

# Amplifier Settling and Charge Bucket Filter Design

TIPL 4405-L

TI Precision Labs – ADCs

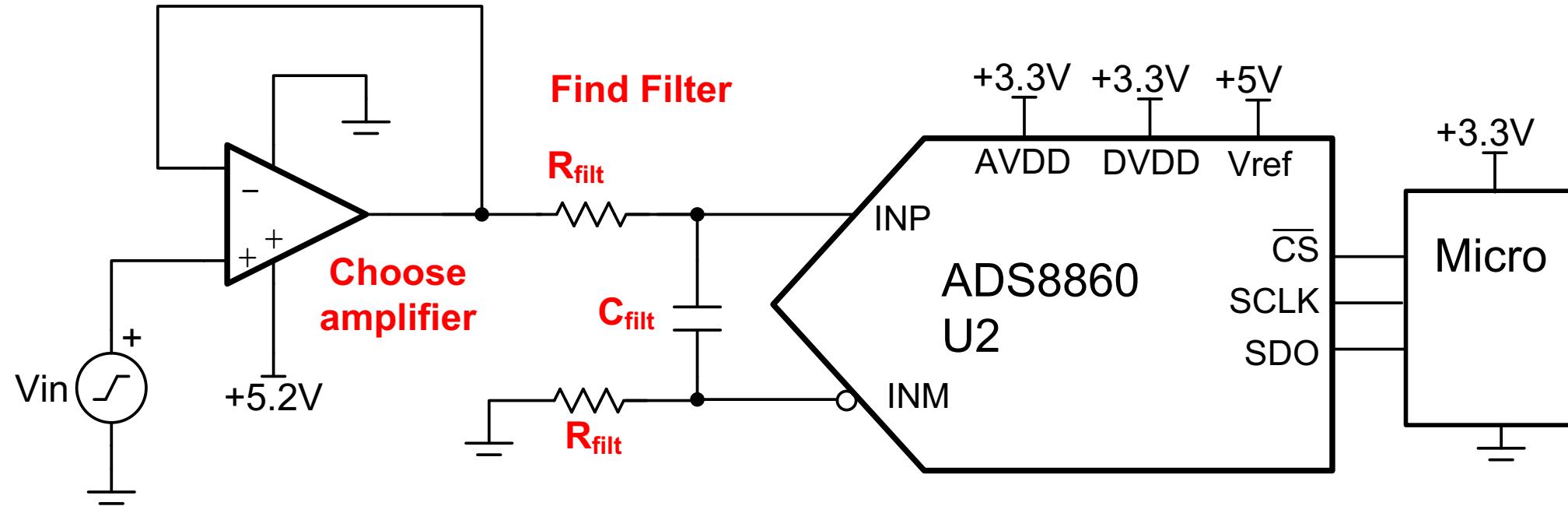
by Art Kay, Dale Li



# Required/Recommended Equipment

- Calculation
  - Determine initial values for RC charge bucket circuit and bandwidth using Analog Engineer's Calculator
- Simulation
  - Optimize RC charge bucket circuit using TINA SPICE
  - Confirm final settling error is less than half of one LSB.
- Measurement
  - Verify THD and SNR for good and bad charge bucket filter design.
  - PLABS-SAR-EVM-PDK
  - <http://www.ti.com/tool/plabs-sar-evm-pdk>
  - Download EVM software and purchase EVM

# Find amplifier and RC circuit



## Amplifier:

- 5V, Rail-to-Rail I/O with Zero Crossover Distortion Required
- Find bandwidth using Analog Engineer's Calculator
- Use parametric search to find device.
- Verify model Open Loop Gain and Open Loop Output Impedance

## RC Charge Bucket Circuit:

- Use Analog Engineer's Calculator for initial values
- Use TINA Simulation to Optimize

# Find the Op Amp Bandwidth and RC Charge Bucket

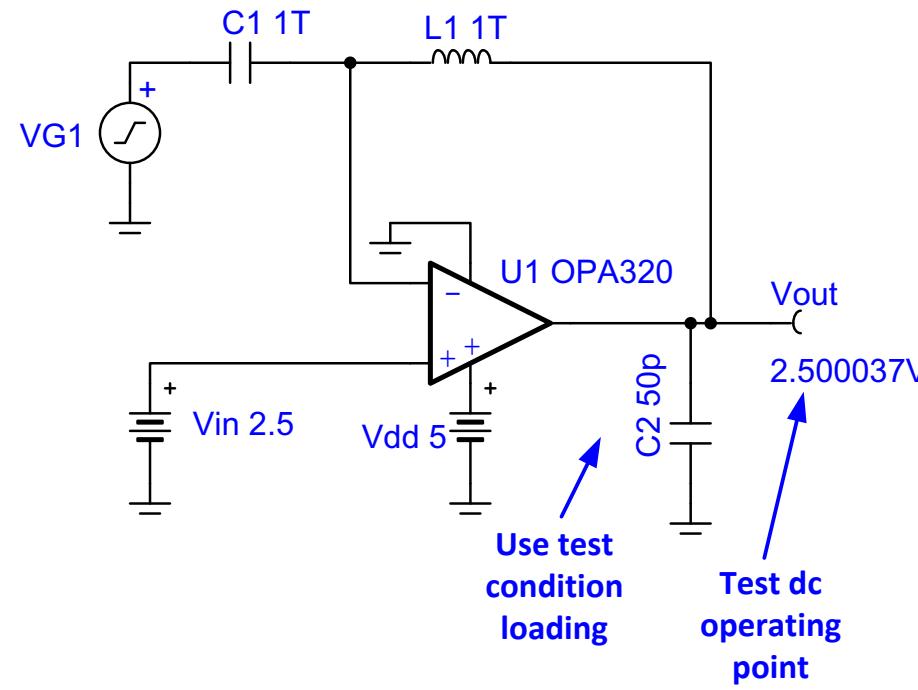
1. Enter the information from the ADS8860 Data Sheet.

2. Results will be used in the simulation

The screenshot shows the 'Main\_Pocket\_Reference\_Calculator.vi' software interface. On the left, a tree view lists various calculators under categories like Converters, Amplifier, and PCB. The 'ADC SAR Drive' calculator is selected. The main window has two tabs: 'Calculator' and 'Simulator'. The 'Calculator' tab displays a configuration panel for a 'Single Ended #2' converter. It includes fields for Resolution (16), Csh (55pF), Full Scale Range (5V), Acquisition Time (290nS), Rfilt/2 Min (4.1 Ohm), Rfilt/2 Max (32.5 Ohm), Cfilt (1.1nF), Gain Bandwidth (17.8M Hz), and Max Error Target (38.15uV). Buttons for 'OK' and 'Help' are at the bottom. A red box highlights the 'Single Ended #2' section, and another red box highlights the Rfilt/2 and Cfilt sections. To the right, a circuit diagram for a 'Single Ended #2: Includes Ground Sense (Negative Input)' is shown. It features a operational amplifier (op-amp) with a non-inverting input (+) connected to ground and an inverting input (-) connected to Vin. The output of the op-amp is connected to a resistor Rfilt/2. From the midpoint of Rfilt/2, one branch goes to a switch S1, then to a shunt capacitor CSH+, then to a switch S3, then to Vsh+. The other branch goes to a shunt capacitor CSH-, then to a switch S4, then to a resistor RSH-, then to Vsh-. A feedback path from Vsh+ to the inverting input (-) is also shown. A capacitor Cfilt is connected between the midpoint of Rfilt/2 and ground.

# Op Amp Model: Open Loop Gain

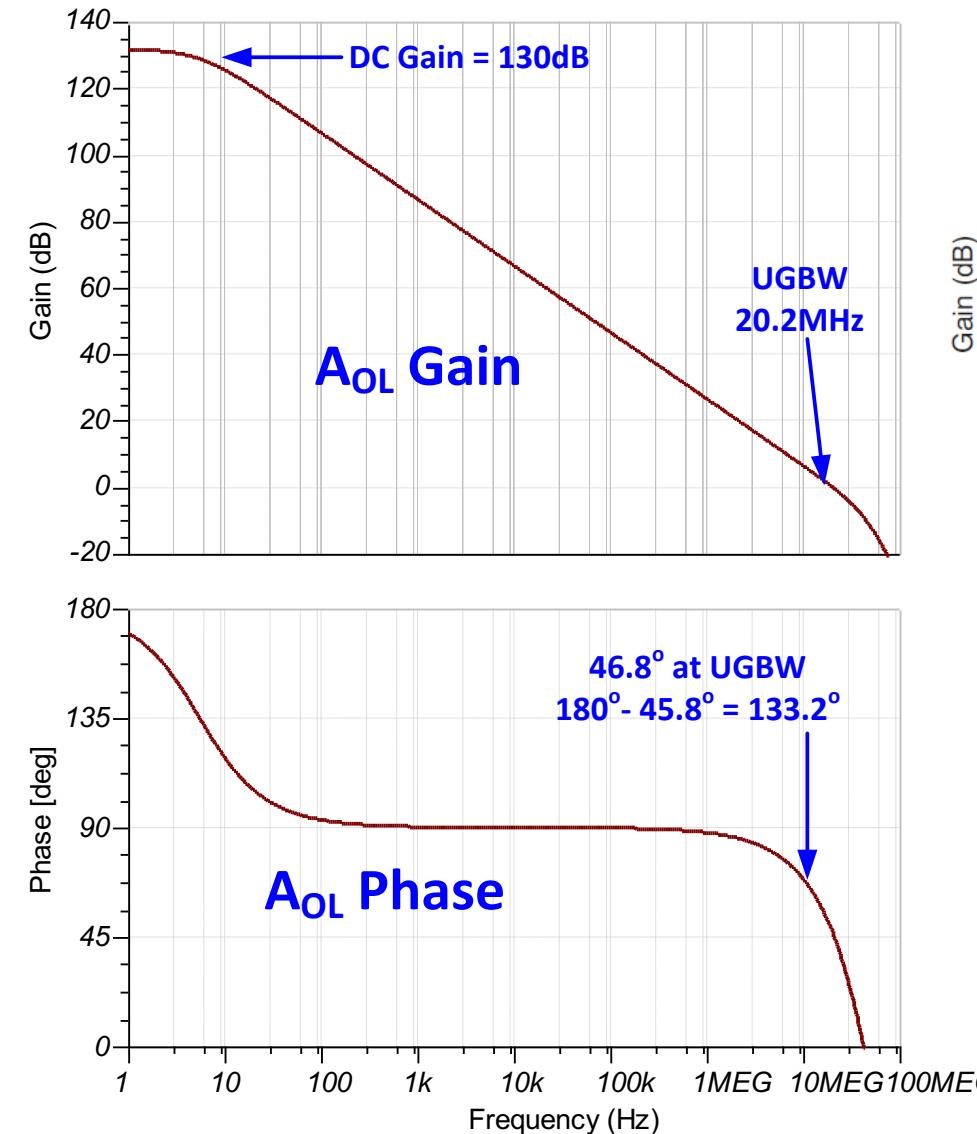
Test Circuit for AOL



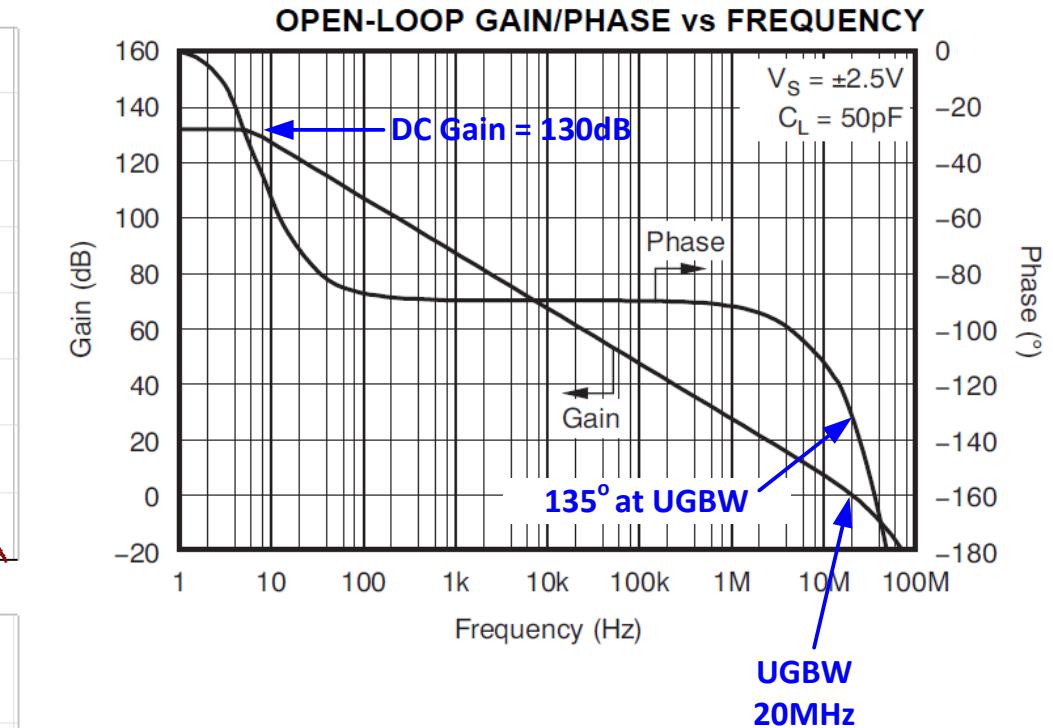
1. Test dc operating point to assure that circuit is correctly wired
2. Run ac simulation for AOL curve

$$A_{OL} = V_{out}$$

Simulated results



Data Sheet Specification



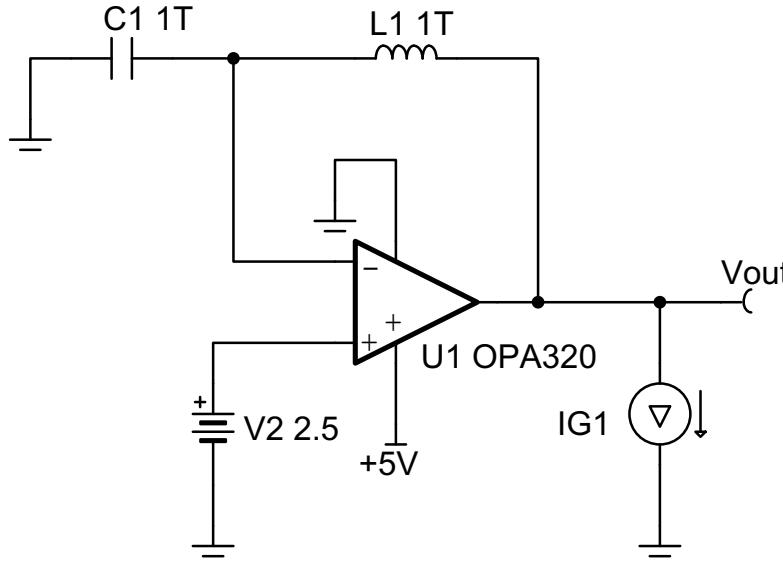
Compare key points on simulation results to data sheet curve.



