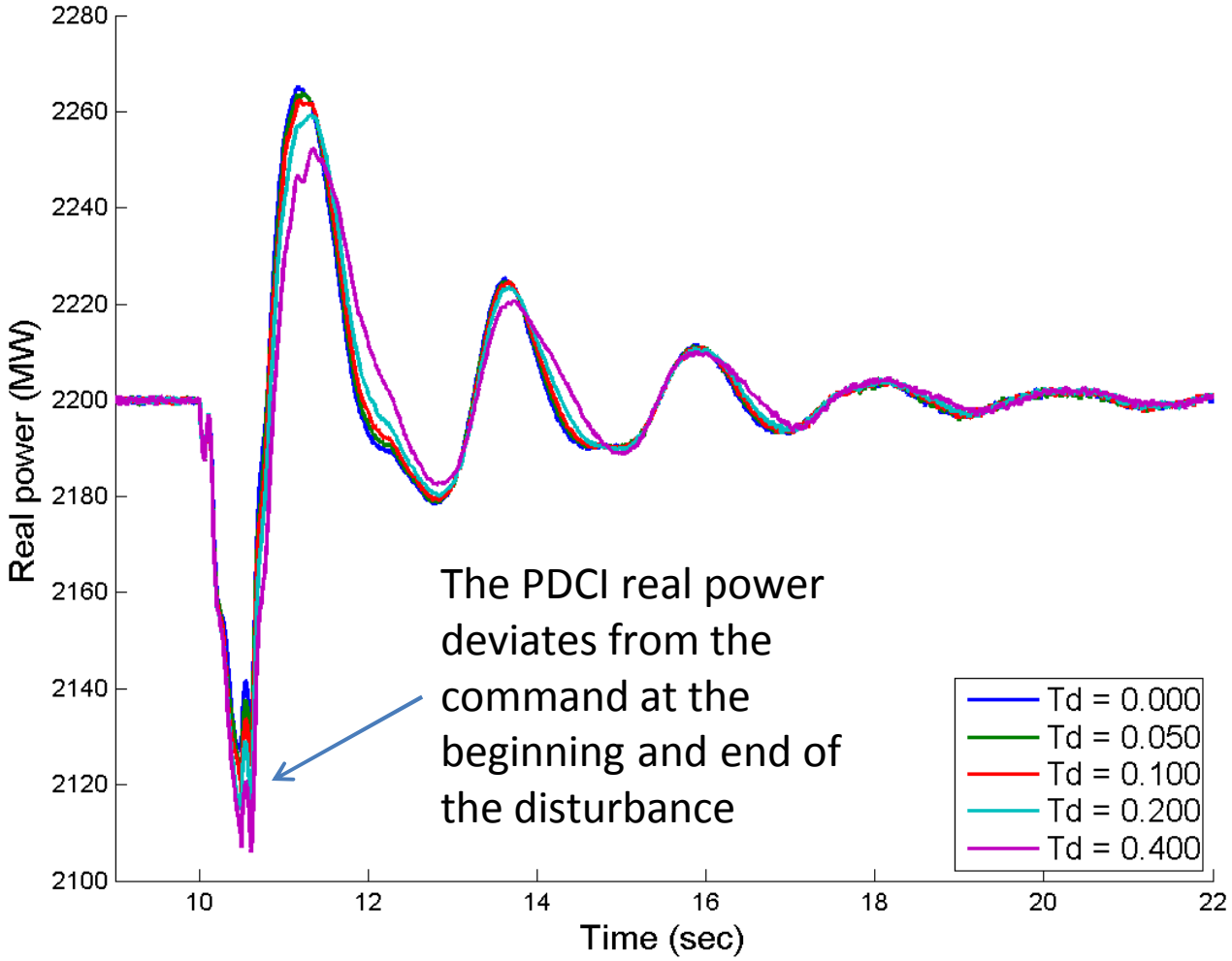
- Implemented with a buffer rather than a Pade approximation

