Aliasing and Anti-aliasing Hands-on Experiment

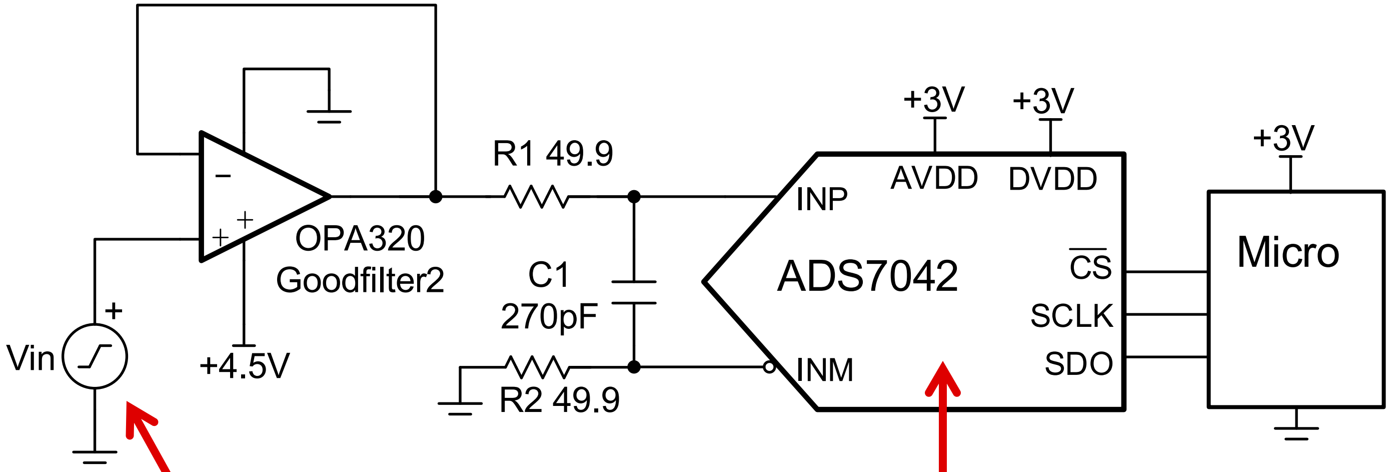
TIPL 4301-L
TI Precision Labs – ADCs

by Art Kay

Required/Recommended Equipment

- Calculation
  - Simple calculation using Nyquist theorem
  - Verification using Analog Engineer's Calculator
  - Anti-Aliasing filter hand calculations
- Simulation
  - Design of Anti-Aliasing filter using FilterPro™
  - Simulation of Anti-Aliasing filter using OPA320 Model
- Measurement
  - PLABS-SAR-EVM-PDK
  - http://www.ti.com/tool/plabs-sar-evm-pdk
  - Download EVM software and purchase EVM

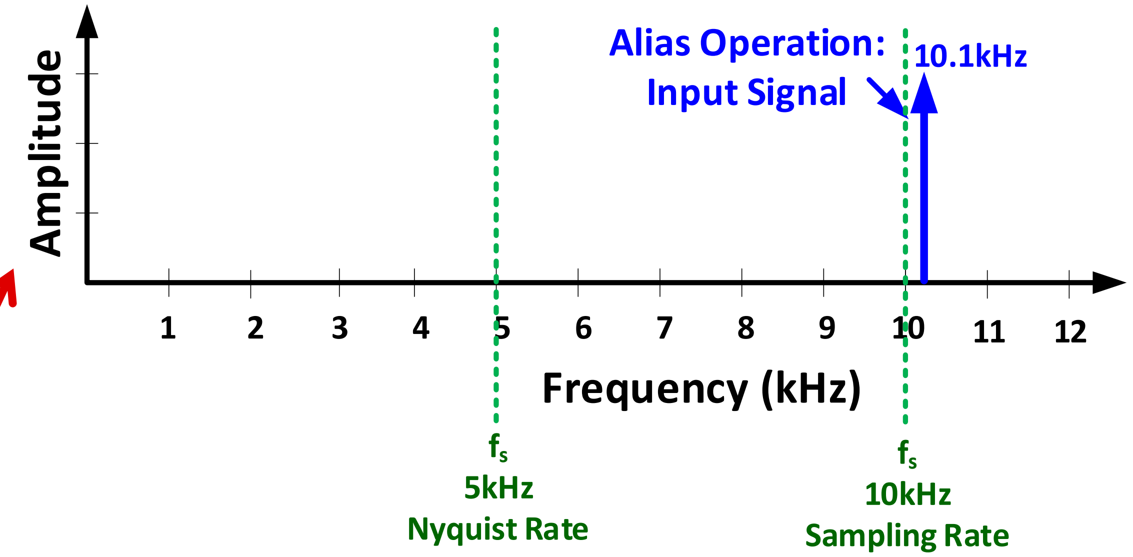
Fill in the Alias frequencies Given f_s and f_{in}