Aol\_opa320.TSC

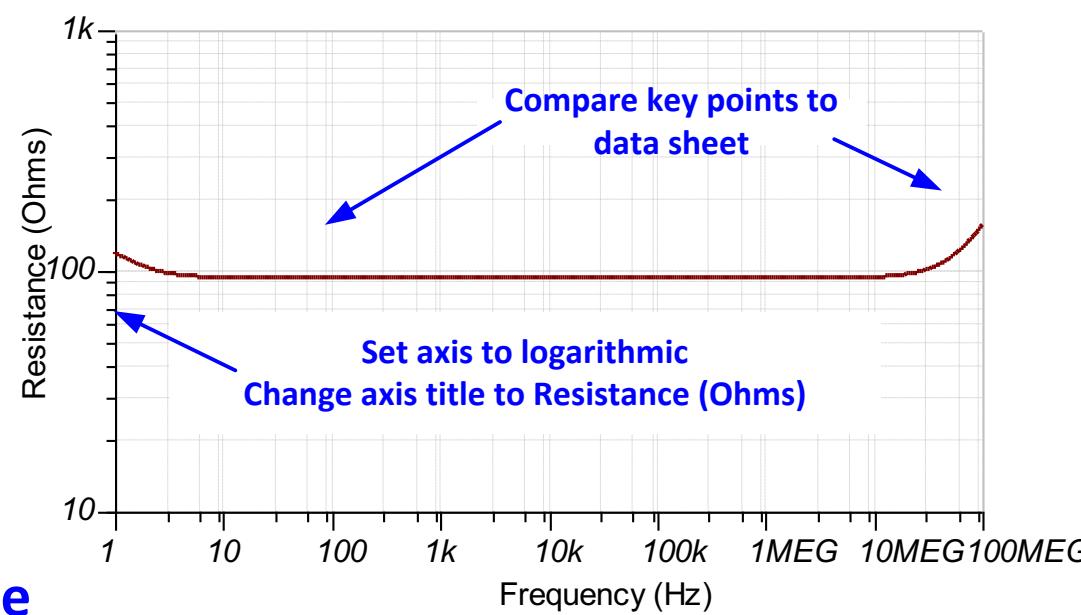
# Op Amp Model: Open Loop Output Impedance

Test Circuit for AOL

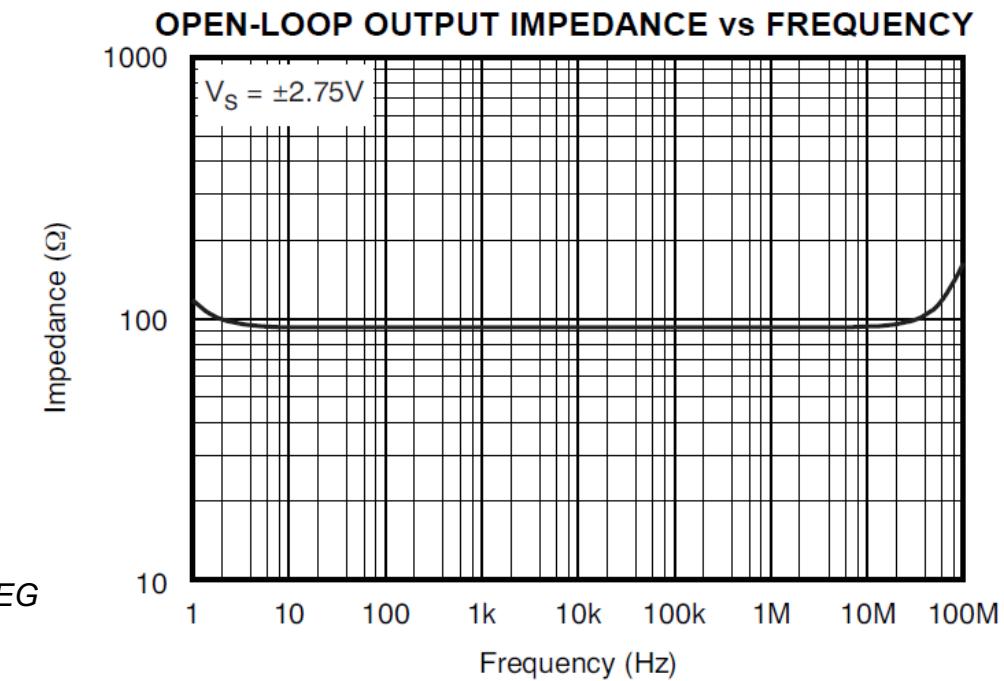


1. Test dc operating point to assure that circuit is correctly wired
2. Run ac simulation for  $Z_o$  curve.  
 $Z_o = V_{out}$ .

Simulated results

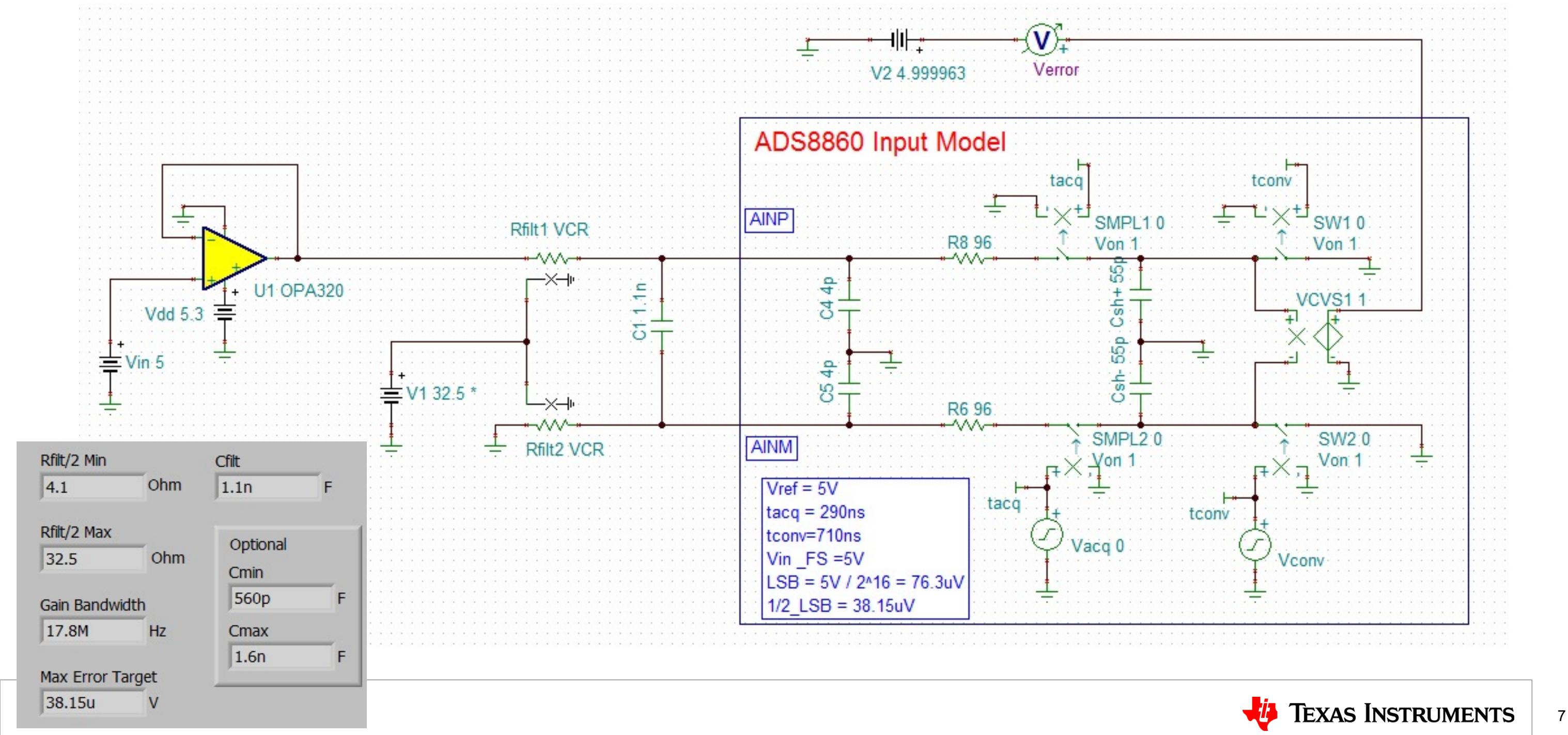


Data Sheet Specification

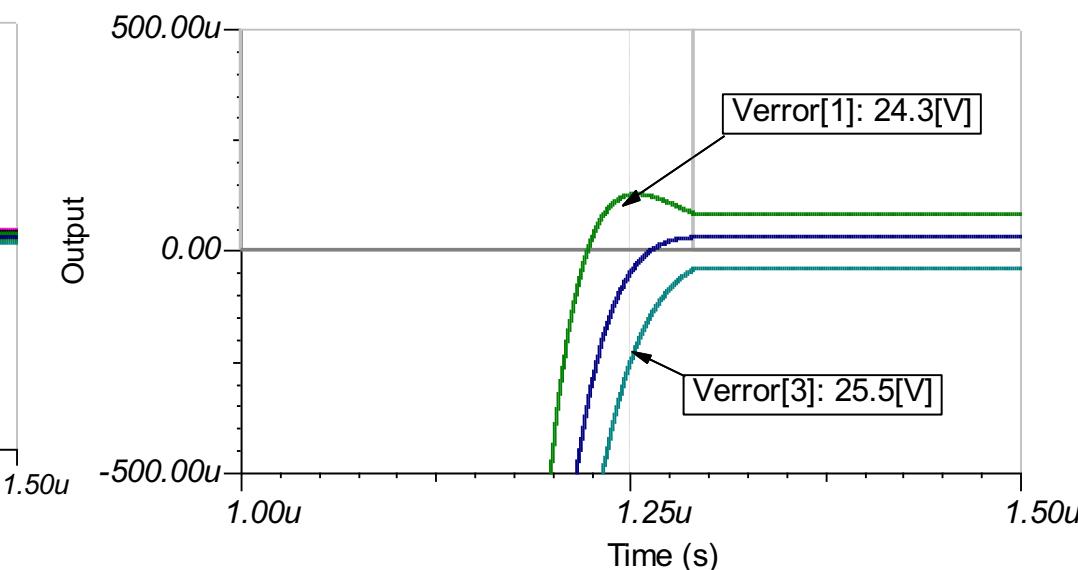
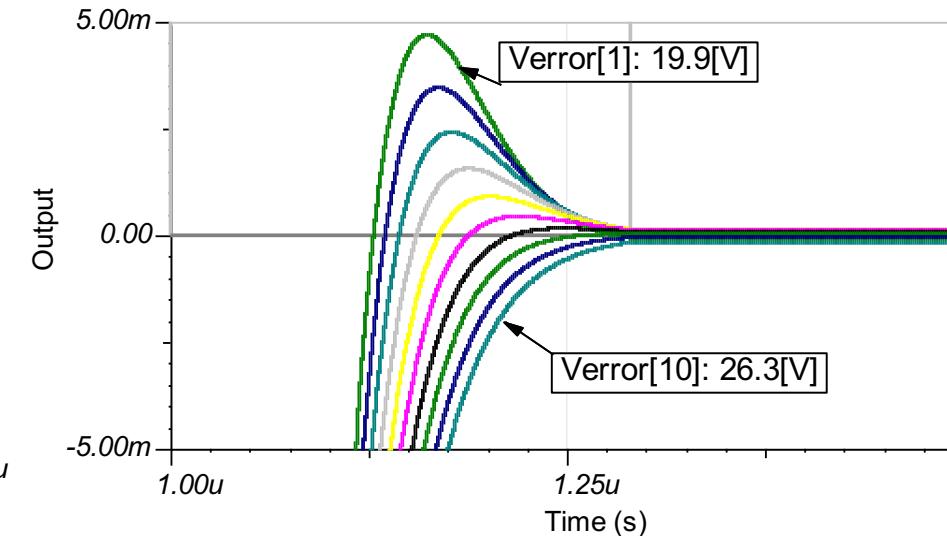
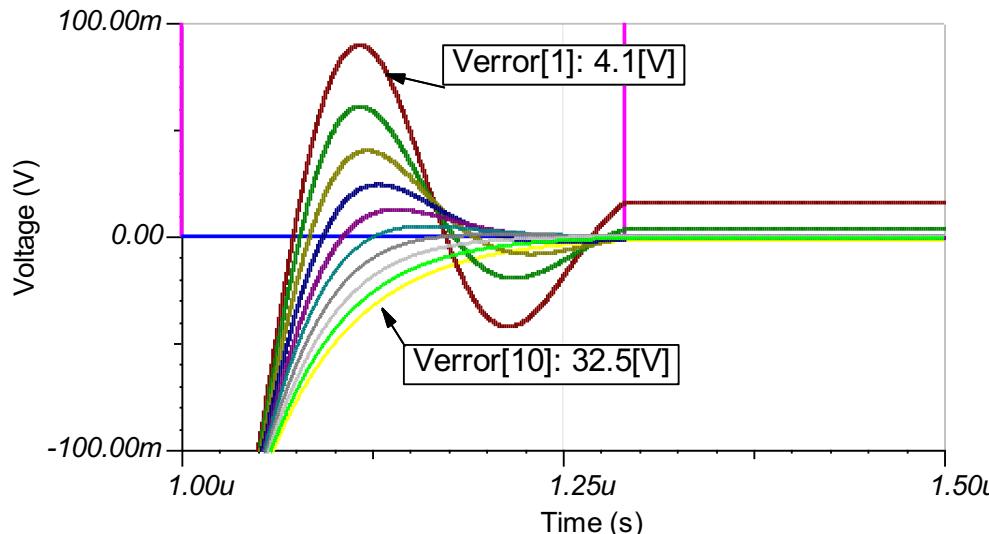