PDCI Real Power Command

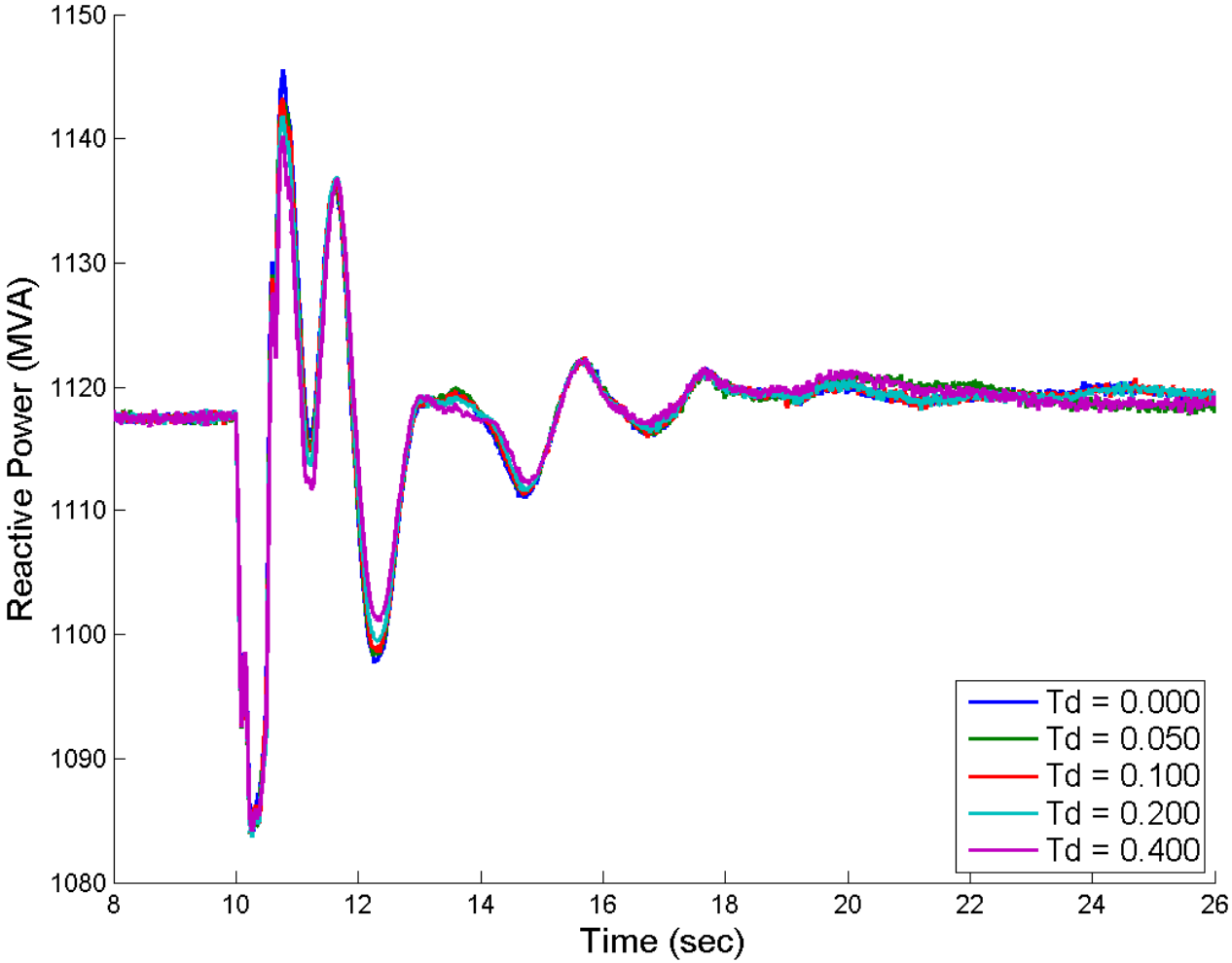


- The time delay "smears