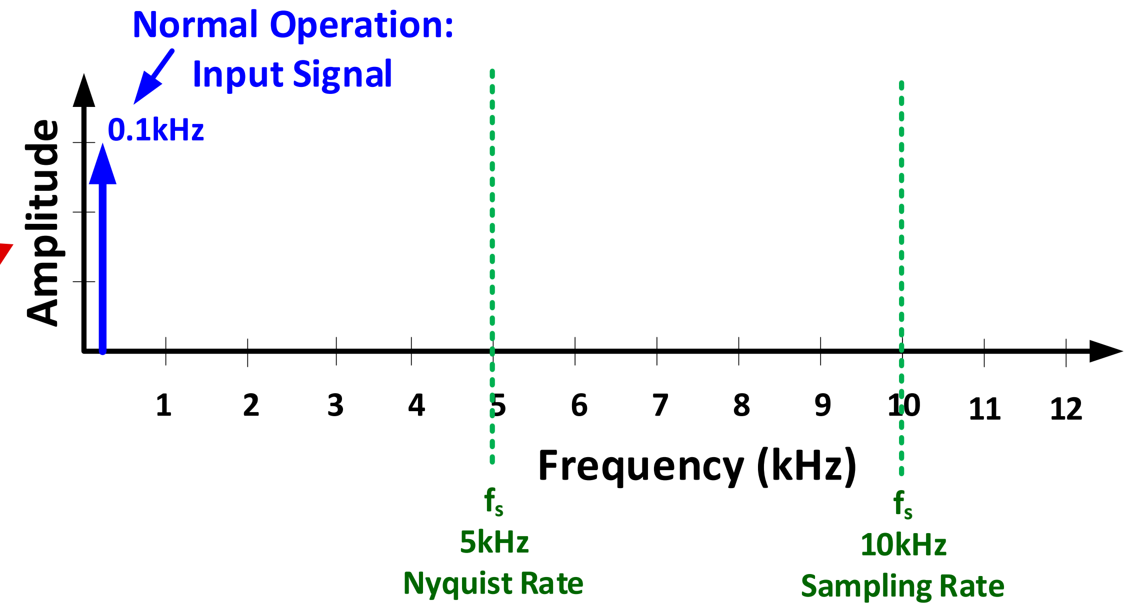


Signal Amplitude:
Vin = 2.9Vpp
Vcm = 1.5V
Normal Operation:
f_{in} = 0.1kHz
Alias Operation:
f_{in} = 10.1kHz

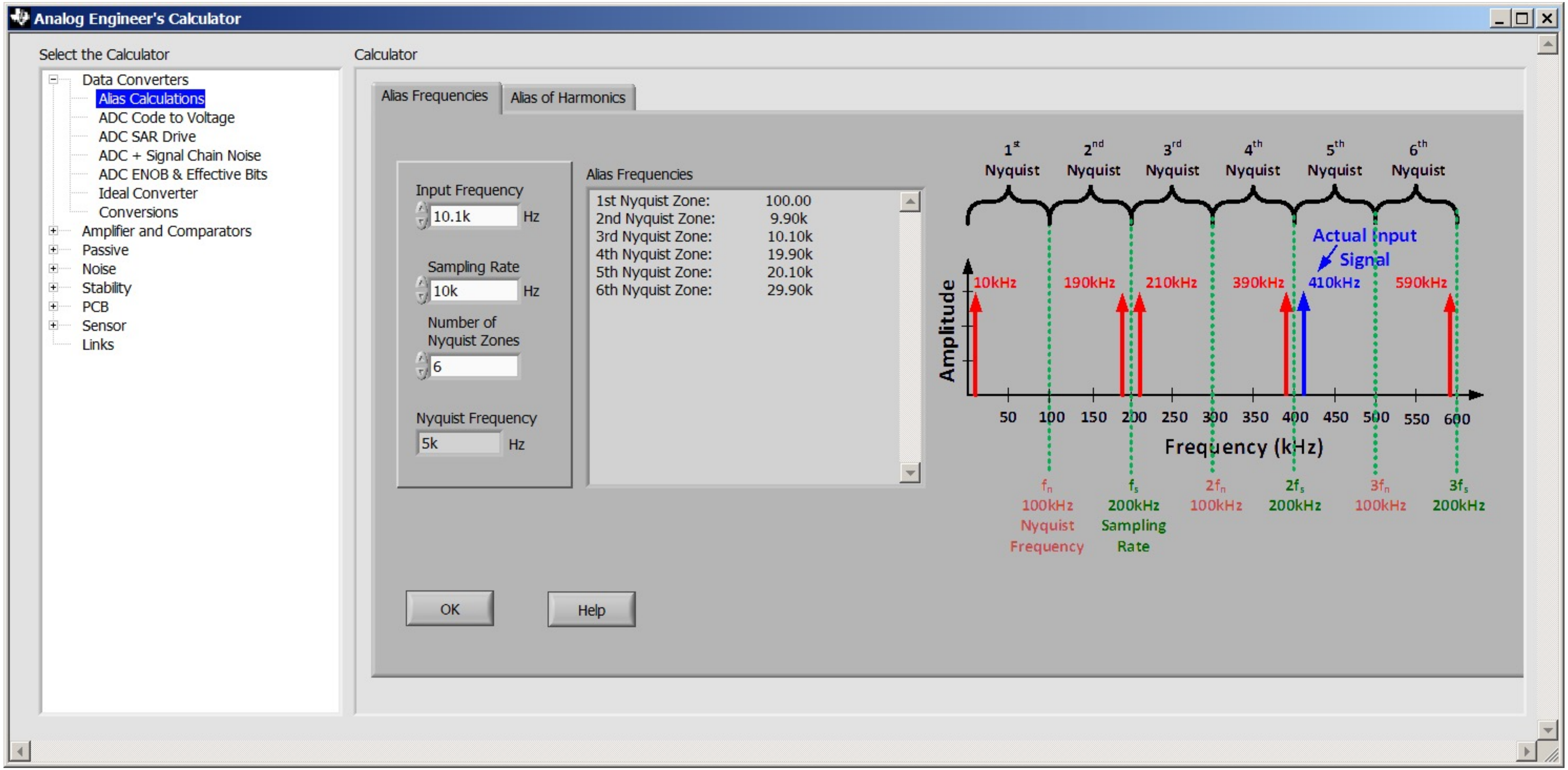
Sampling rate:
f_s = 10ksps

Fill in all the alias frequencies in the diagrams.