Zo opa320.TSC

# Find the Op Amp Bandwidth and RC Charge Bucket



# Parameter Step $R_{filt}$



ADS8860\_OPA320 - 1st - iteration.TSC

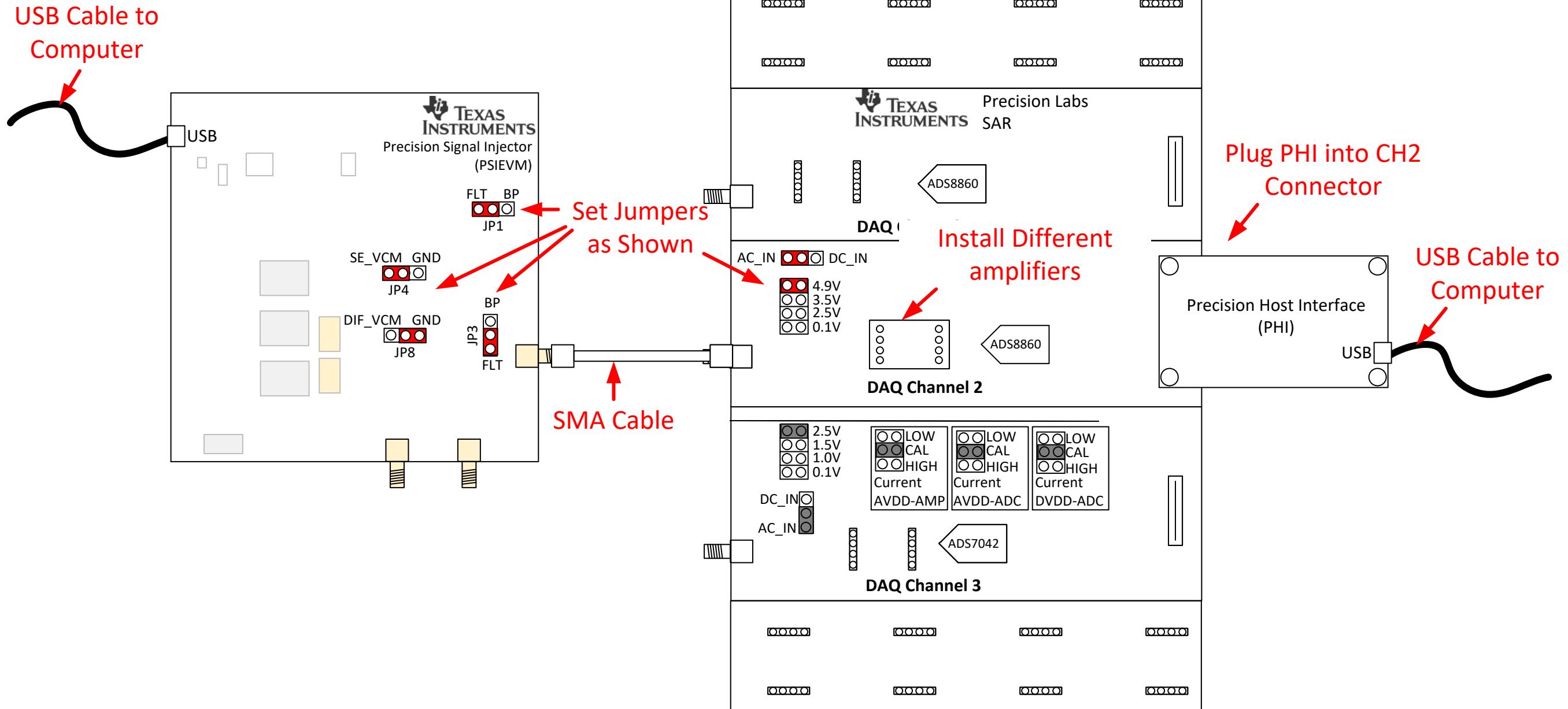


ADS8860\_OPA320 - 2nd - iteration.TSC



ADS8860\_OPA320 - 3rd - iteration.TSC

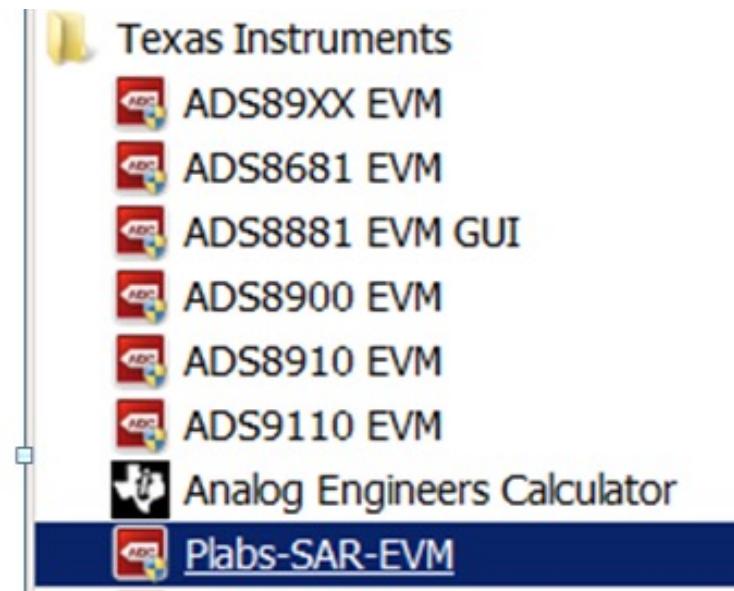
# Connect the hardware



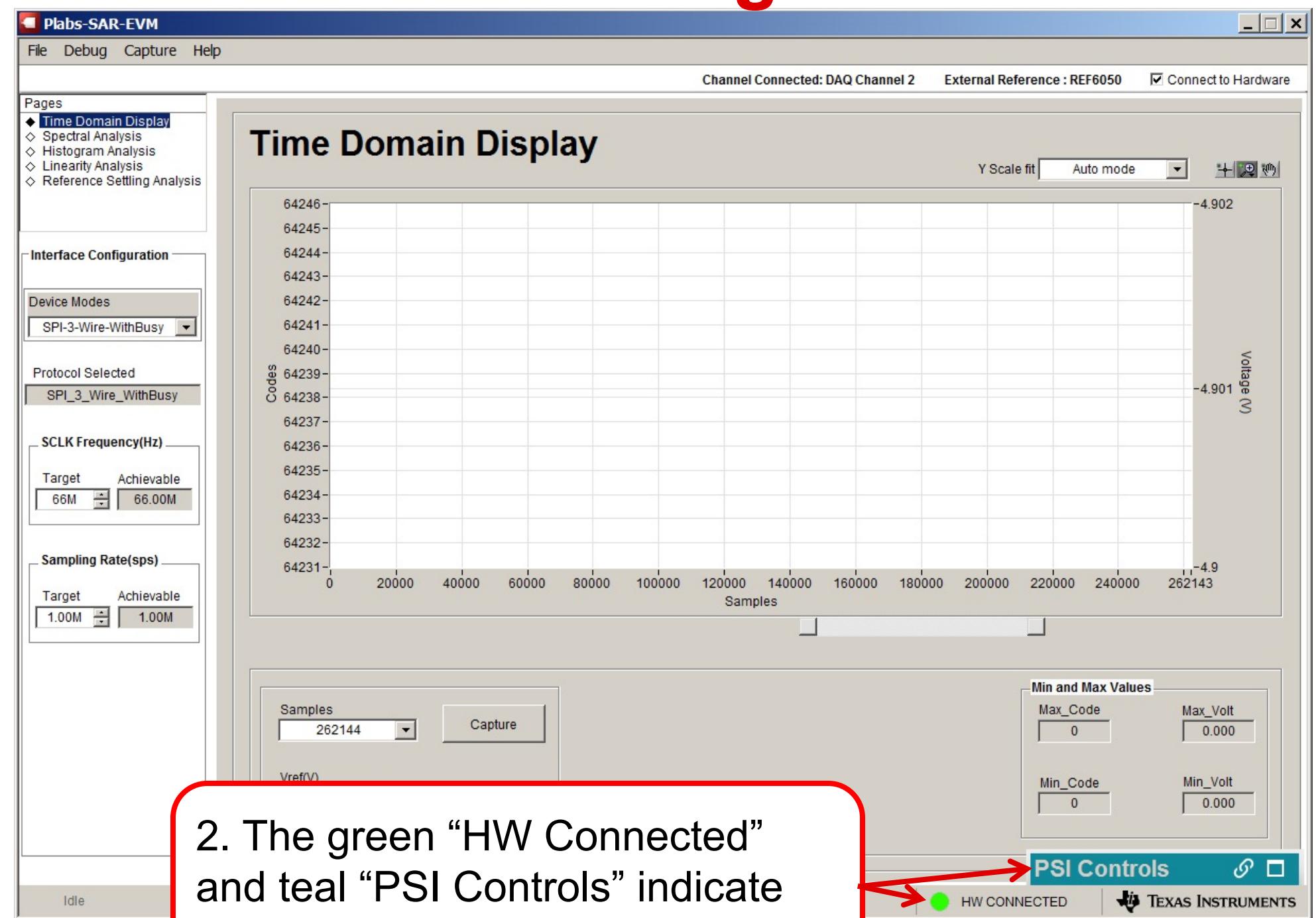
# Record results as we progress through Experiment

Device					Simulated Settling Error $\frac{1}{2}\text{LSB}=38\mu\text{V}$	Example Measurements		Your Measurements	
	Device	Samp. Rate	$V_{\text{offset}}$ (V)	$V_{\text{in}}$ (V)	$V_{\text{error}}$ (V)	SNR (dB)	THD (dB)	SNR (dB)	THD (dB)
	ADS8860 Data Sheet					93	-108		
1	OPA320 Good filter1	1M	2.5	4.9	28uV	93.3	-108.8		
2	OPA320 Bad filter	1M	2.5	4.9	-41mV	82.5	-73.4		
3	OPA333 Low Bandwidth	1M	2.5	4.9	-91mV	54.1	-55.9		
4	OPA316 Crossover	1M	1.8	3.6	36.7mV	86.1	-85.0		
5	OPA316 Crossover	500k	1.8	3.6	47uV	90.3	-102.4		

# Start & Setup the Plabs-Power Scaling EVM Software



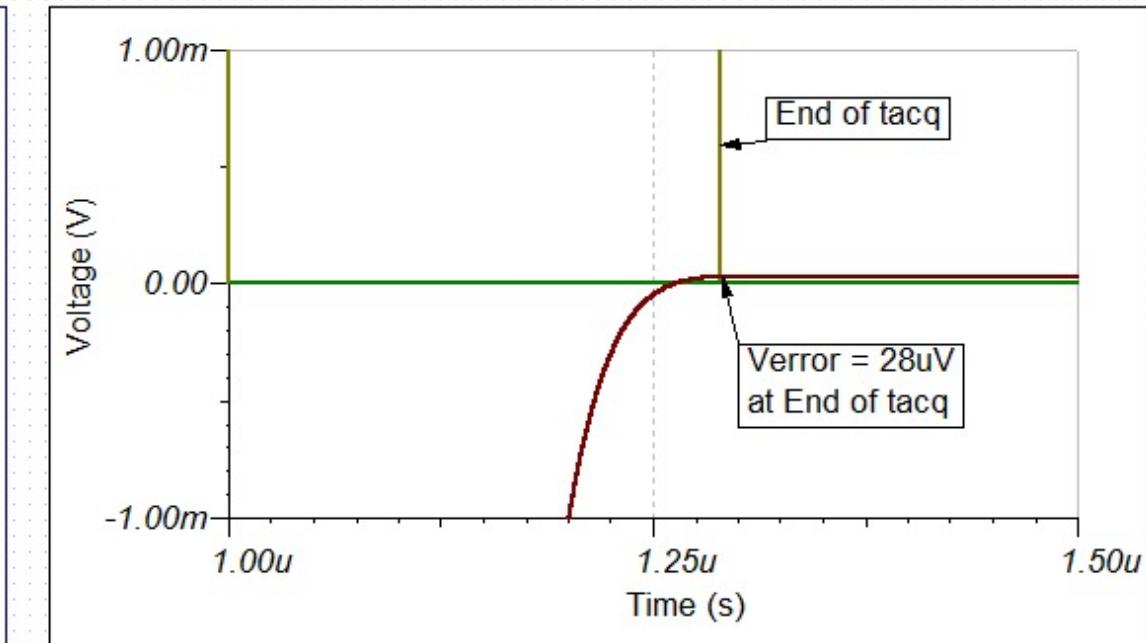
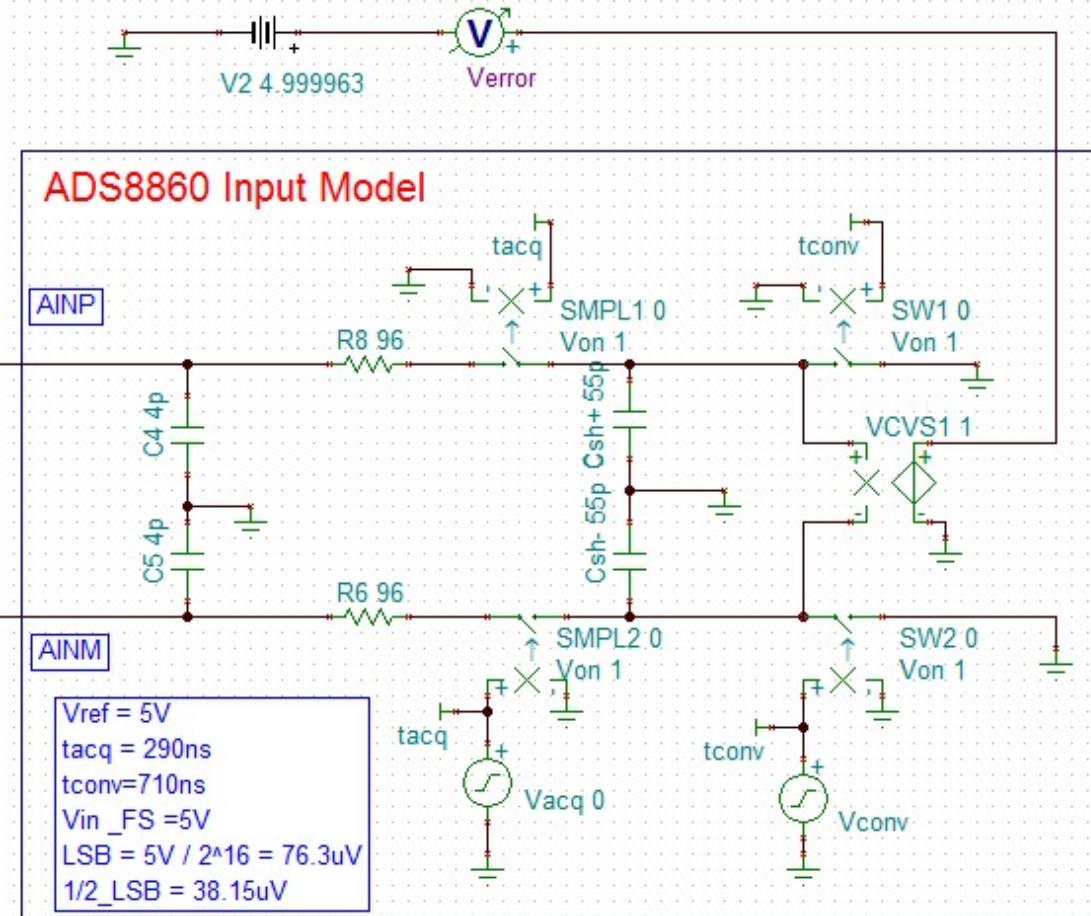
1. Select “Plabs-SAR-EVM” from “start>All Programs”



2. The green “HW Connected” and teal “PSI Controls” indicate good hardware communication.

# 1: OPA320\_Good Filter1

Note RC circuit is from optimization.