out" the real power command

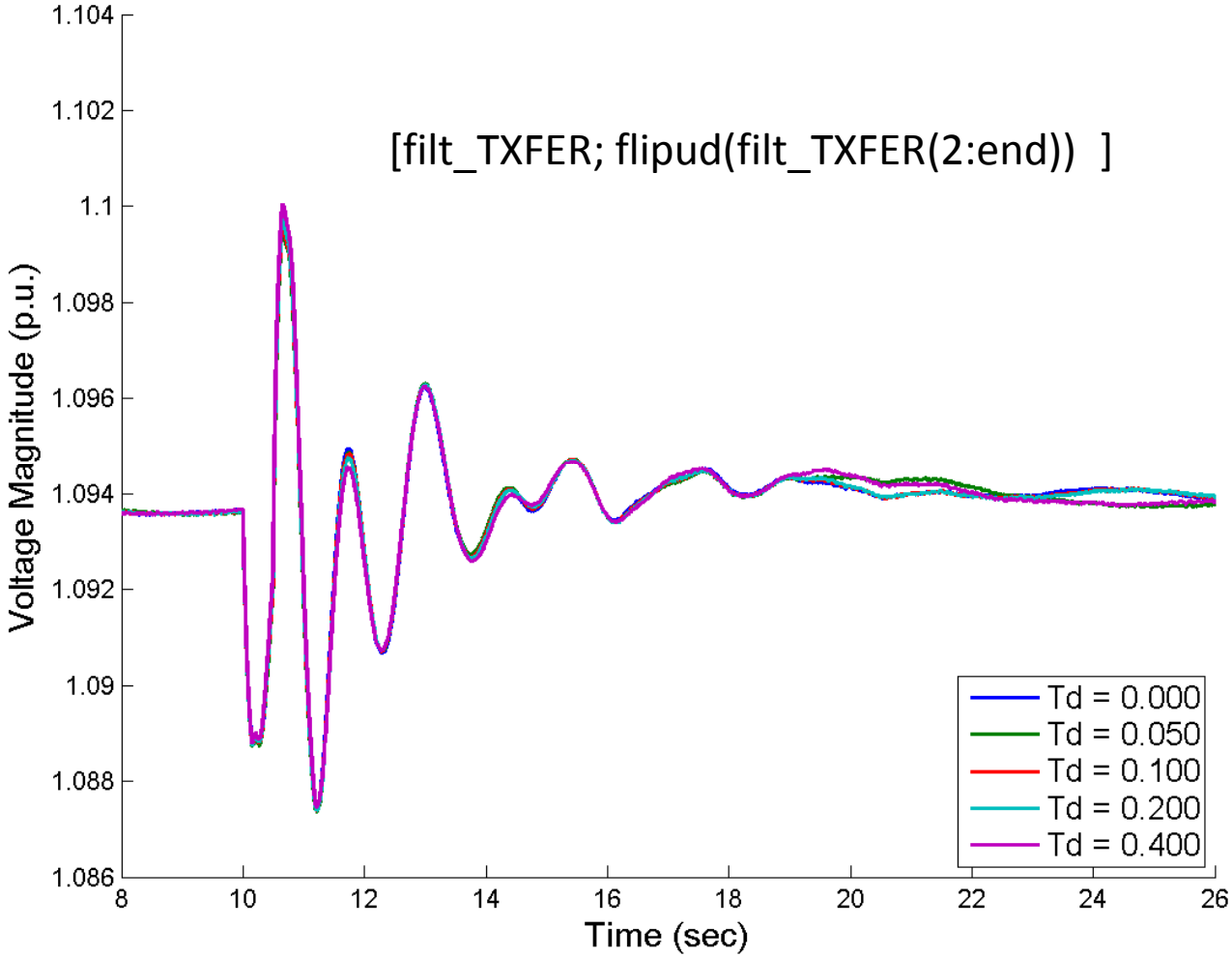
PDCI Real Power (ac)