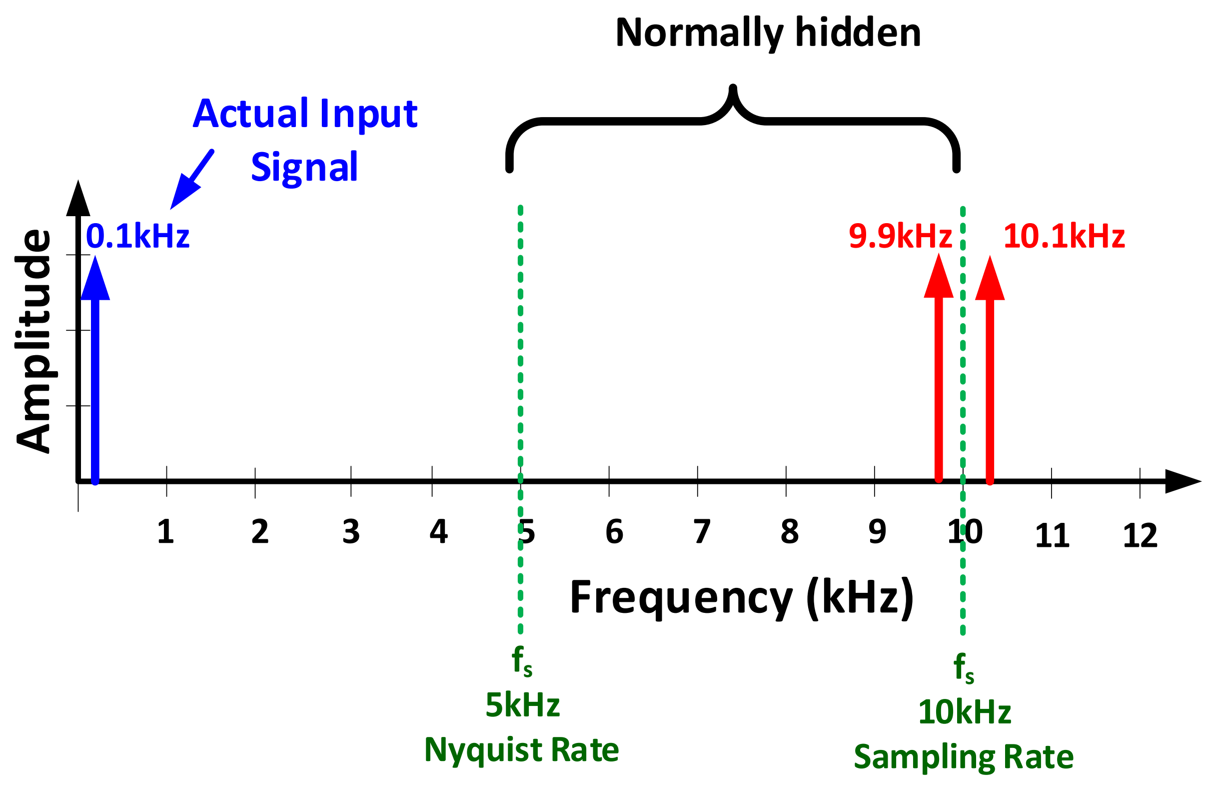


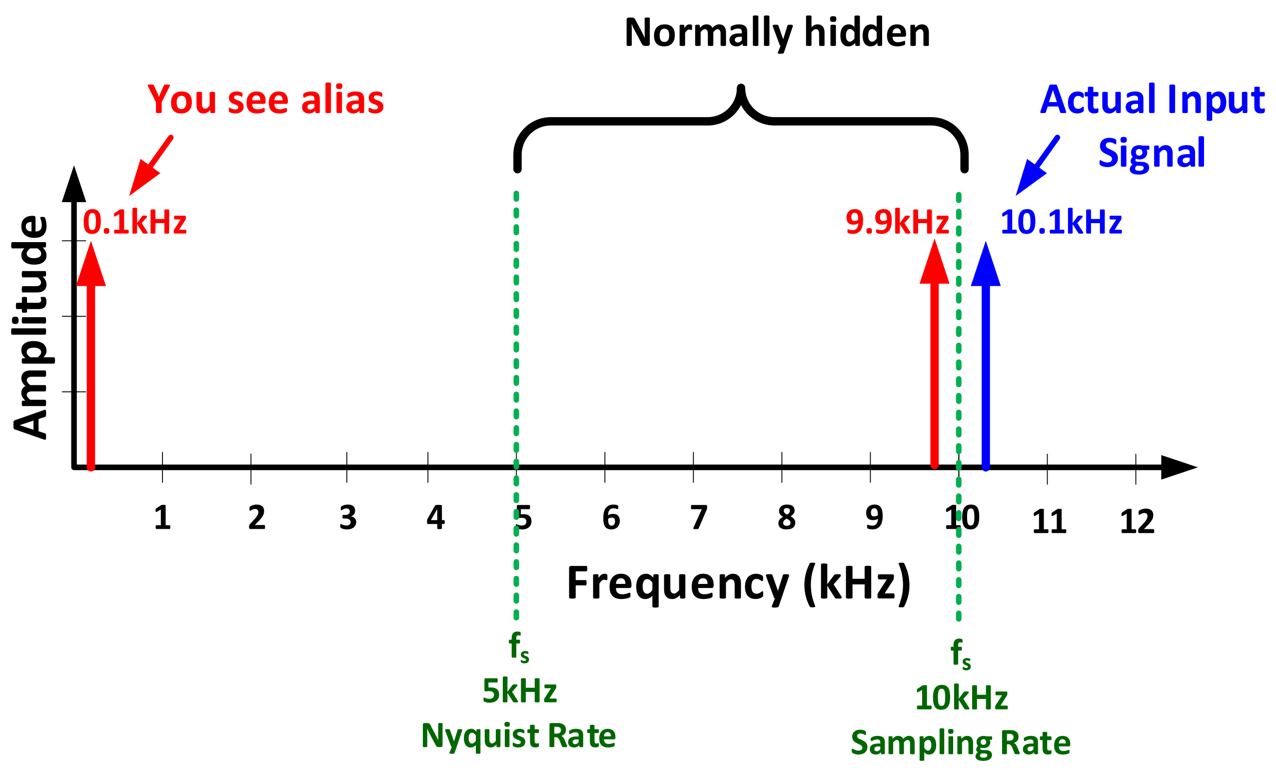
Analog Engineers Calculator: find Alias frequencies