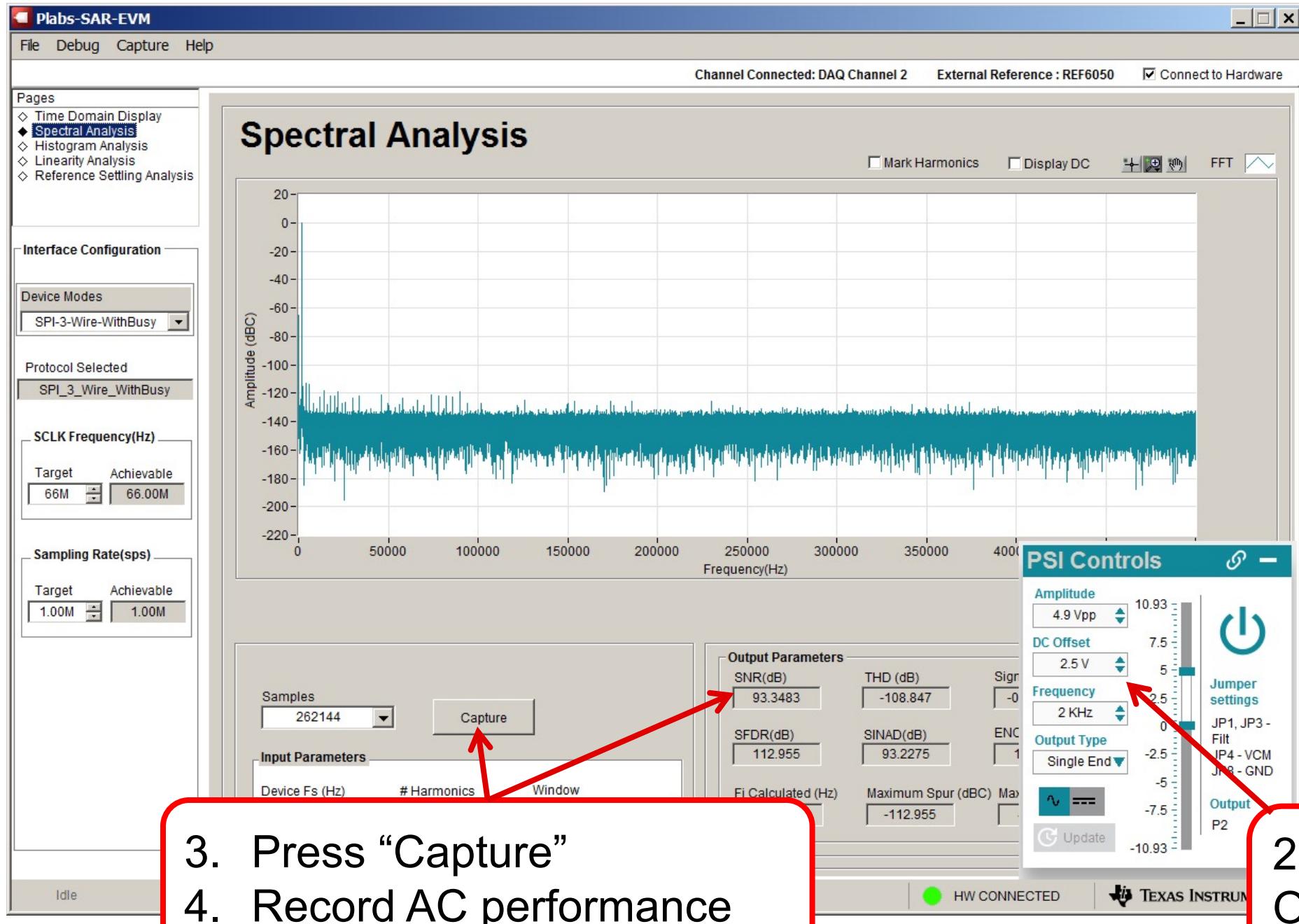


Error Target = 38 $\mu$ V  
Simulate Error = 28 $\mu$ V



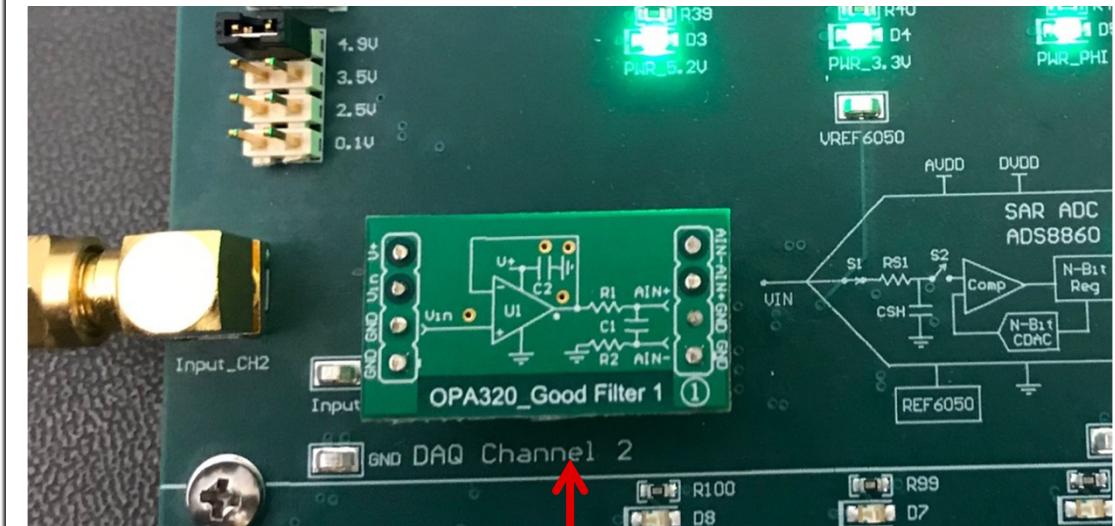
ADS8860\_OPA320 - good filter.TSC

# 1: OPA320\_Good Filter1



3. Press “Capture”
4. Record AC performance

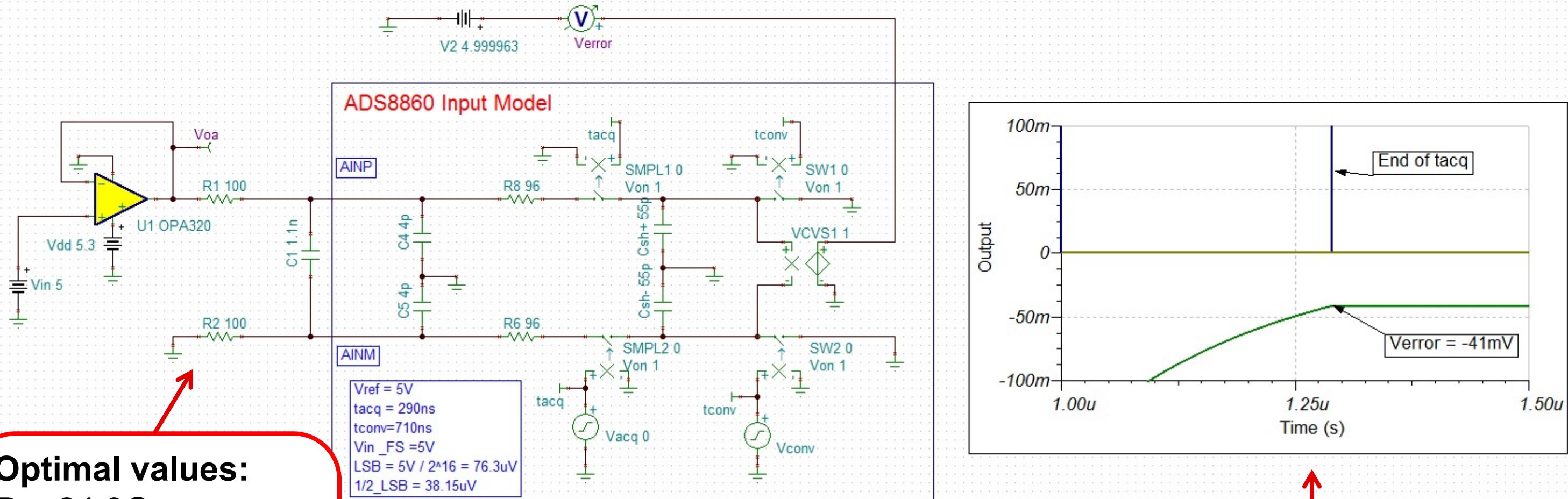
	SNR (dB)	THD (dB)
ADS8860 Spec.	93	-108
Good Filter 1	93.3	-108.8



1. Install OPA320\_Good filter 1 coupon card in socket.

2. Amplitude = 4.9V  
Offset = 2.5V  
Frequency = 2kHz

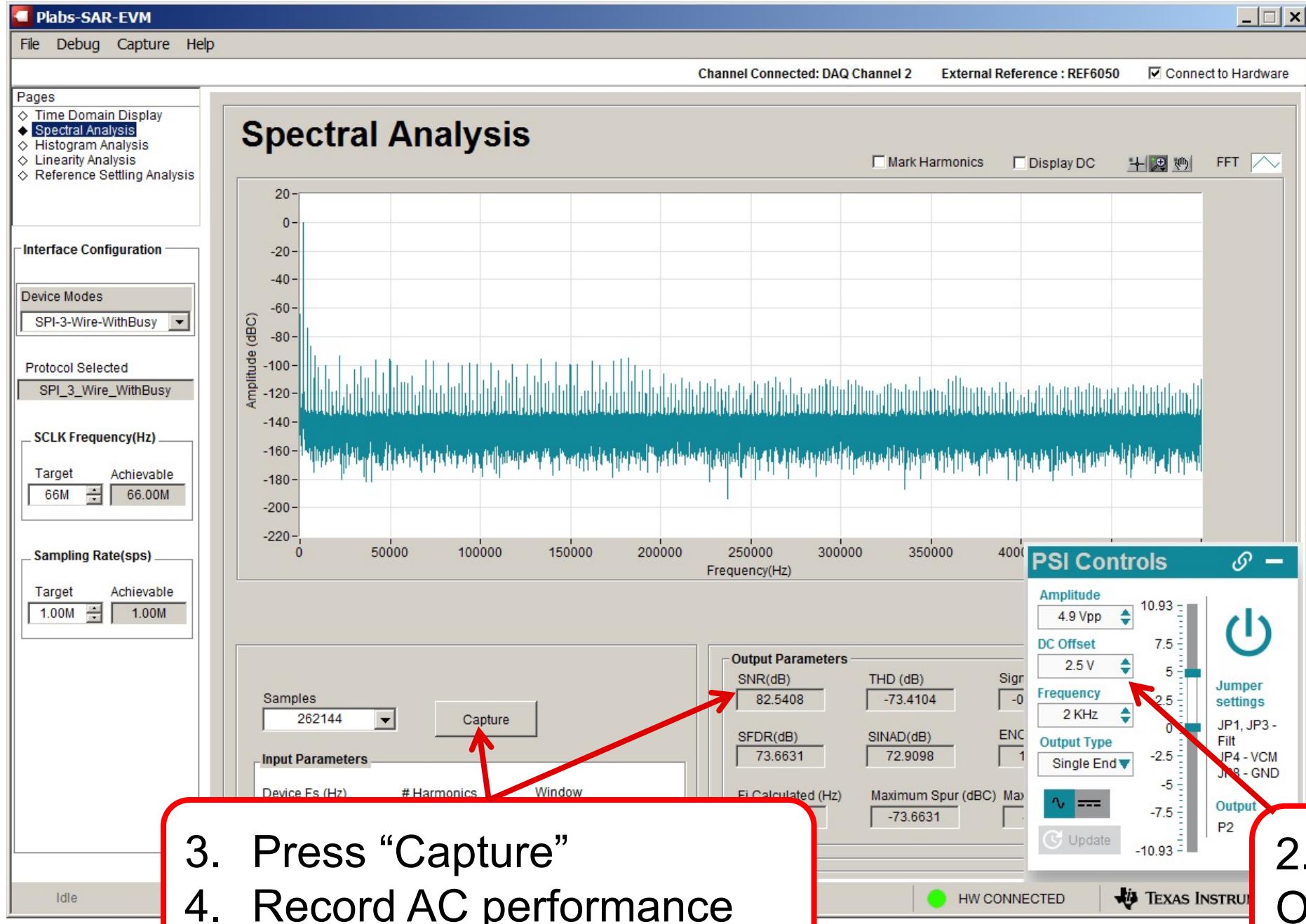
## 2: OPA320 Bad Filter



Kepware  
ADS8860\_OPA320 - bad filter.TSC

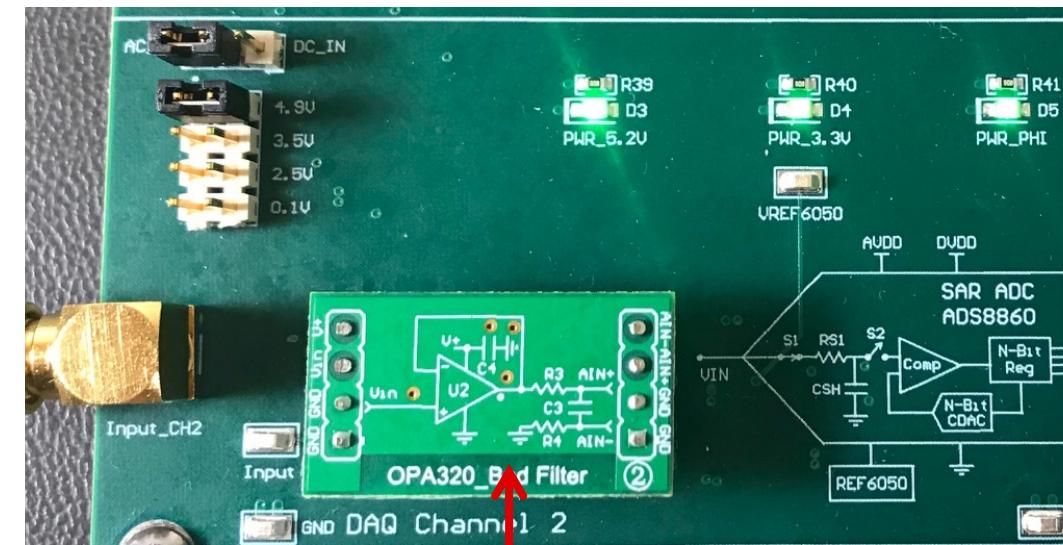
Error Target =  $38\mu\text{V}$   
Simulate Error =  $-41\text{mV}$

