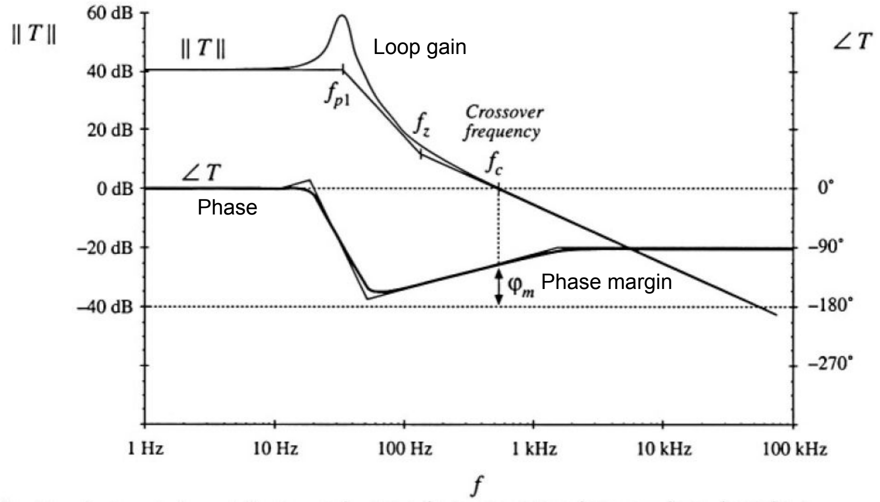
C200/C220 Compensator Design: Voltage Mode Control

Sep 2nd 2022

Bode Plot Basics

- Why compensator?
  - In a Voltage regulator, the output filter (Lout, Cout) and the PWM modulator create the converter forward plant
  - Bode plots (loop gain and phase) are employed to analyze the frequency response of this linear system
  - In the loop, a Compensator is inserted to ensure stability and dynamic performance