Reactive Power at Celilo



Voltage at Celilo



PDCI Chirp

- Developed three PSLF simulation options:
  - Linear chirp

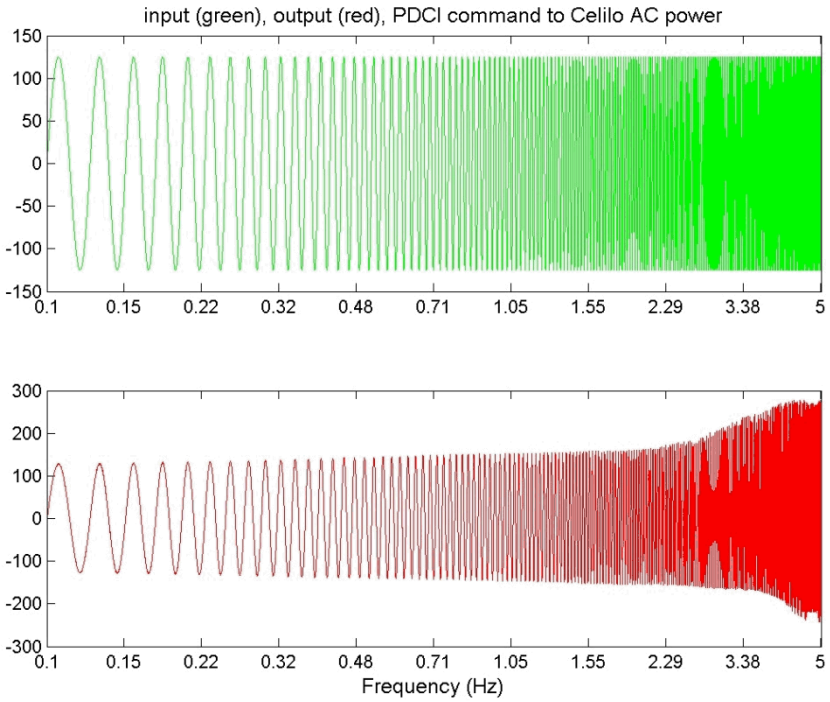
    $$f(t) = f_0 + kt$$

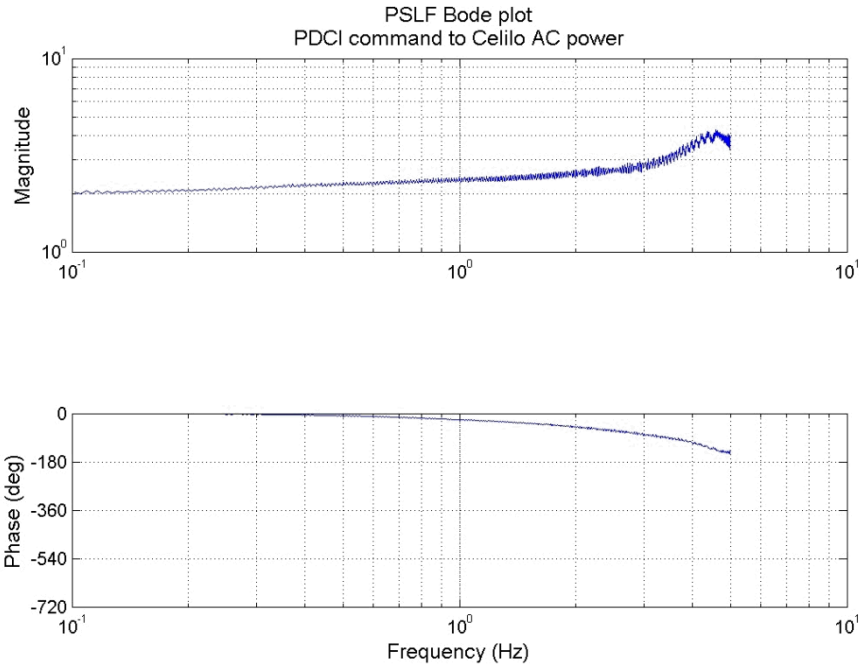
  - Log chirp

    $$f(t) = f_0 + k^t$$

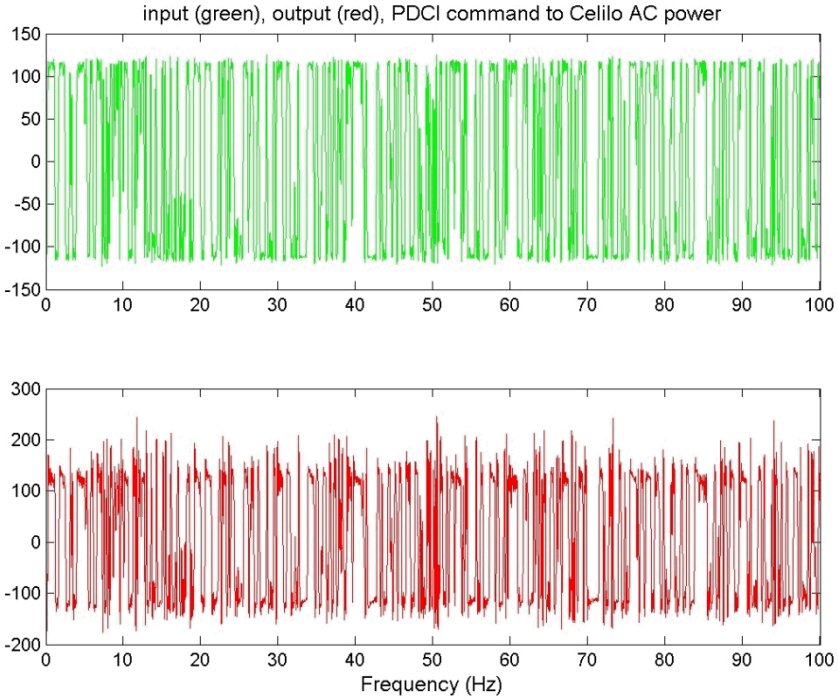
  - PDCI actual (from file)