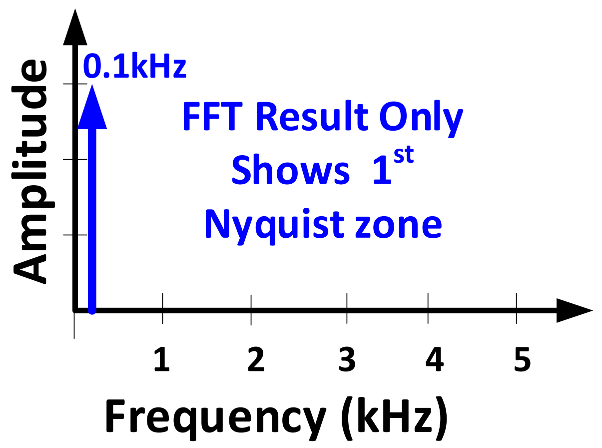


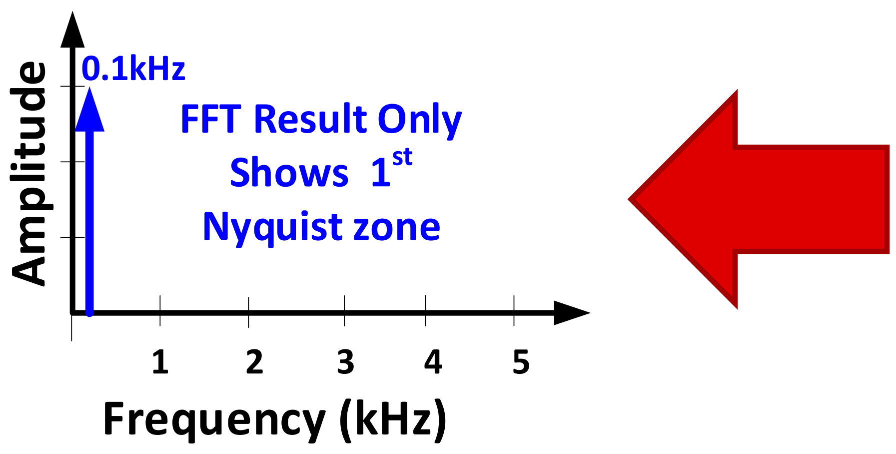
http://www.ti.com/tool/analog-engineer-calc

Solutions: Normal Operation vs. Aliased Signal









You see the same FFT results for both a 0.1kHz and 10.1kHz input signal.