## 2: OPA320 Bad Filter



3. Press “Capture”
4. Record AC performance

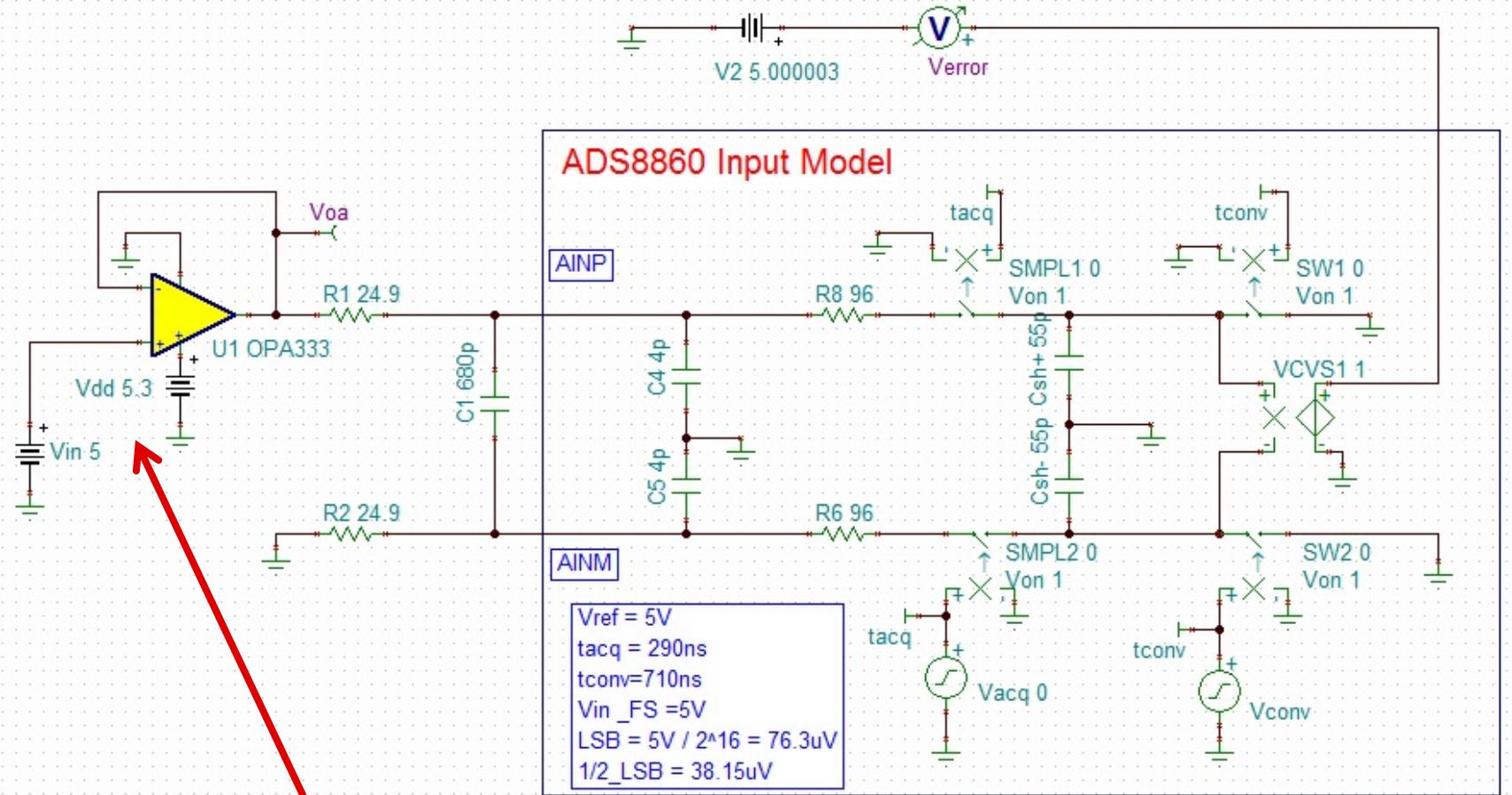
	SNR (dB)	THD (dB)
ADS8860	93	-108
Bad Filter	82.5	-73.4



1. Install OPA320\_Bad Filter coupon card in socket.

2. Amplitude = 4.9V  
Offset = 2.5V  
Frequency = 2kHz

### 3: OPA333 Low Bandwidth



**Bandwidth Required:**

Gain Bandwidth= 17.8MHz

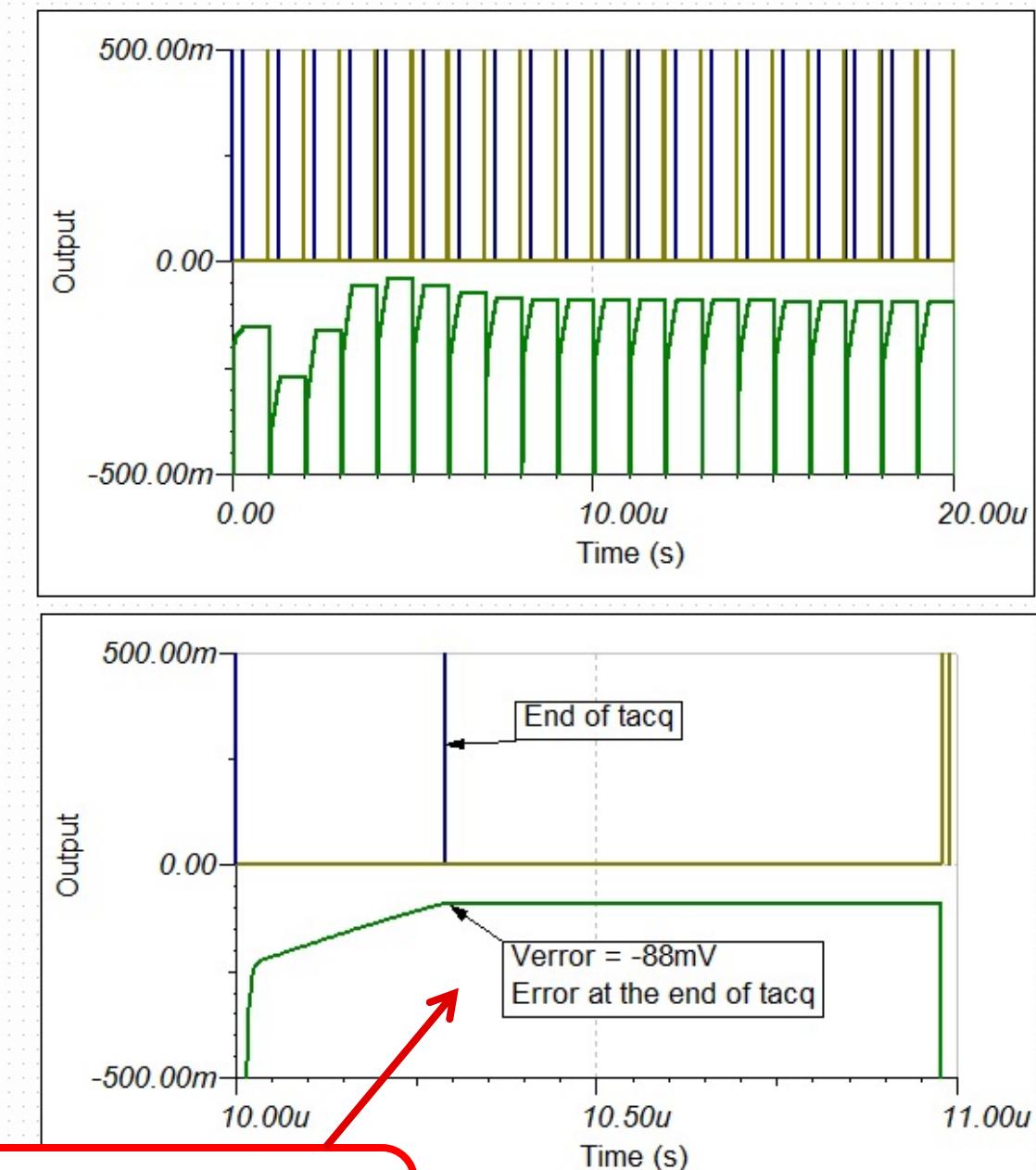
**OPA333 Bandwidth:**

Gain Bandwidth= 350kHz

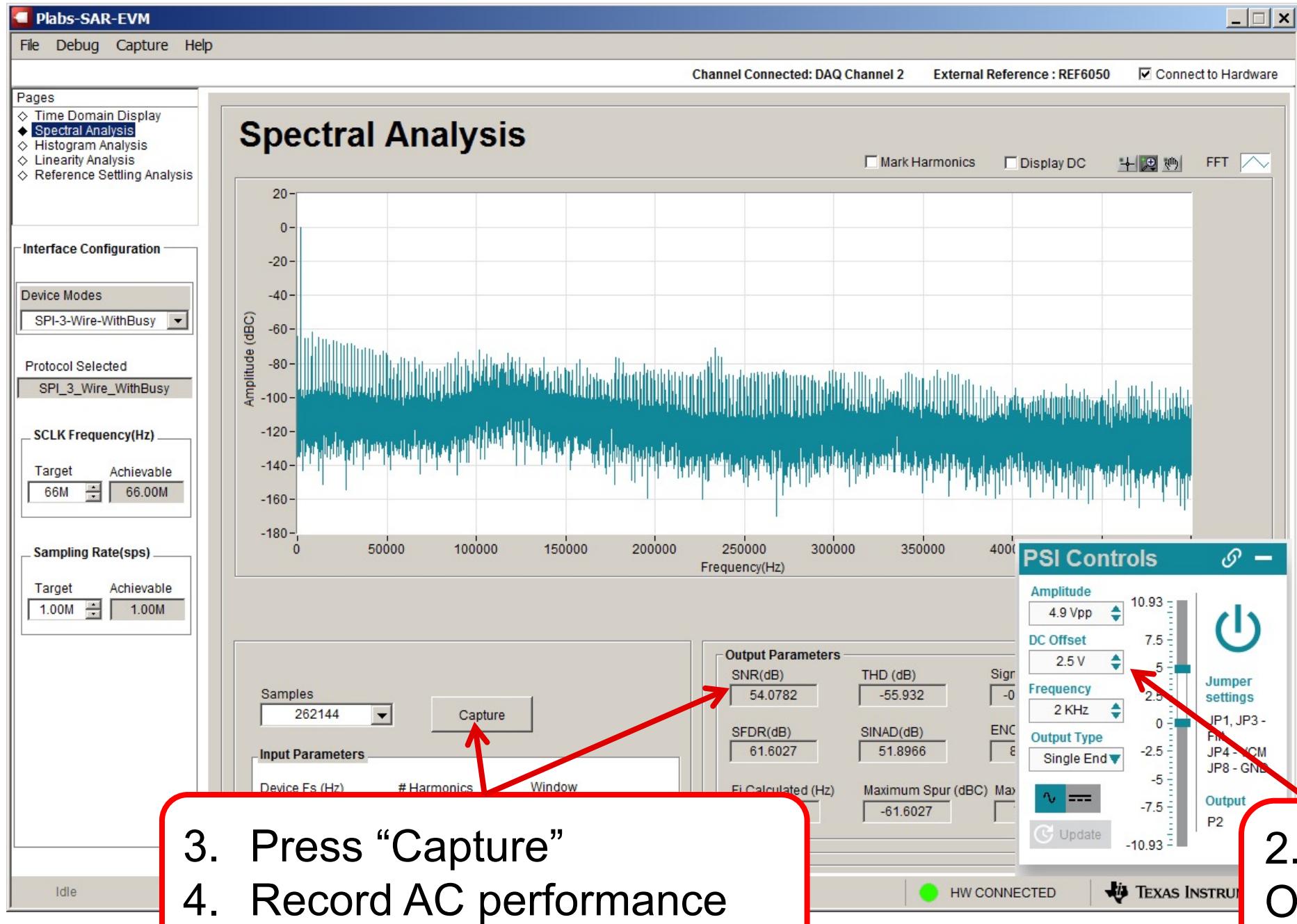


ADS8860\_OPA333 - Low Bandwidth.TSC

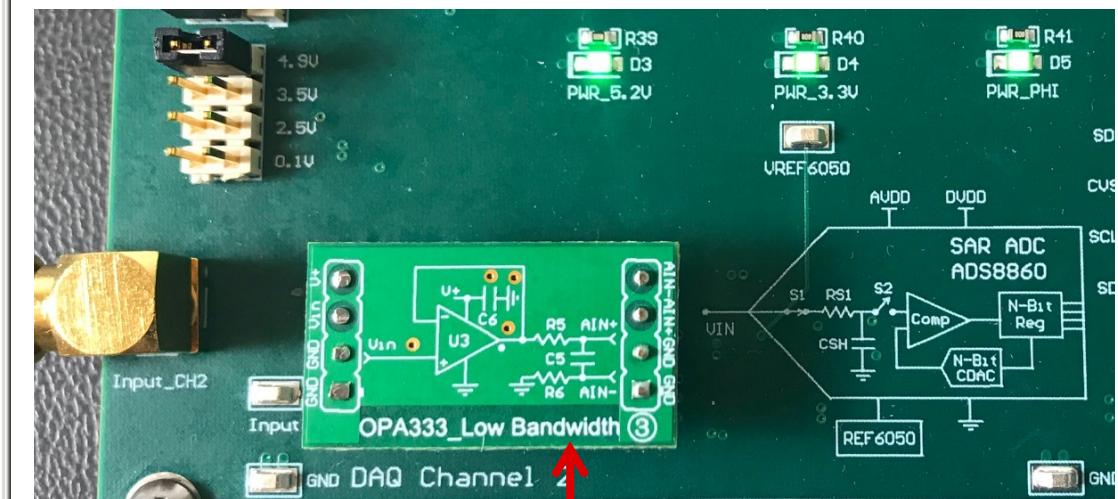
Error Target = 38μV  
Simulate Error = -88mV