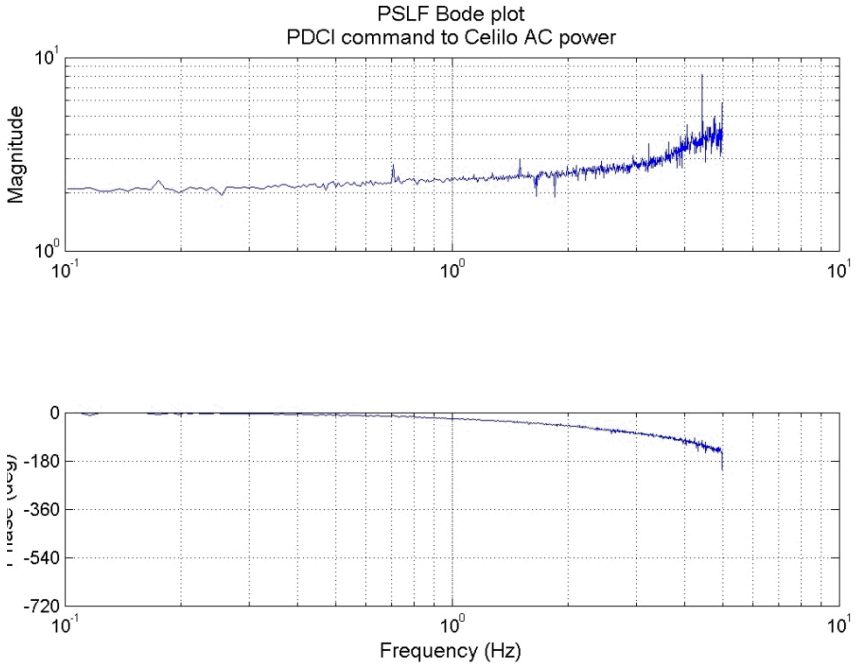
Log Chirp


input (green), output (red), PDCI command to Celilo AC power
150
100
50
0
-50
-100
-150
0.1
0.15
0.22
0.32
0.48
0.71
1.05
1.55
2.29
3.38
5
300
200
100
0
-100
-200
-300
Frequency (Hz)


PSLF Bode plot
PDCI command to Celilo AC power
Magnitude
Phase (deg)
0
-180
-360
-540
-720
Frequency (Hz)