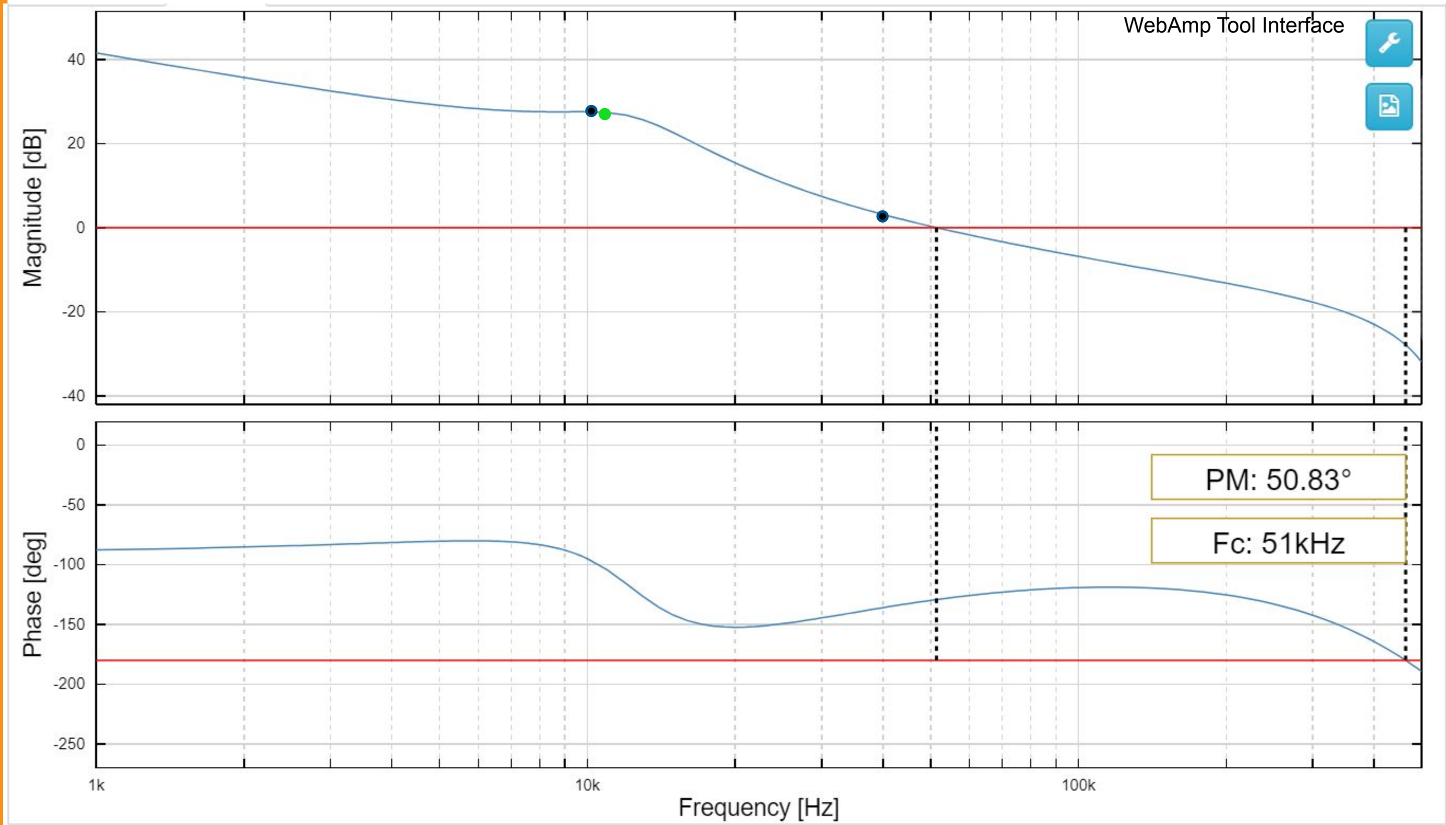


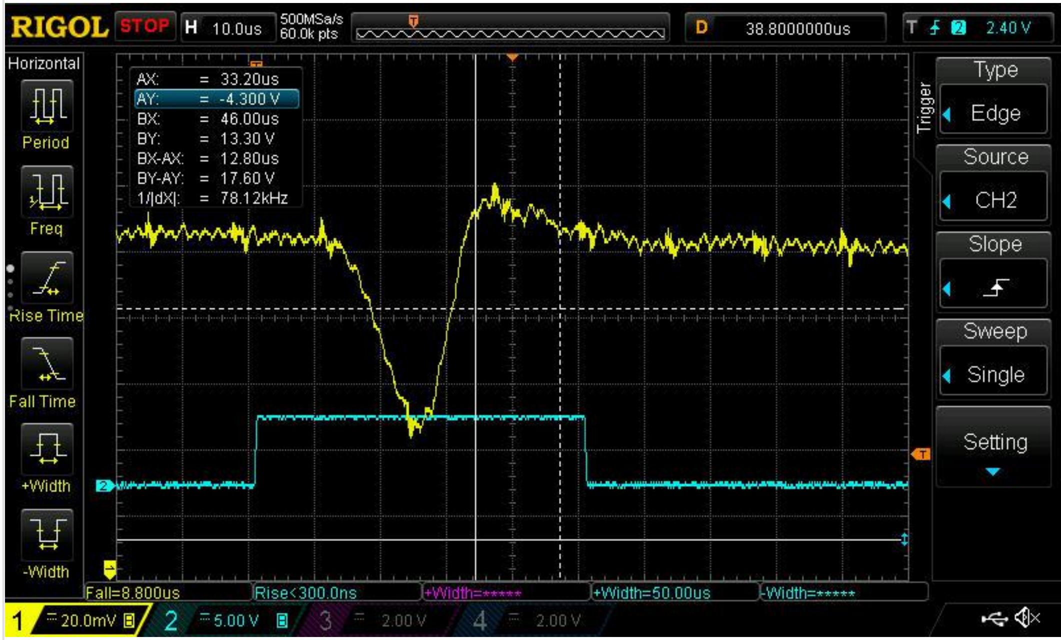
Compensator Design Example

- Power component: C200/C220
- Vin = 12 V
- Vout = 1.3 V
- f_SW = 571 kHz
- Lout, L= 1.1 uH
- DCR = 3.15 mΩ
- Cout, C = 4x47 uF
- Resonant frequency f_LC=1/(2∗π∗√LC) = 11 kHz
- Load: 0 – 5 A
- Voltage mode compensator parameters: f_{Z1}, f_{Z2}, DC Gain