Hand Calculation to Find Alias Frequencies

Equation

$$f_{alias} = |k \cdot f_s + f_{in}|$$

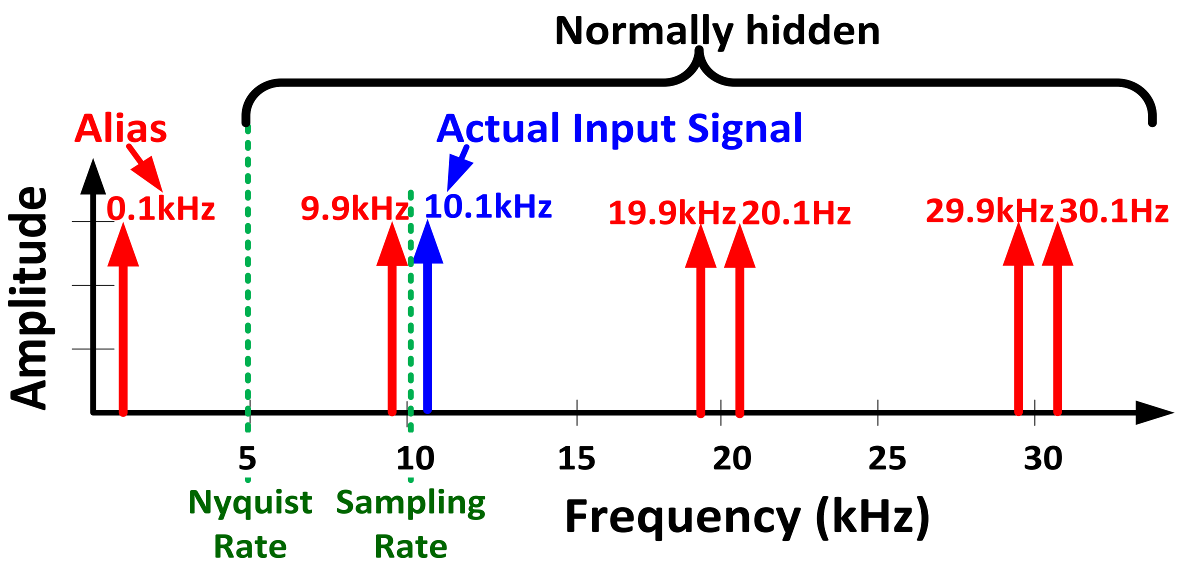
Where

k = -N…-2, -1, 0, 1, 2 …N

N = Nyquist Zones

f_s = sampling rate

f_{in} = input frequency



Example

$k = \cdots - 4, -3, -2, -1, 0, 1, 2 \cdots$

$f_s = 10kHz$

$f_{in} = 10.1kHz$

$f_{alias} = |n \cdot f_s + f_{in}|$

$f_{alias}(-4) = |-4 \cdot 10kHz + 10.1kHz| = 29.9kHz$

$f_{alias}(-3) = |-3 \cdot 10kHz + 10.1kHz| = 19.9kHz$

$f_{alias}(-2) = |-2 \cdot 10kHz + 10.1kHz| = 9.9kHz$

$f_{alias}(-1) = |-1 \cdot 10kHz + 10.1kHz| = 0.1kHz$

$f_{alias}(0) = (0 \cdot 10kHz + 10.1kHz) = 10.1kHz$

$f_{alias}(1) = (1 \cdot 10kHz + 10.1kHz) = 20.1kHz$

$f_{alias}(2) = (2 \cdot 10kHz + 10.1kHz) = 30.1kHz$

Design an Anti-aliasing Filter: find Cutoff

System Requirements

f_s = 10kHz, $f_{Nyquist}$ = 5kHz

$V_{in@Nyquist}$ = 20mVpp, FSR = 3V

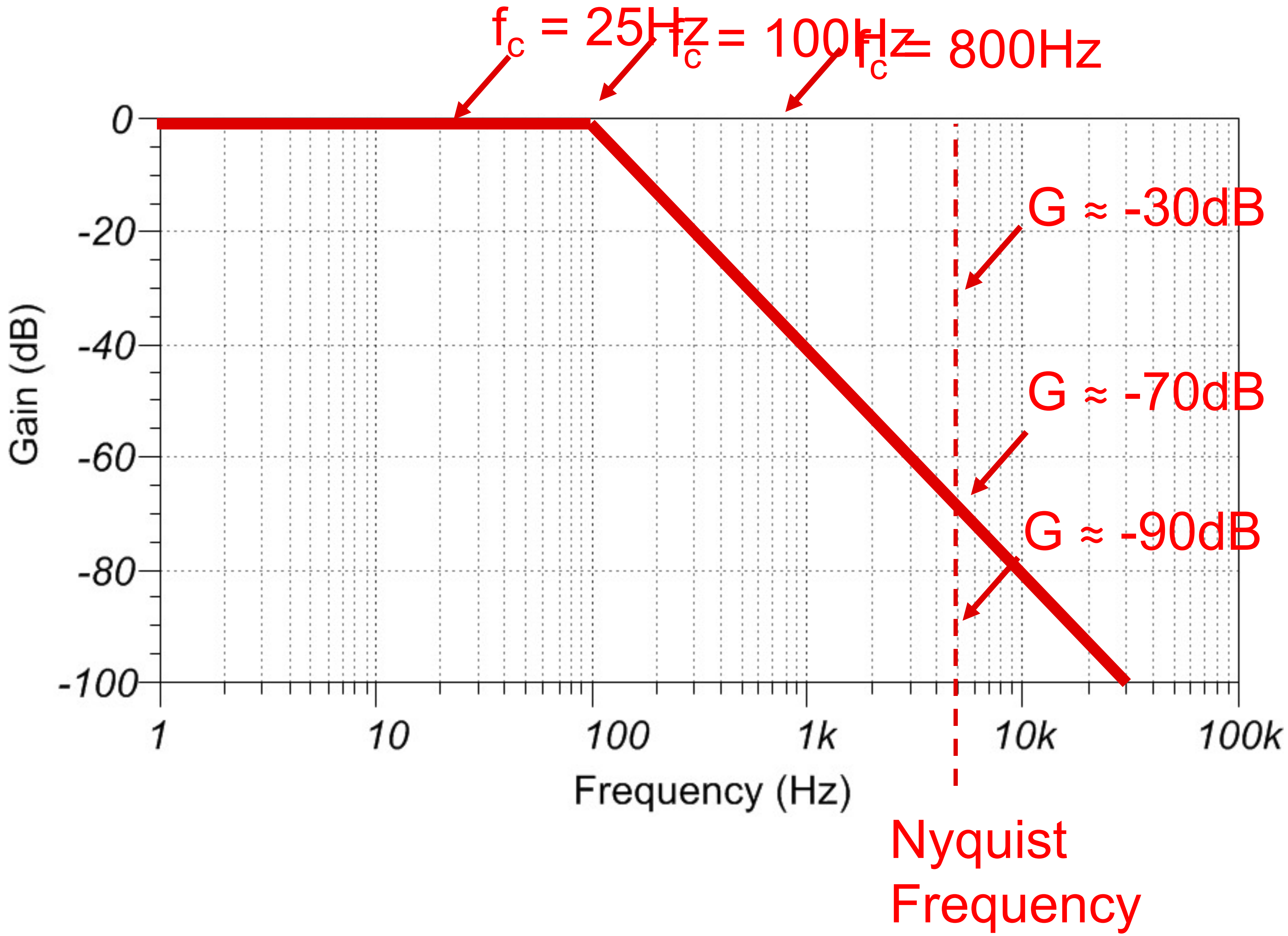
Resolution = 12 bits

Filter Specifications:

2nd Order Filter, find f_c

Goal:

Find f_c to attenuate the 20mVpp alias at the Nyquist frequency to less then half an LSB.



Design an Anti-aliasing Filter: find Cutoff

System Requirements

f_s = 10kHz, $f_{Nyquist}$ = 5kHz

$V_{in@Nyquist}$ = 20mVpp, FSR = 3V

Resolution = 12 bits

Filter Specifications:

2nd Order Filter, find f_c

Goal:

Find f_c to attenuate the 20mV alias at the Nyquist frequency to less then half an LSB.

$$0.5LSB = 0.5\left(\frac{FSR}{2^N}\right) = 0.5\left(\frac{3V}{2^{12}}\right) = 366\mu V$$