# 3: OPA333 Low Bandwidth



	SNR (dB)	THD (dB)
ADS8860	93	-108
Low Bandwidth	54.1	-55.9

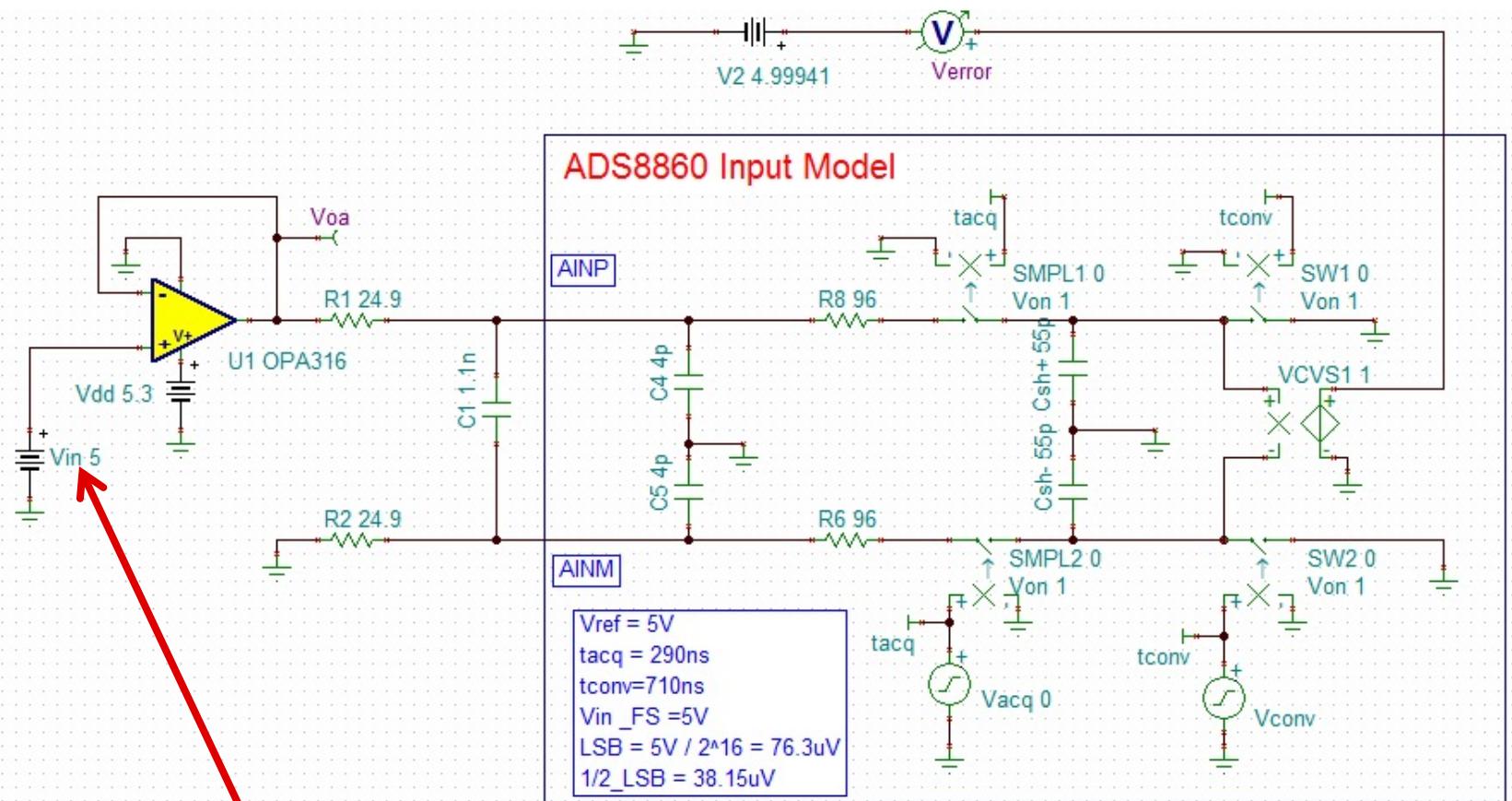


1. Install OPA333\_Low Bandwidth coupon card in socket.

3. Press “Capture”  
4. Record AC performance

2. Amplitude = 4.9V  
Offset = 2.5V  
Frequency = 2kHz

# 4: OPA316 Crossover, fs = 1Msps



**Bandwidth Required:**

Gain Bandwidth= 17.8MHz

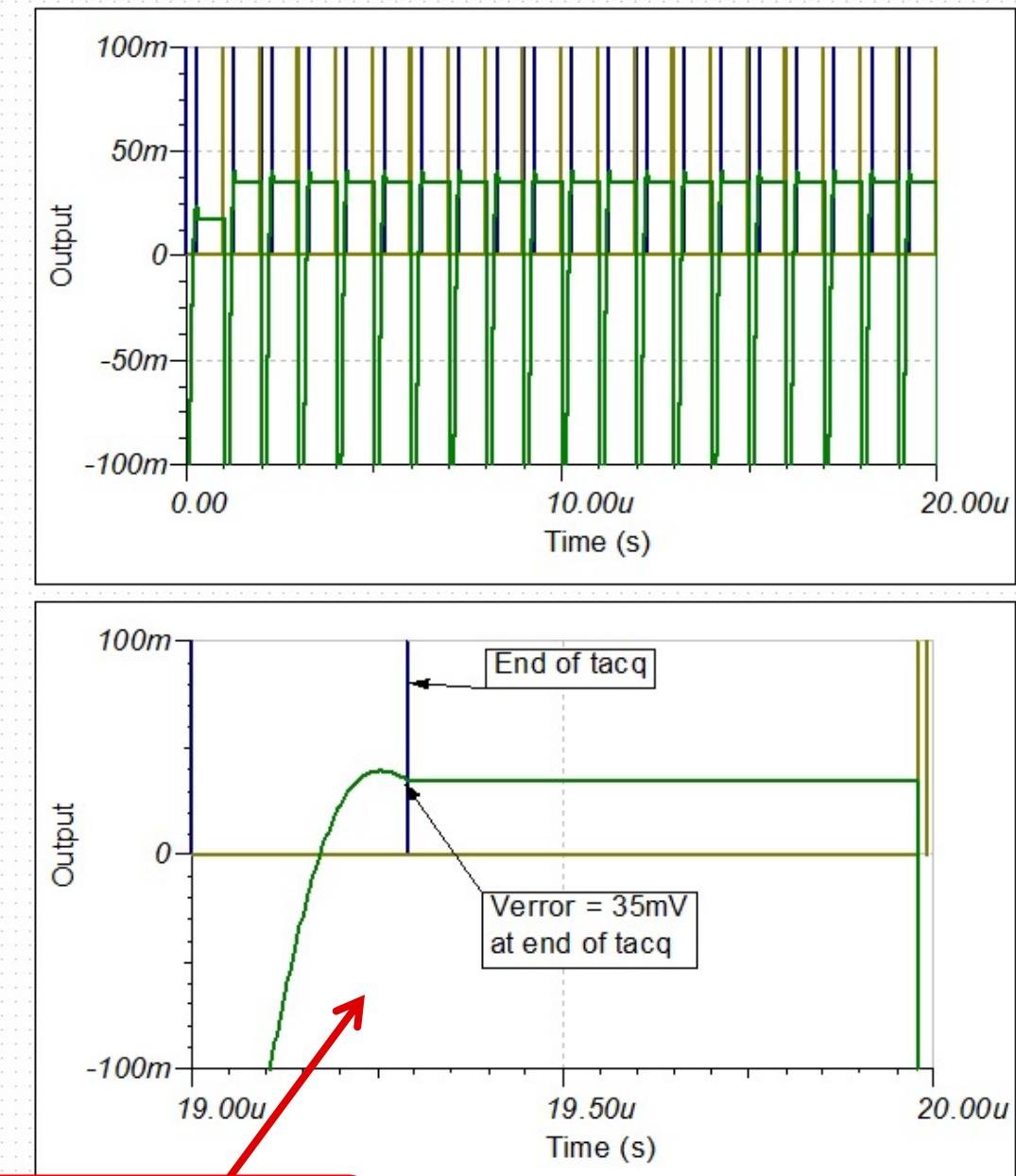
**OPA316 Bandwidth:**

Gain Bandwidth= 10MHz

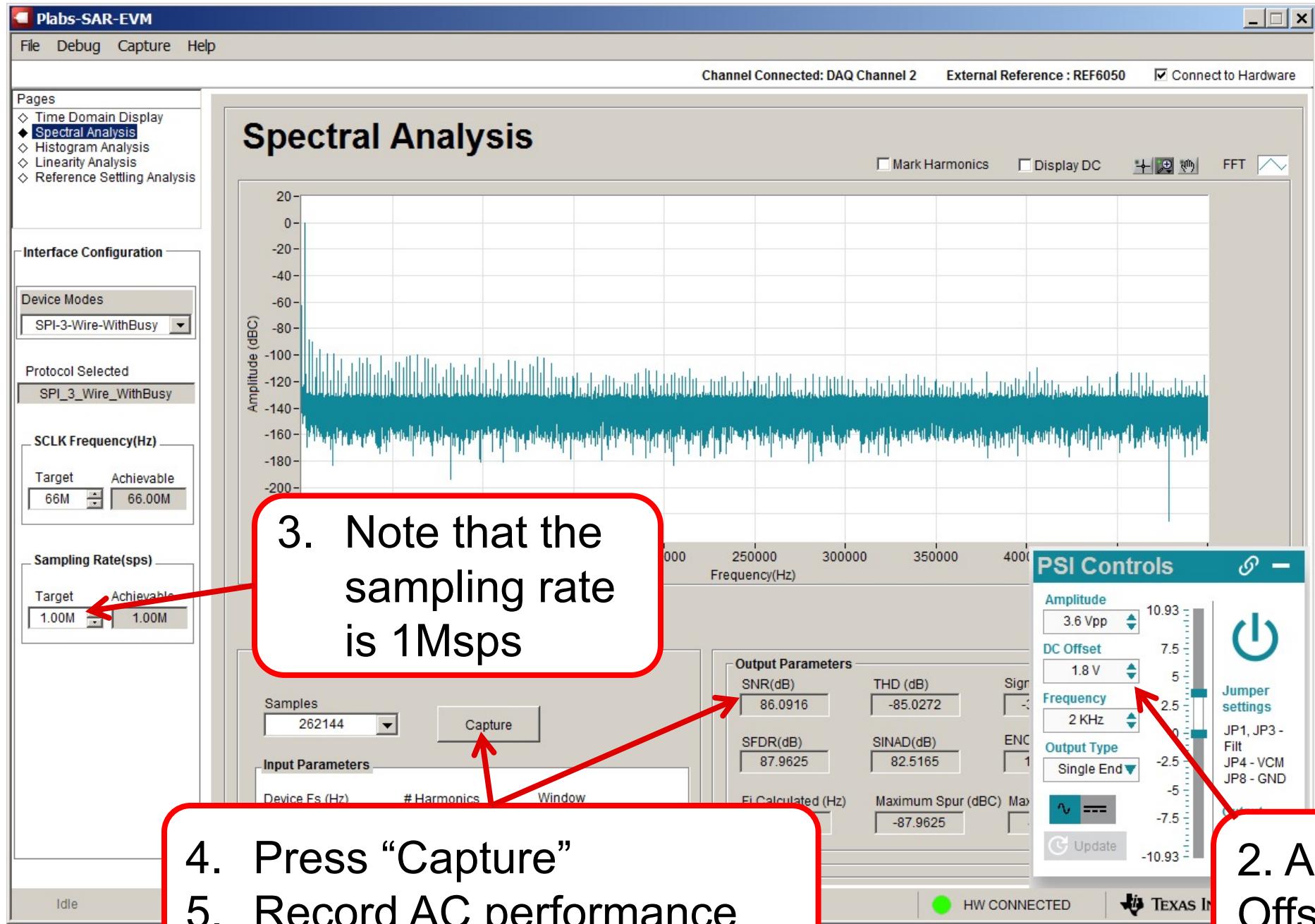


ADS8860\_OPA316 - Crossover-1Msps.TSC

Error Target =  $38\mu V$   
Simulate Error = 35mV



# 4: OPA316 Crossover, fs = 1Msps



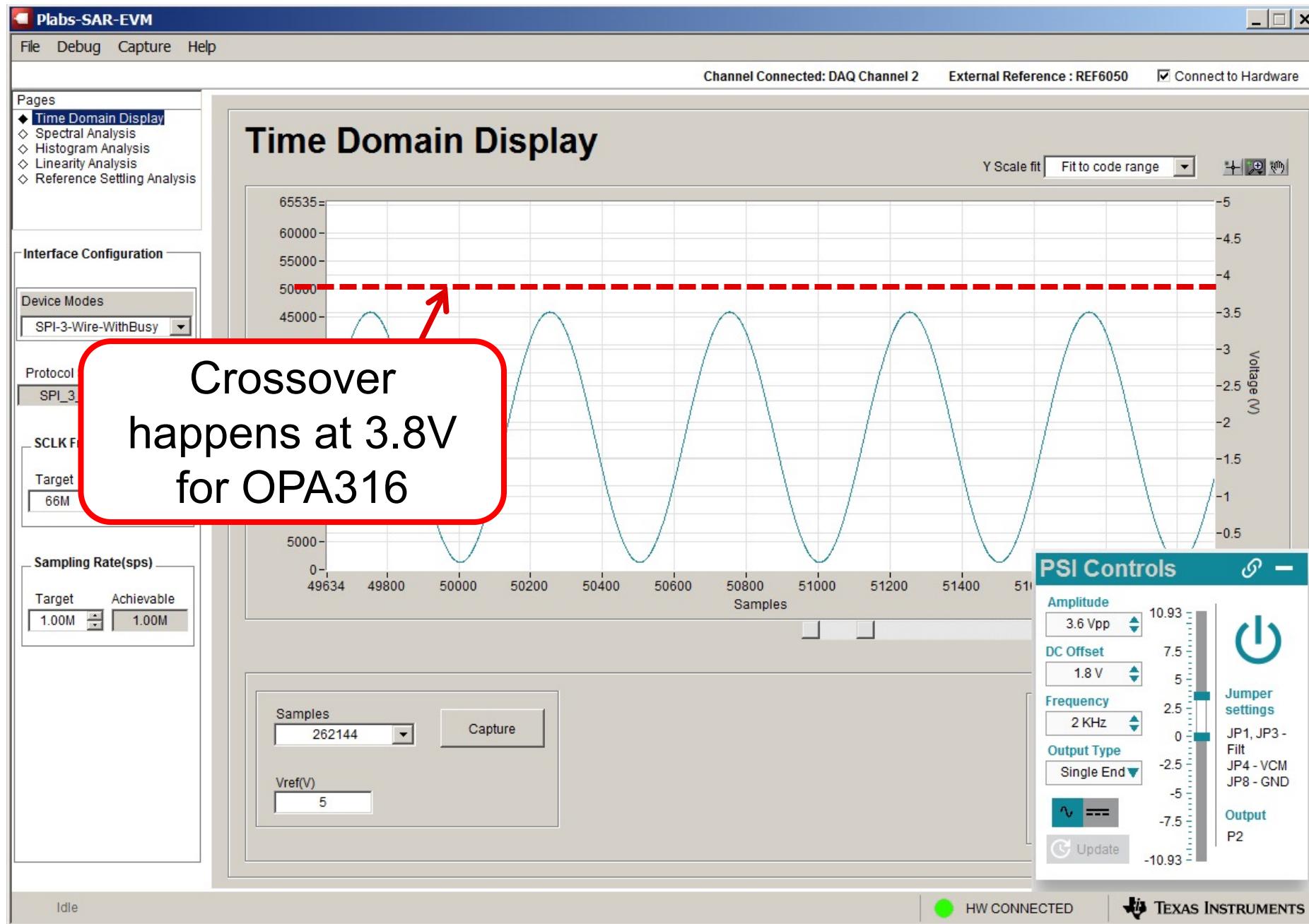
	SNR (dB)	THD (dB)
ADS8860	93	-108
Crossover 1Msps	86.1	-85.0