Compensator Design 1

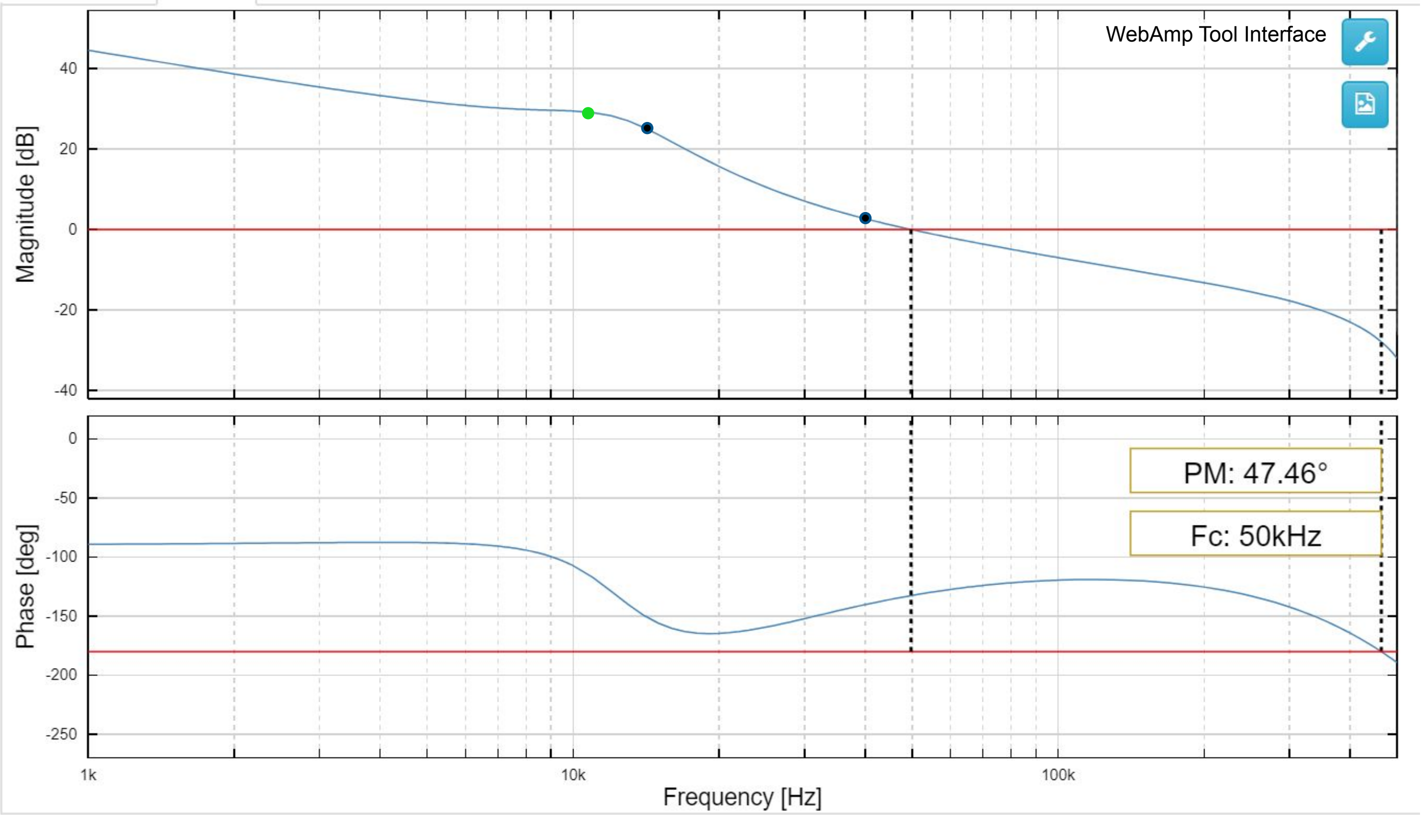
Gain = 650
Z1 = 10.6 kHz
Z2 = 40 kHz

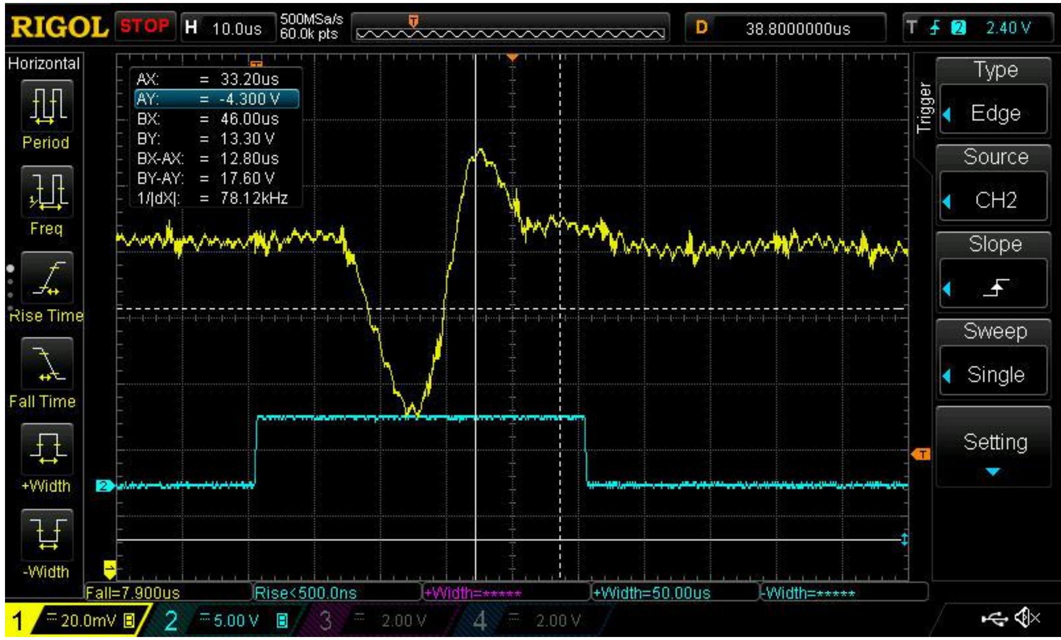




Compensator Design 2 - Increasing f_{Z1}

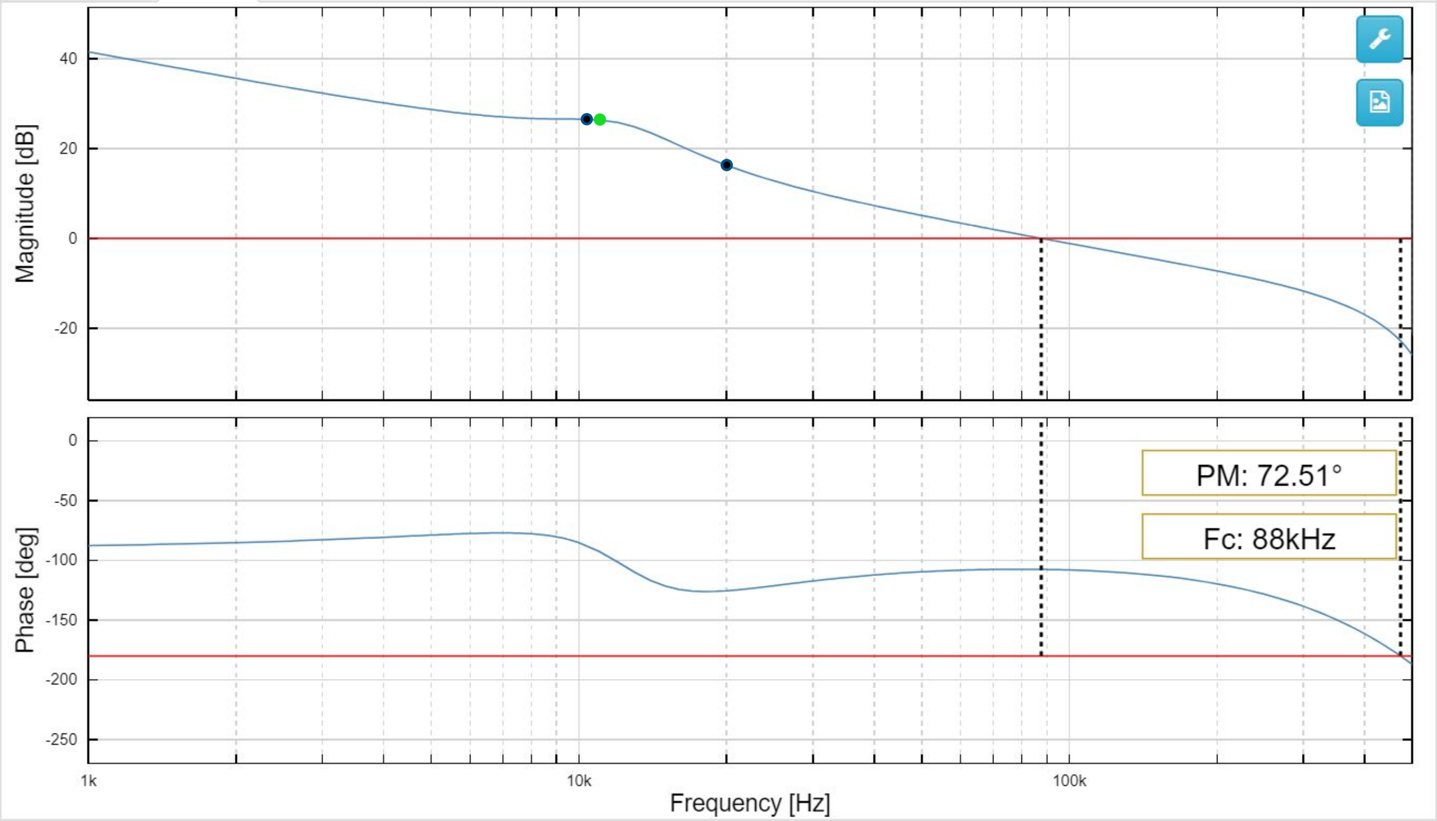
Gain = 650
Z1 = 15 kHz
Z2 = 40 kHz

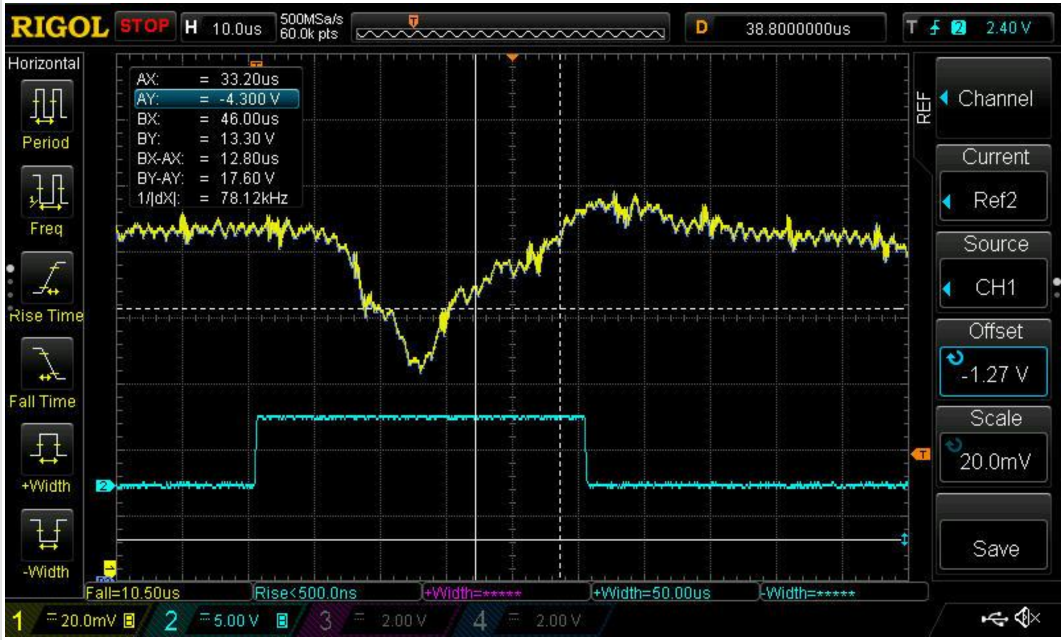