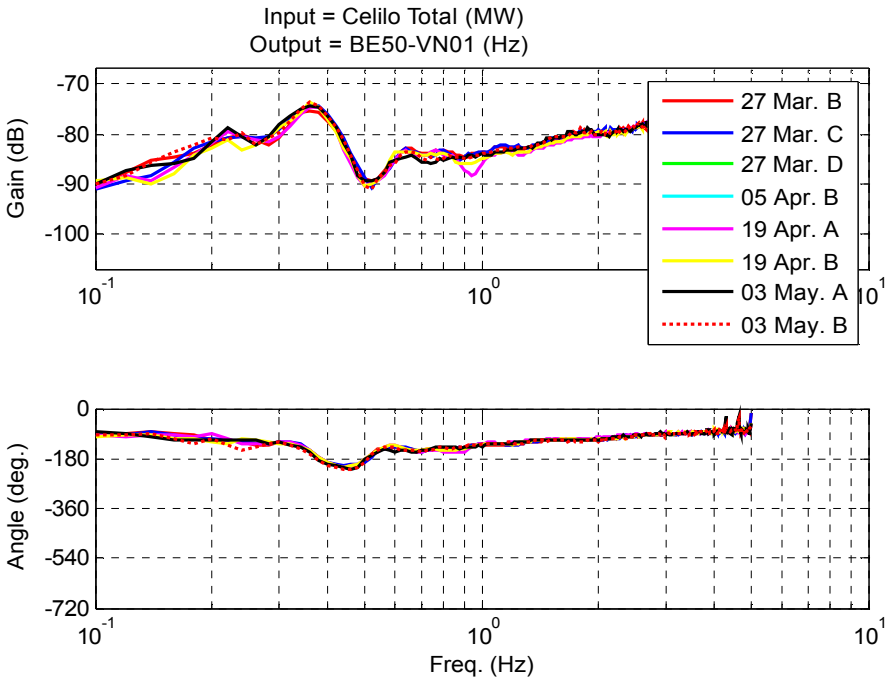
Actual PDCI Chirp

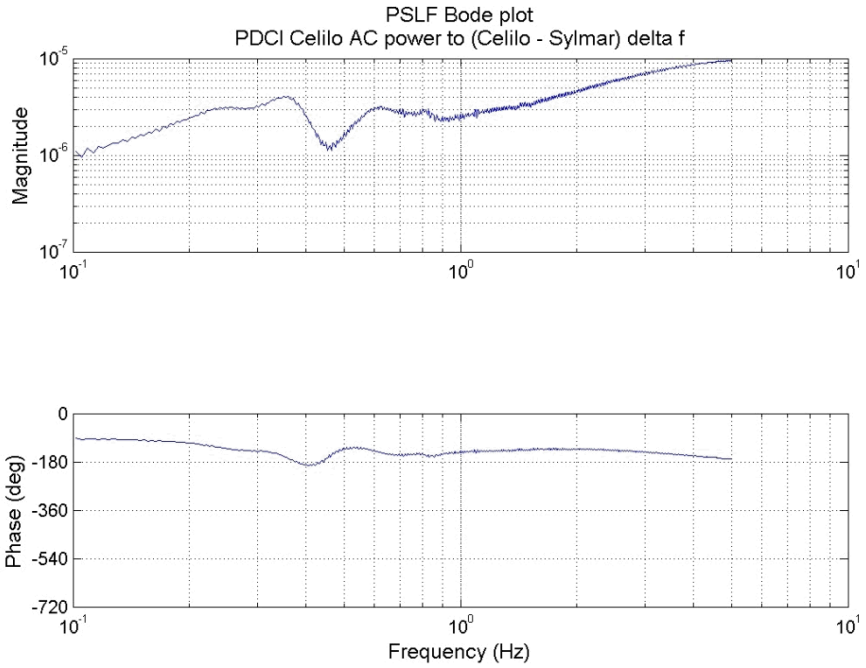




Celilo-Sylmar Feedback

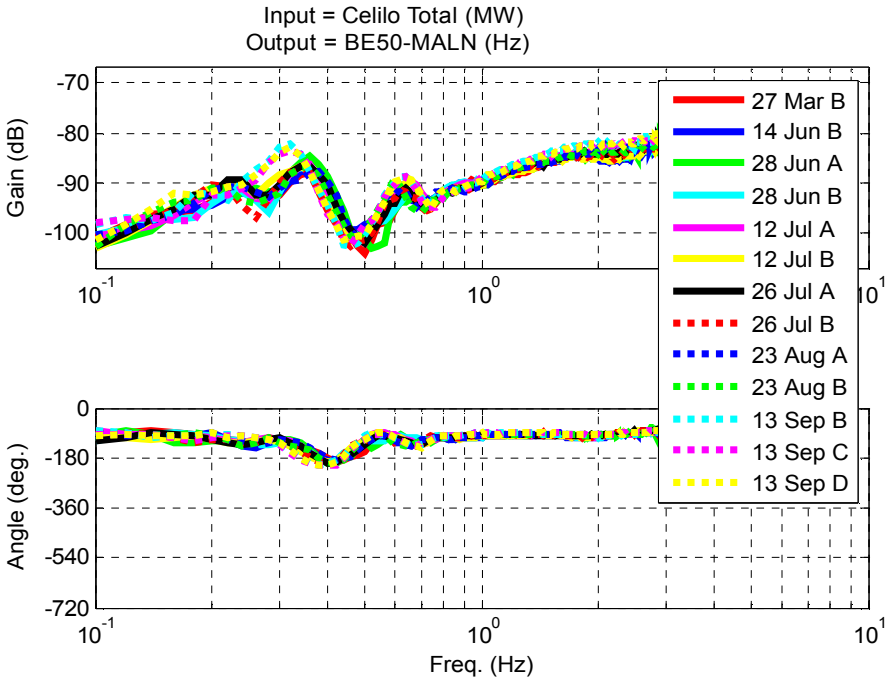