Find the required attenuation

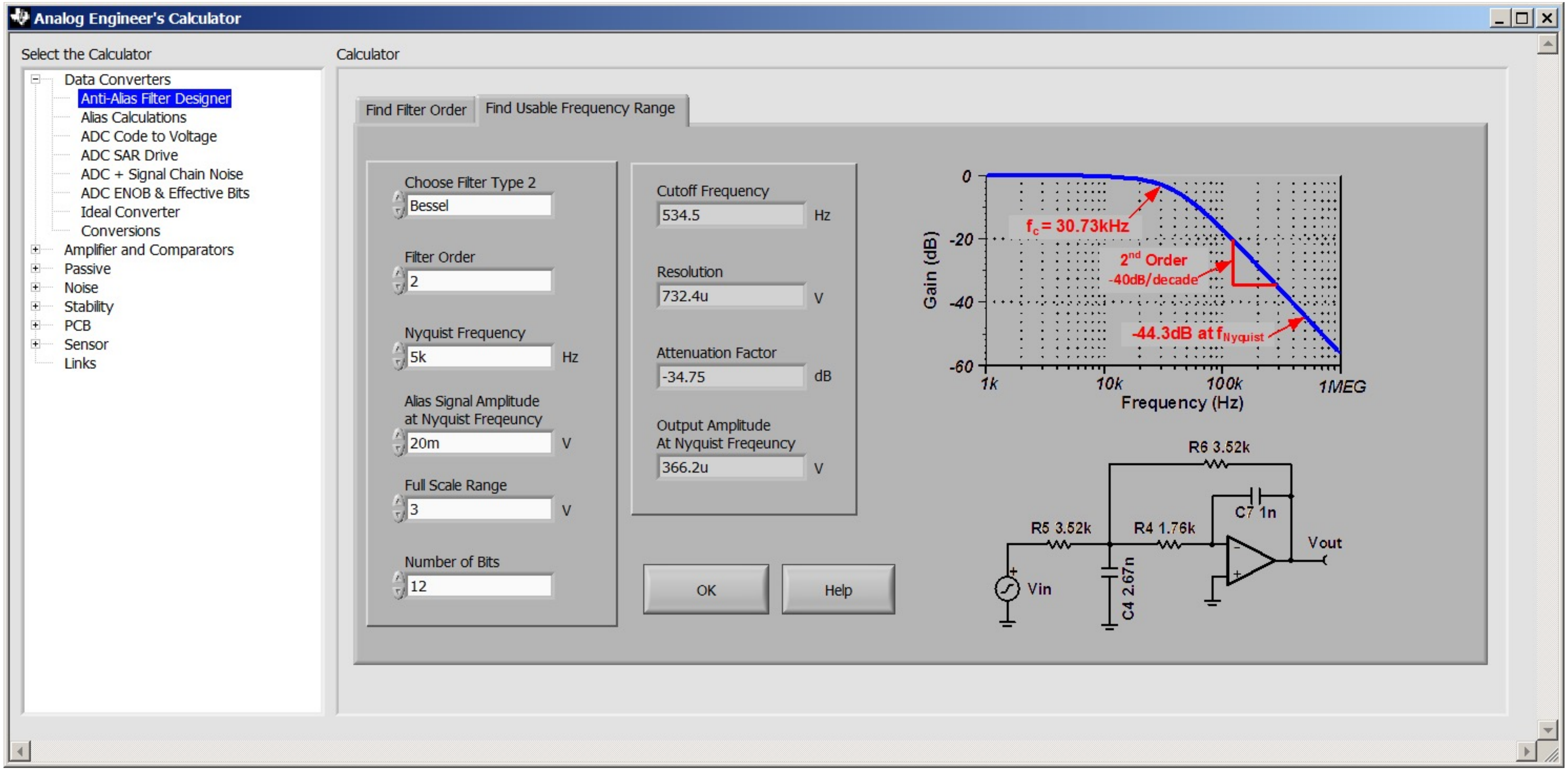
$$G = \frac{0.5LSB}{V_{in@Nyquist}} = \frac{366\mu V}{20mV} = 18.31mV/V, -34.7dB$$

Find f_c for G = 18.31mV/V at f = $f_{Nyquist}$ = 5kHz

$$|G(f)| = \frac{1.622}{\sqrt{\left(\frac{f}{f_c}\right)^4 + 1.622\left(\frac{f}{f_c}\right)^2 + 2.631}}$$

Not a closed form equation!