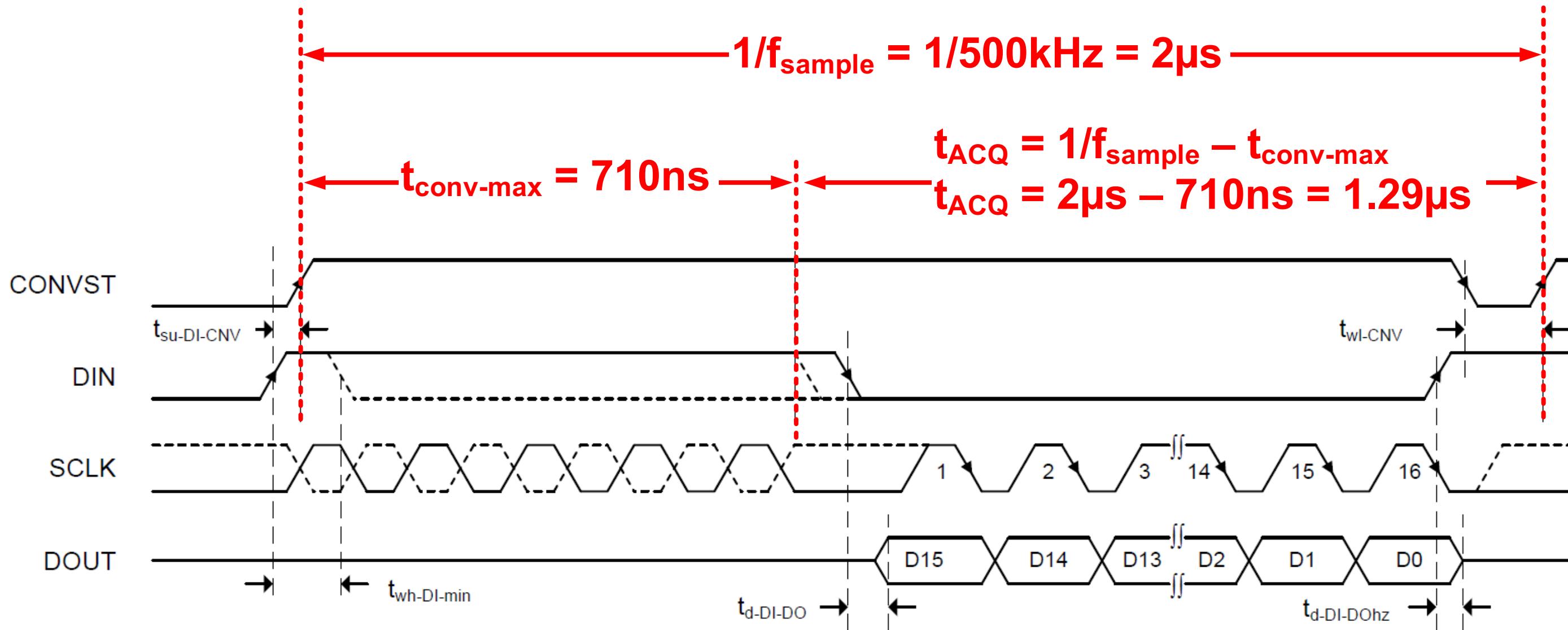
**1. Install OPA316\_Crossover coupon card in socket.**

**2. Amplitude = 3.6V  
Offset = 1.8V  
Frequency = 2kHz**

# Input signal range to avoid crossover distortion



# Changing the Sampling Rate to 500kHz



# Changing the Sampling Rate to 500kHz

Analog Engineer's Calculator

Select the Calculator

Data Converters

- Anti-Alias Filter Designer
- Alias Calculations
- ADC Code to Voltage
- ADC SAR Drive**
- ADC FFT Processing
- ADC + Signal Chain Noise
- ADC ENOB & Effective Bits
- Ideal Converter
- Conversions

Amplifier and Comparators

Passive

Noise

Stability

PCB

Sensor

Links

Calculator

Select Type: Single Ended #2

Resolution: 16

C<sub>sh</sub>: 55p F

Full Scale Range: 5 V

Acquisition Time: 1.29u s

R<sub>filt/2 Min</sub>: 18.1 Ohm

C<sub>filt</sub>: 1.1n F

R<sub>filt/2 Max</sub>: 144.5 Ohm

Optional C<sub>min</sub>: 560p F

C<sub>max</sub>: 1.6n F

Gain Bandwidth: 4M Hz

Max Error Target: 38.15u V

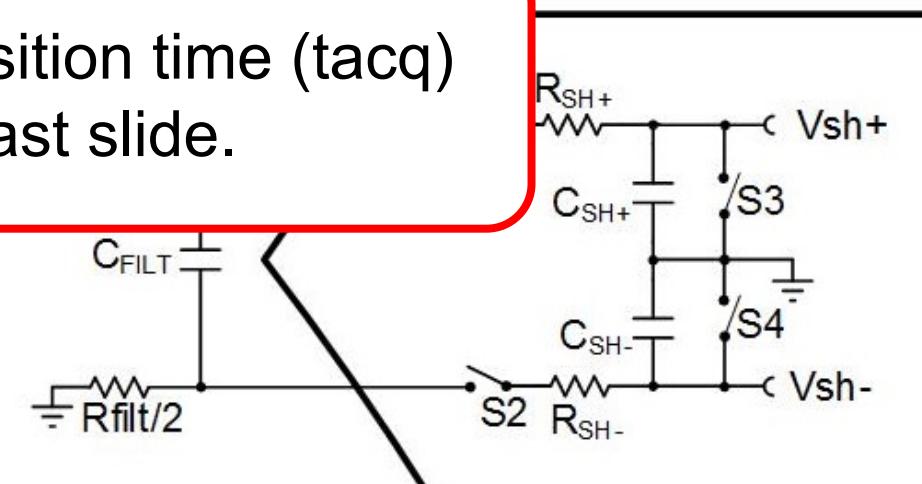
OK Help

Acquisition time (tacq) from last slide.

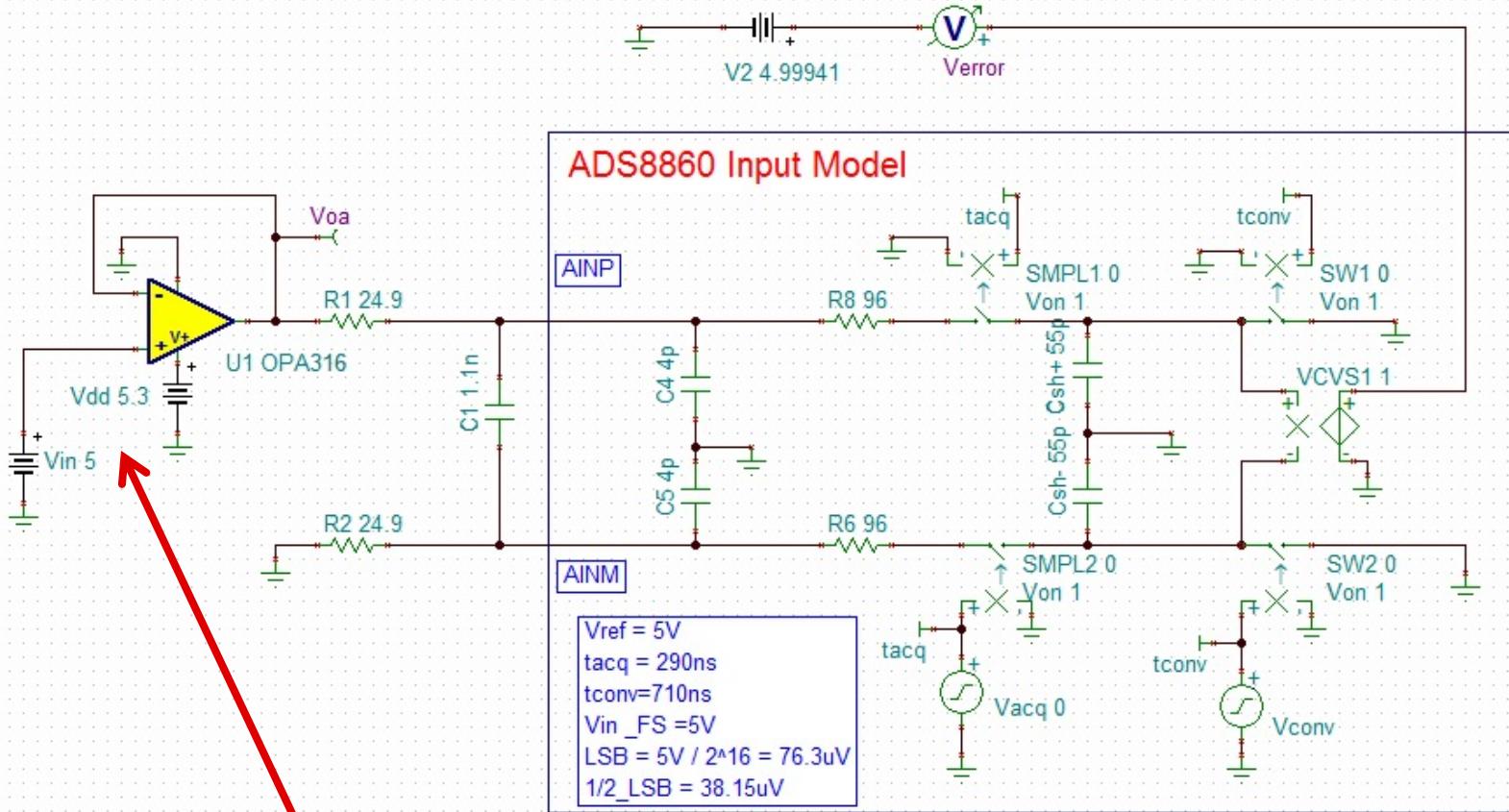
Single Ended #2: Includes Ground Sense (Negative Input)

Note: the values of Rfilt, and Cfilt are intended as a starting point for TINA SPICE parameter step sweep. See the help file for details.

**Bandwidth Required:**  
Gain Bandwidth= 4MHz  
**OPA316 Bandwidth:**  
Gain Bandwidth= 10MHz

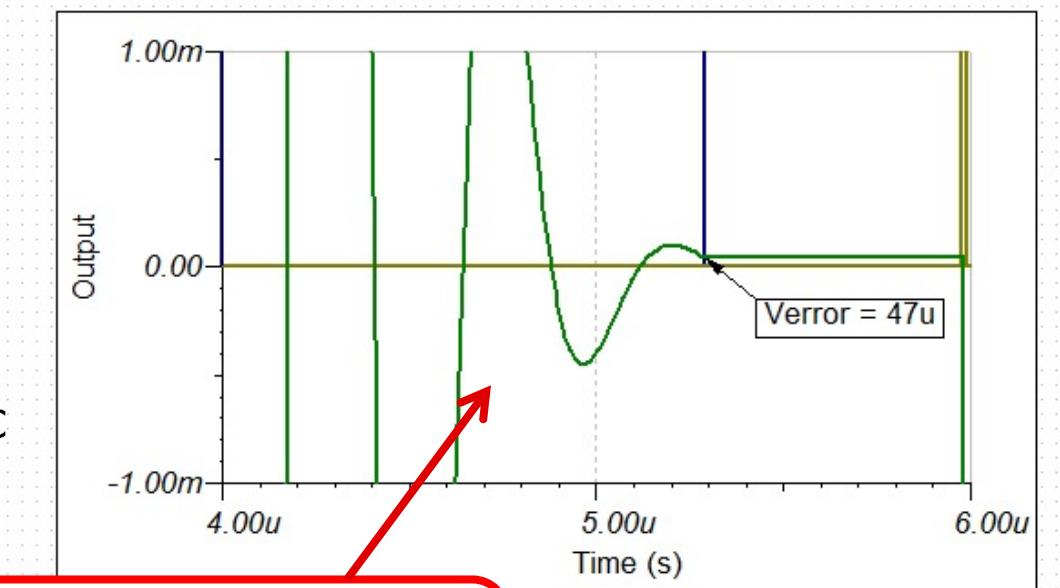
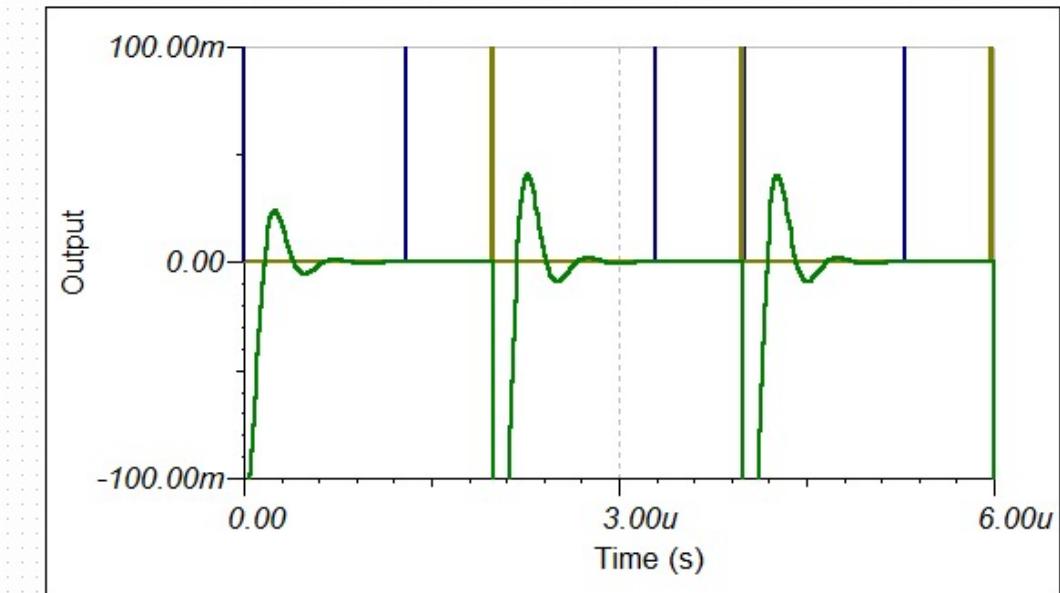