PSLF (2015HS) vs. Actual Bode Plots

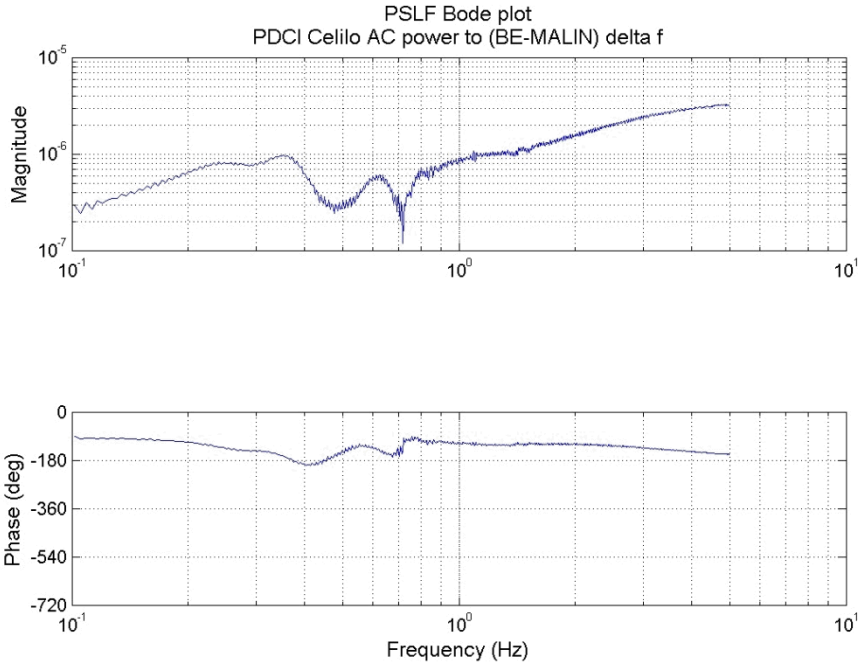




BE50-MALN Feedback

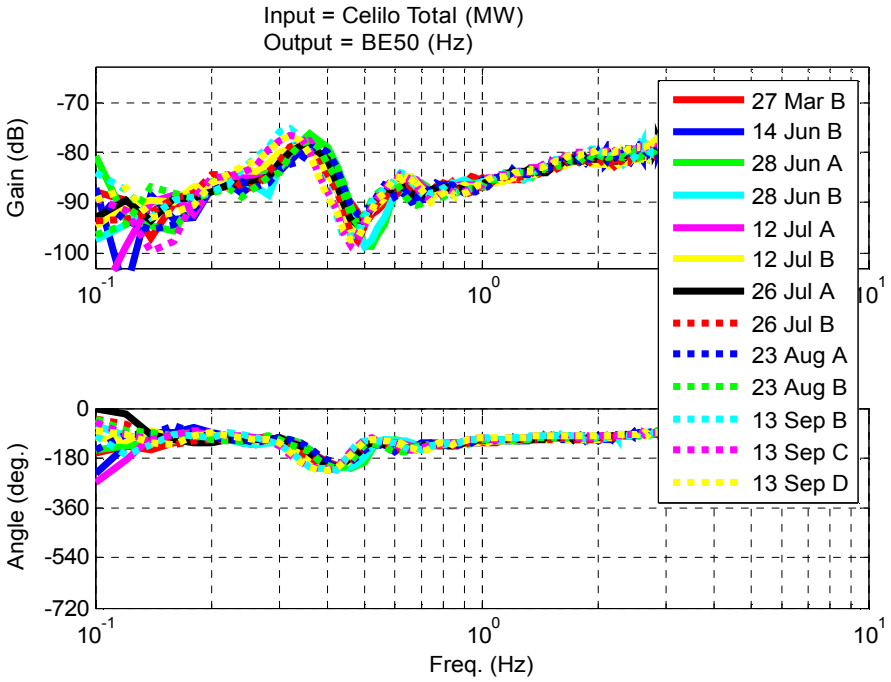