Calculator: Find Antialiasing Filter Cutoff



Design an Anti-aliasing Filter: find Order

System Requirements

f_s = 10kHz, $f_{Nyquist}$ = 5kHz

$V_{in@Nyquist}$ = 20mV, FSR = 3V

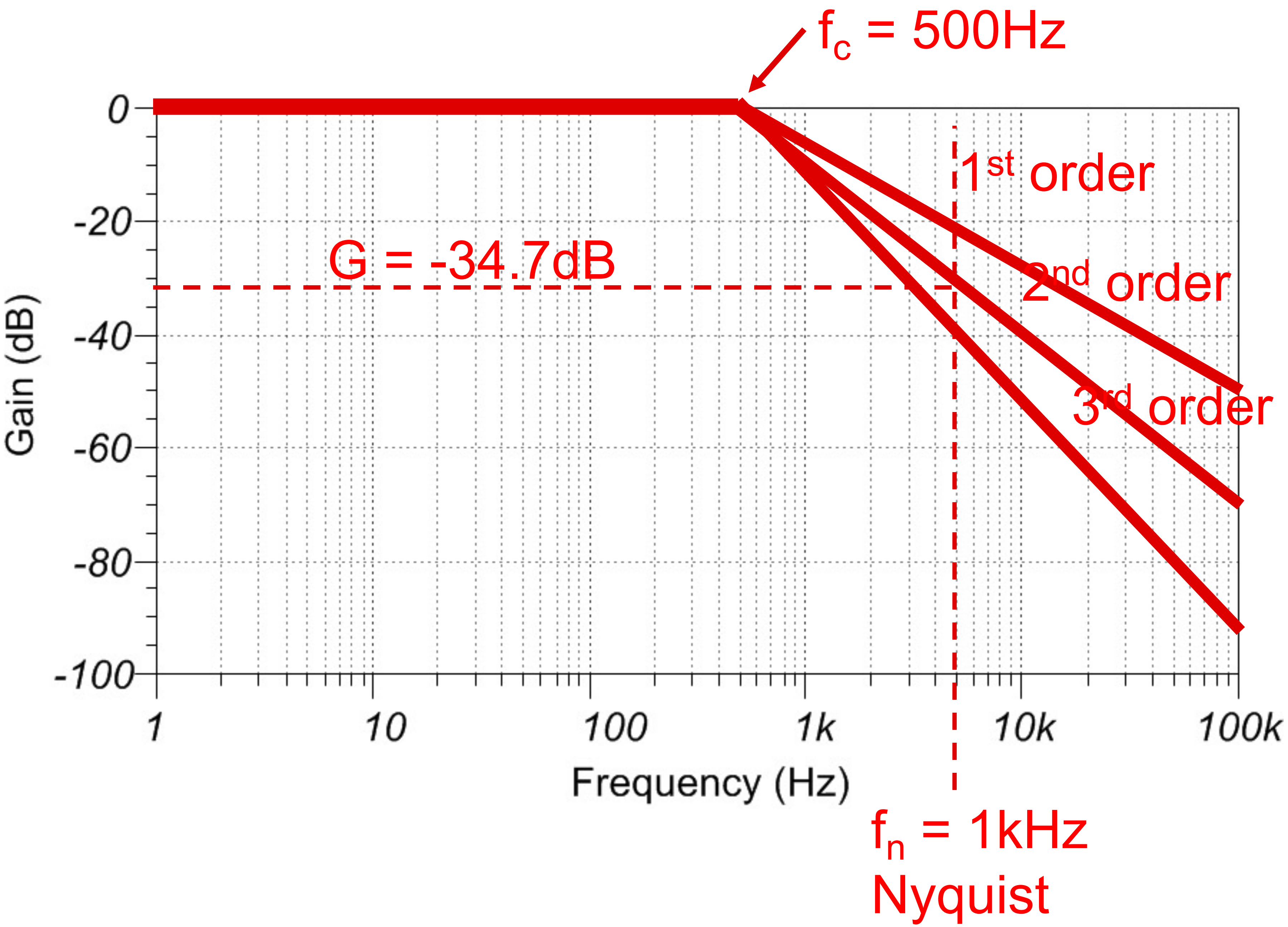
Resolution = 12 bits

Filter Specifications:

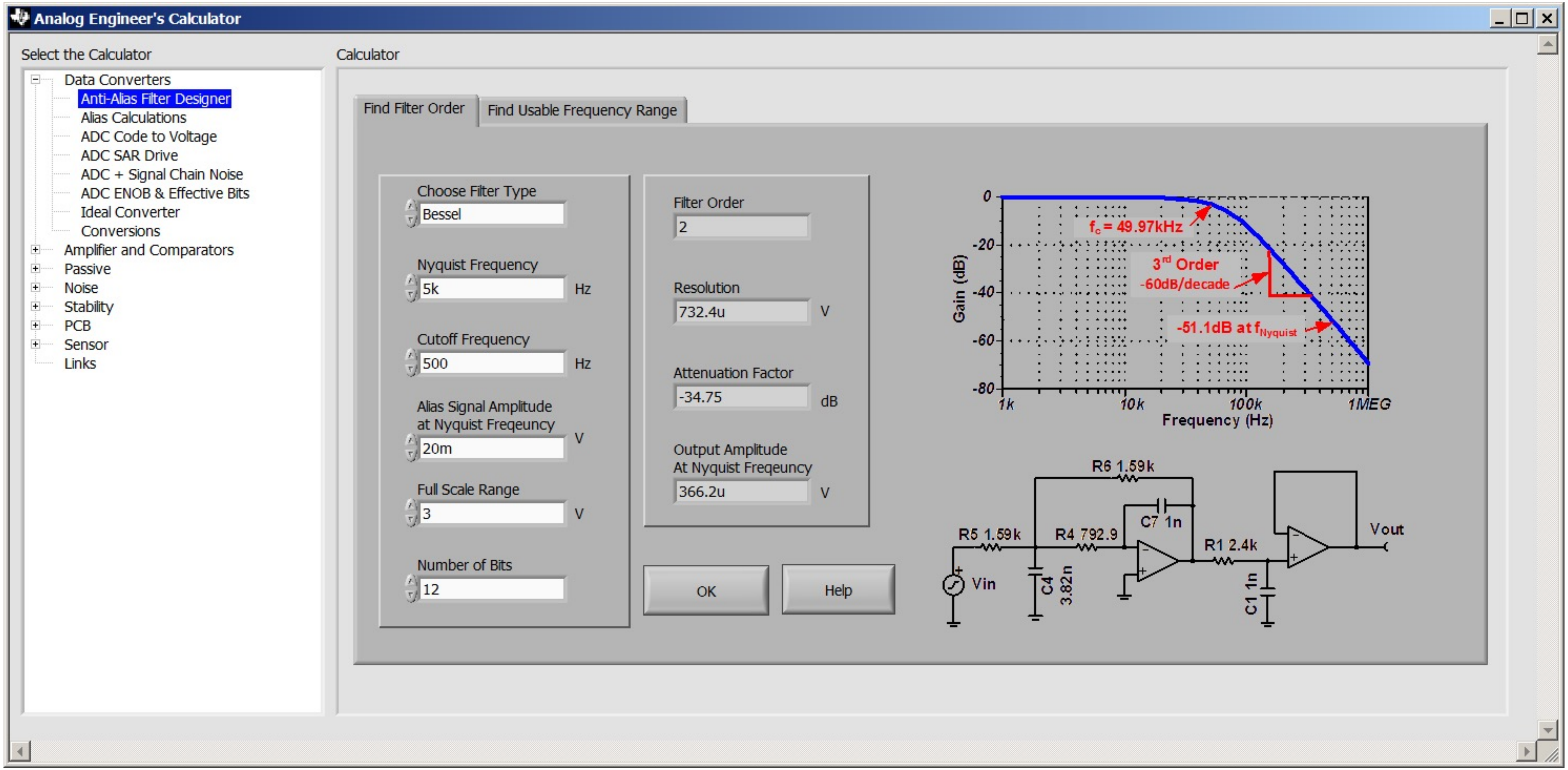
f_c= 1kHz, find Order

Goal:

Find the order to to attenuate the 20mV alias at the Nyquist frequency to less then half an LSB. From previous design Gain is -34.7dB.