# 5: OPA316 Crossover, fs = 500ksps



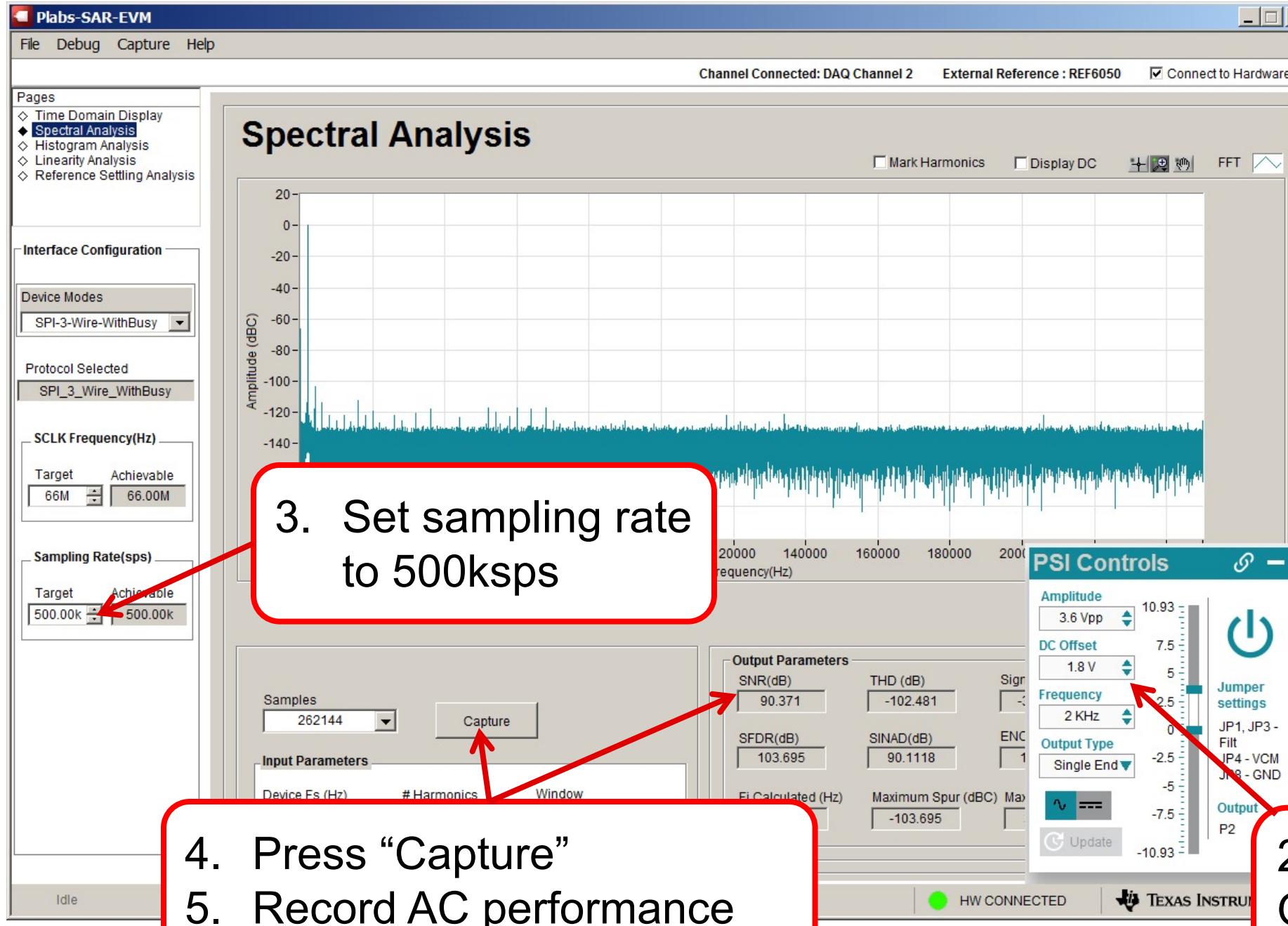
**Bandwidth Required:**  
 Gain Bandwidth= 4MHz  
**OPA316 Bandwidth:**  
 Gain Bandwidth= 10MHz

ADS8860\_OPA316 - Crossover-500ksps.TSC

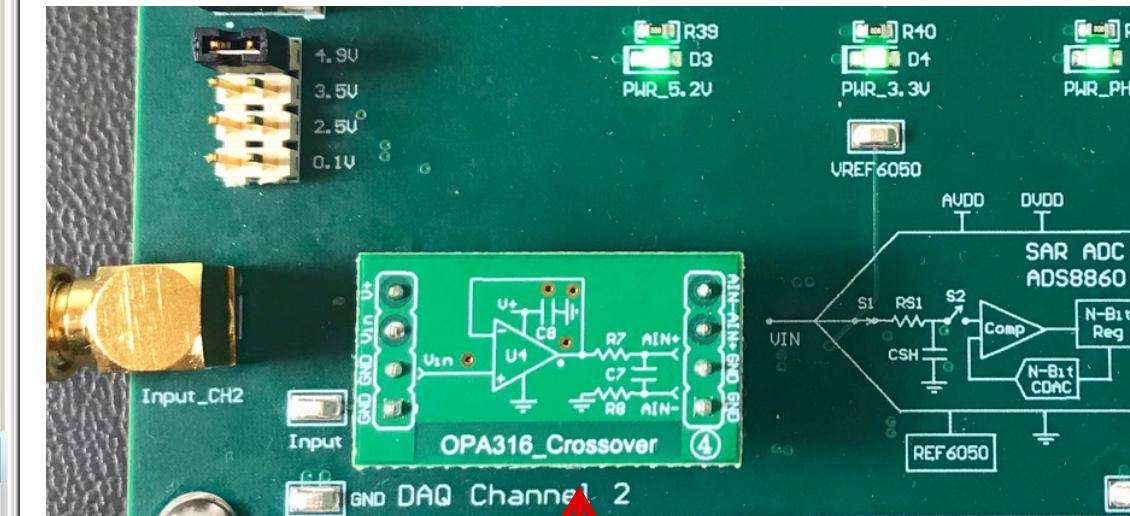


Error Target =  $38\mu\text{V}$   
 Simulate Error =  $47\mu\text{V}$

# OPA316 Crossover, fs = 500ksps



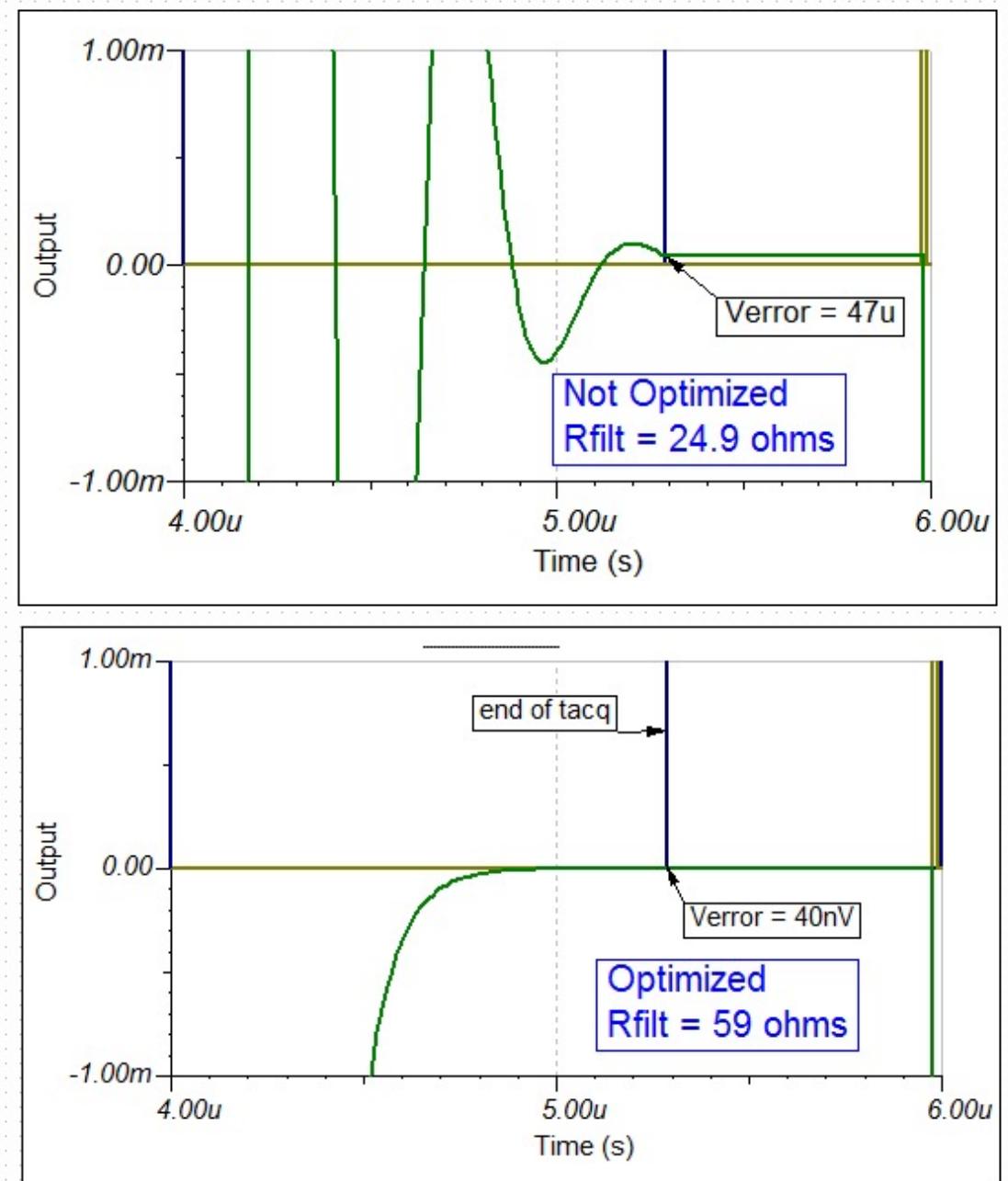
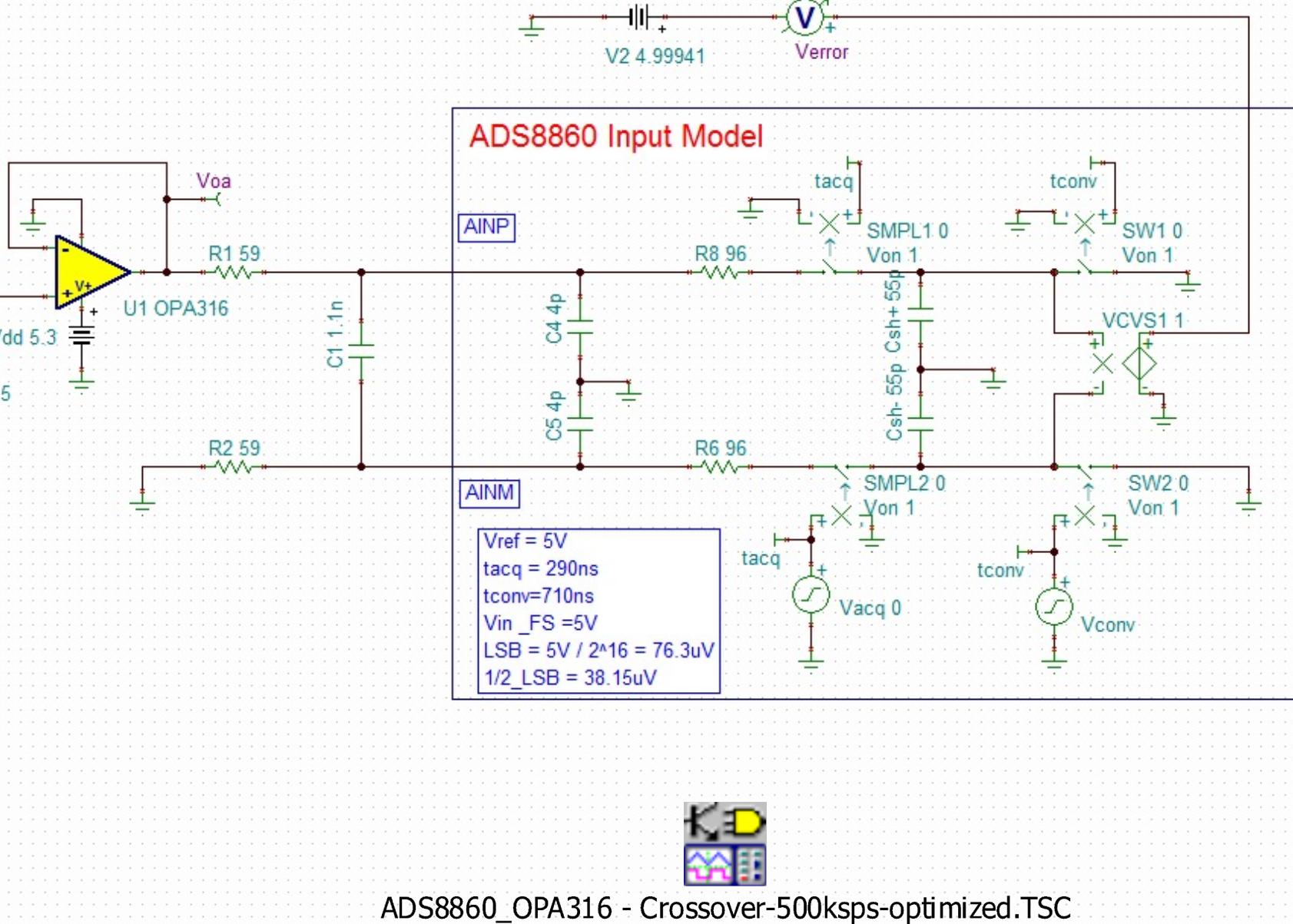
	SNR (dB)	THD (dB)
ADS8860	93	-108
Crossover 1Msps	86.1	-85.0
Crossover 500ksps	90.3	-102



1. No device change needed.

2. Amplitude = 3.6V  
Offset = 1.8V  
Frequency = 2kHz

# Settling can be improved



# Measured vs Expected Results

Your results should show the same trend as the expected result but the specific values will differ.

Device					Simulated Settling Error $\frac{1}{2}\text{LSB}=38\mu\text{V}$	Example Measurements		Your Measurements	
	Device	Samp. Rate	$V_{\text{offset}}$ (V)	$V_{\text{in}}$ (V)	$V_{\text{error}}$ (V)	SNR (dB)	THD (dB)	SNR (dB)	THD (dB)
	ADS8860 Data Sheet					93	-108		
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5	OPA316 Crossover	500k	1.8	3.6	47uV	90.3	-102.4		

# Thanks for your time!