PSLF (2015HS) vs. Actual Bode Plots

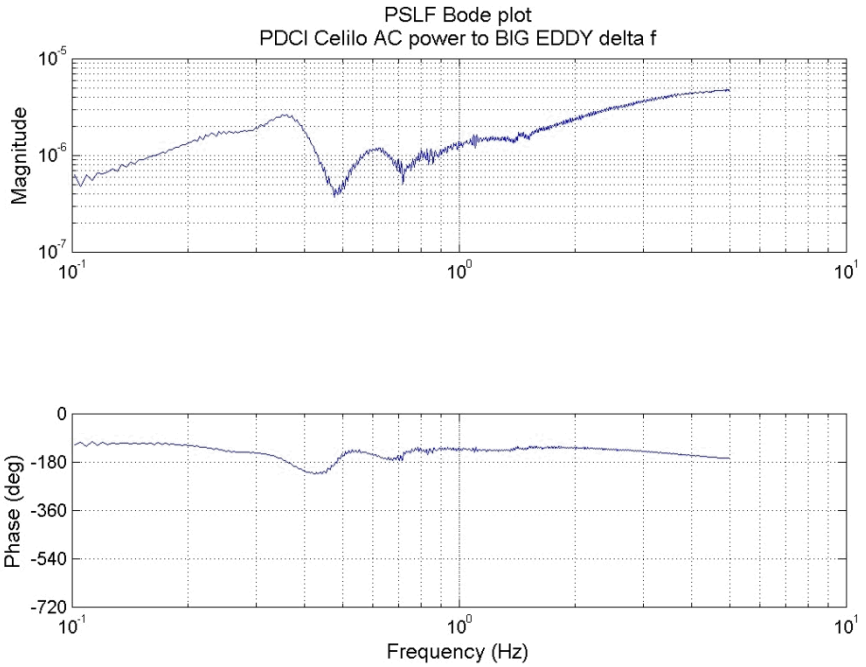




BE50 Feedback

PSLF (2015HS) vs. Actual Bode Plots





CHJ5-PV50 Feedback

PSLF (2015HS) vs. Actual