Compensator Design 3 - Decreasing f_{Z2}

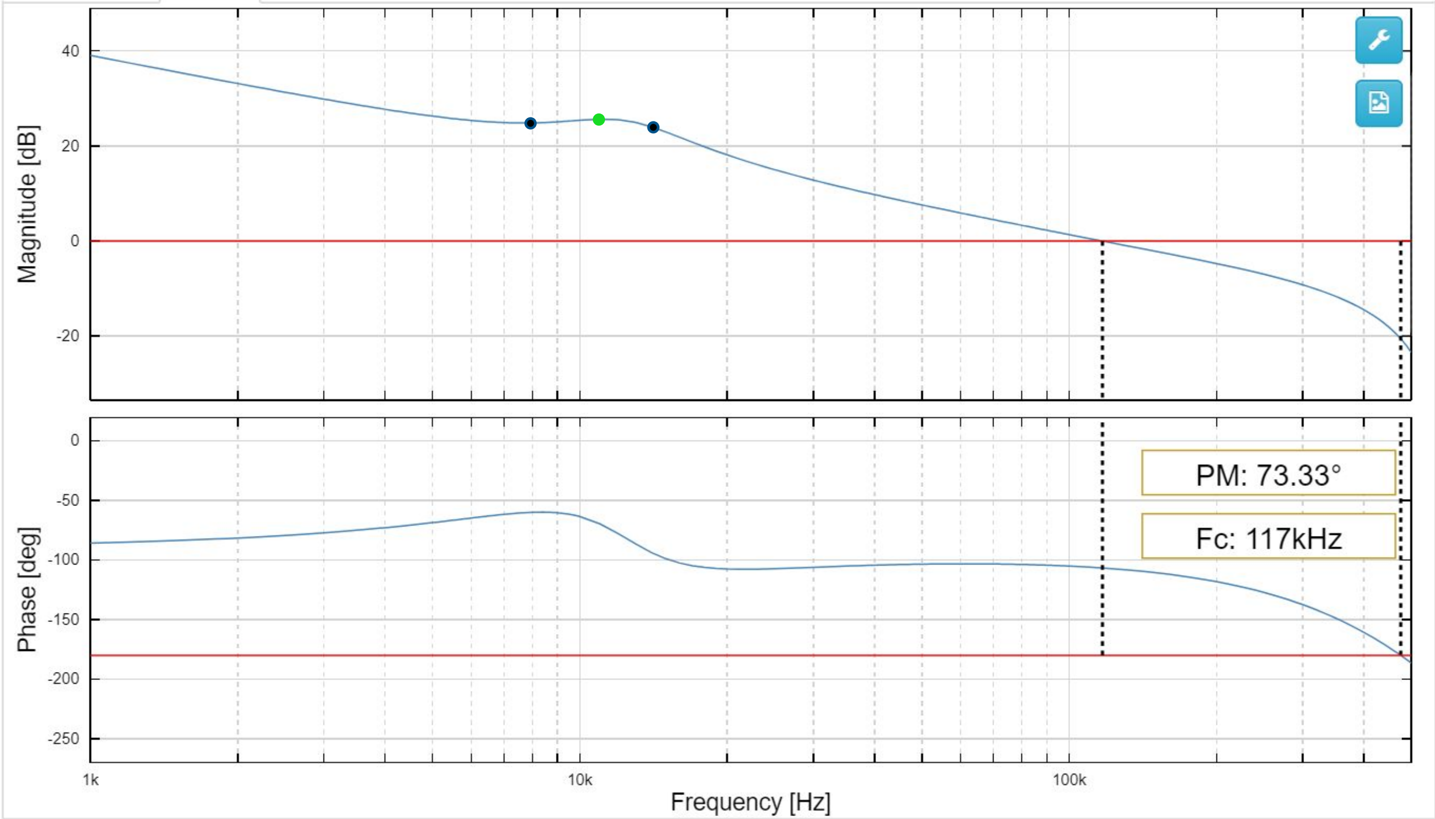
Gain = 650
Z1 = 10.6 kHz
Z2 = 20 kHz





Compensator Design 4 - Decreasing f_{Z1} and f_{Z2}

Gain = 650
Z1 = 8 kHz
Z2 = 15 kHz

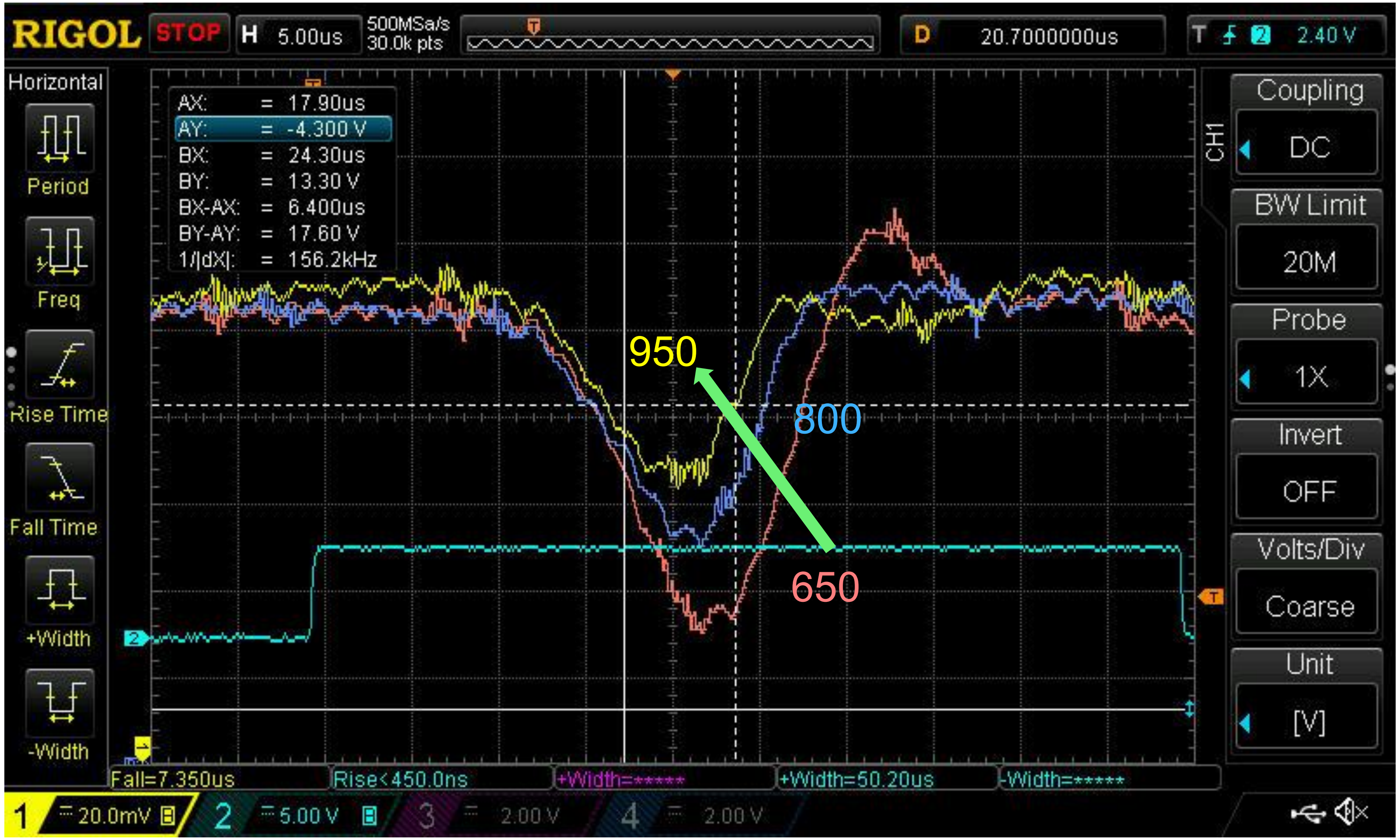


- Crossover frequency, f_c=117 kHz is too high for F_{sw} = 571 kHz, resulting in ringing and possible instability
- Thumb-rule: choose $f_c \leq F_{sw}/10$
- Bode plot is based on linear modeling, PCB parasitics and other non-linearities affect Bode plot accuracy beyond frequencies = $F_{sw}/5$

Effects of different Gain settings

Z1 = 10.6 kHz
Z2 = 40 kHz

Gain	PM (deg)	Fc (kHz)
650	51	51
800	54	60
950	57	70



- Increased DC Gain increases crossover frequency, f_C

Compensator Design Steps

1. Place first zero, f_{Z1}, slightly below filter's resonant frequency, $f_{LC}=1/(2*\pi*\sqrt{LC})$
2. Place second zero, f_{Z2} at around $f_{SW}/12$
3. Modify DC gain to obtain desired crossover frequency

- Recommendations:
  - Crossover frequency (F_c):
    - Optimal: $0.05*f_{SW}<F_c<0.1*f_{SW}$
    - Acceptable: $0.03*f_{SW}<F_c<0.12*f_{SW}$
  - Phase Margin (PM):
    - Optimal: PM>45°
    - Acceptable: PM>35°