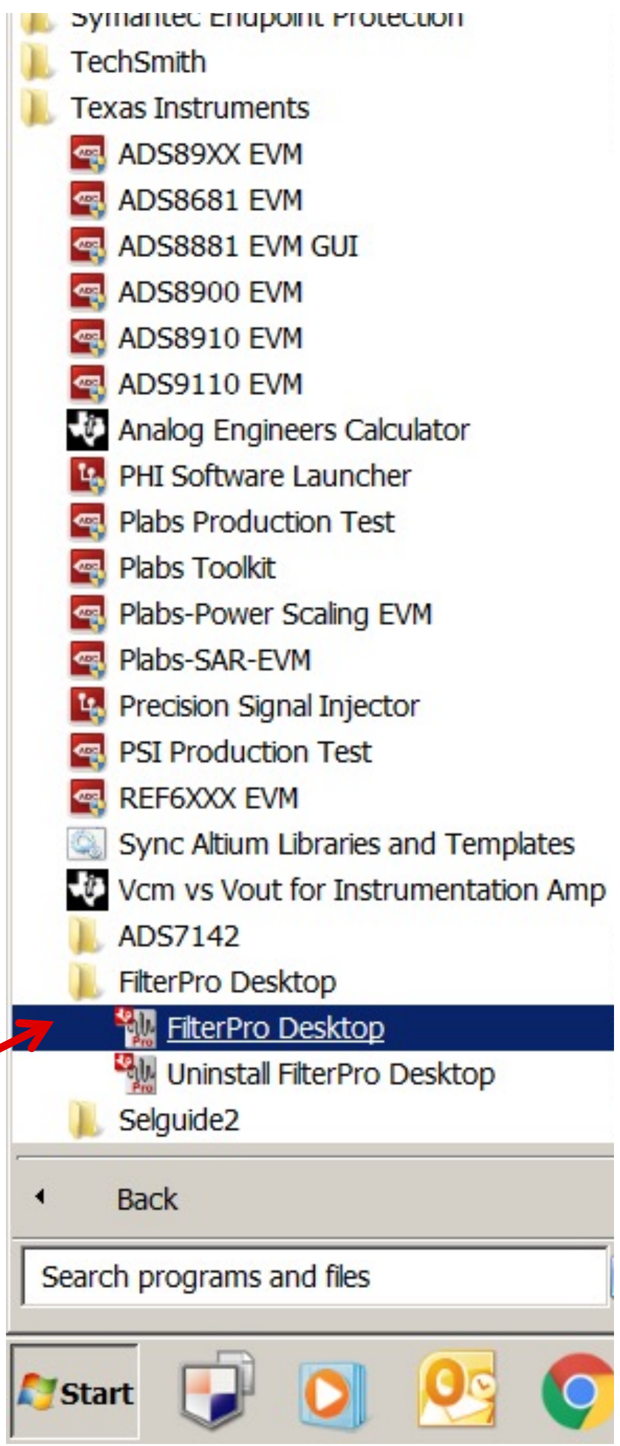
Calculator: Find Antialiasing Filter Order



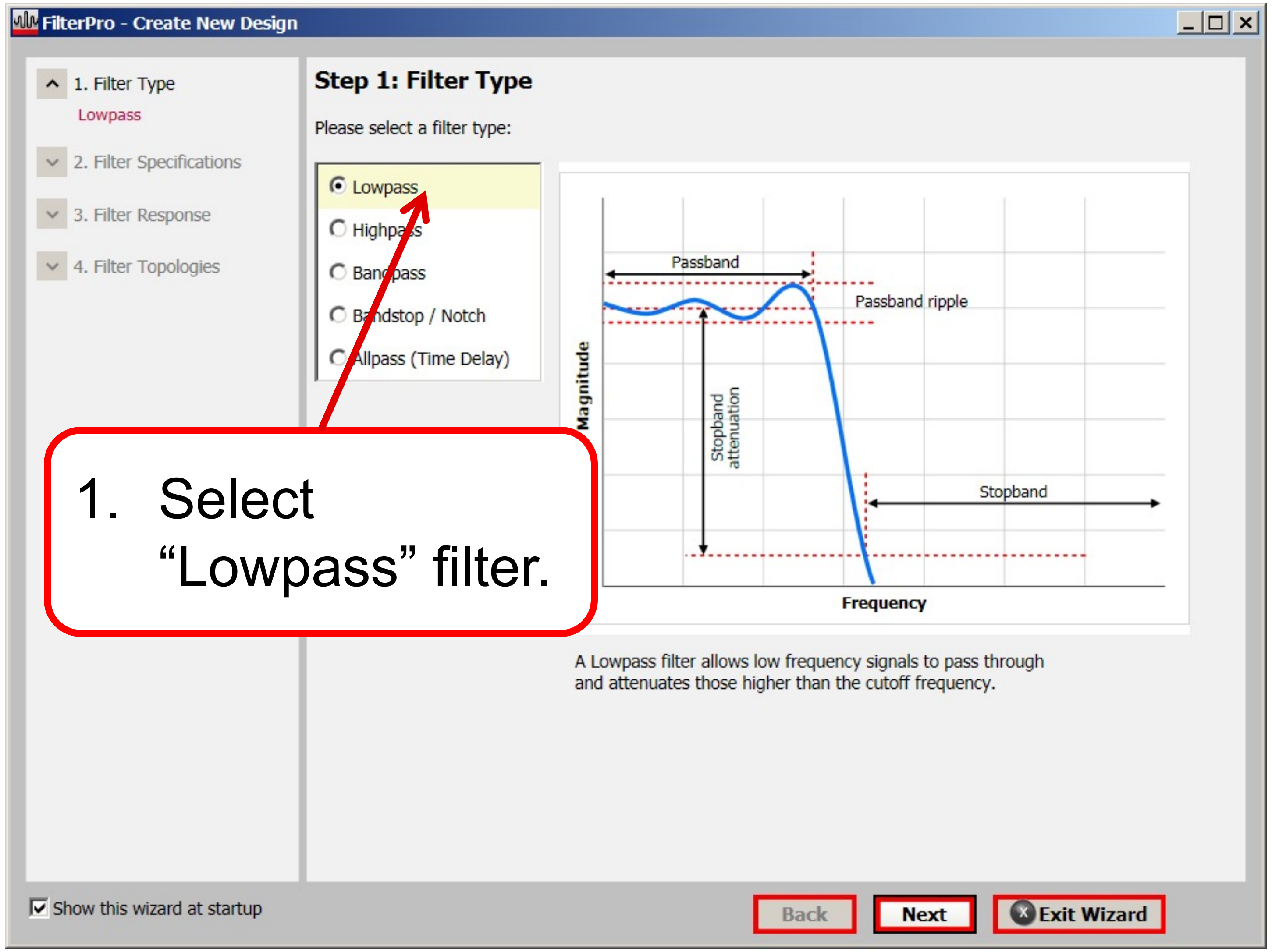
Designing the Antialiasing filter

- Download FilterPro v3.1
- http://www.ti.com/filterpro-dt
- Active filter design software.

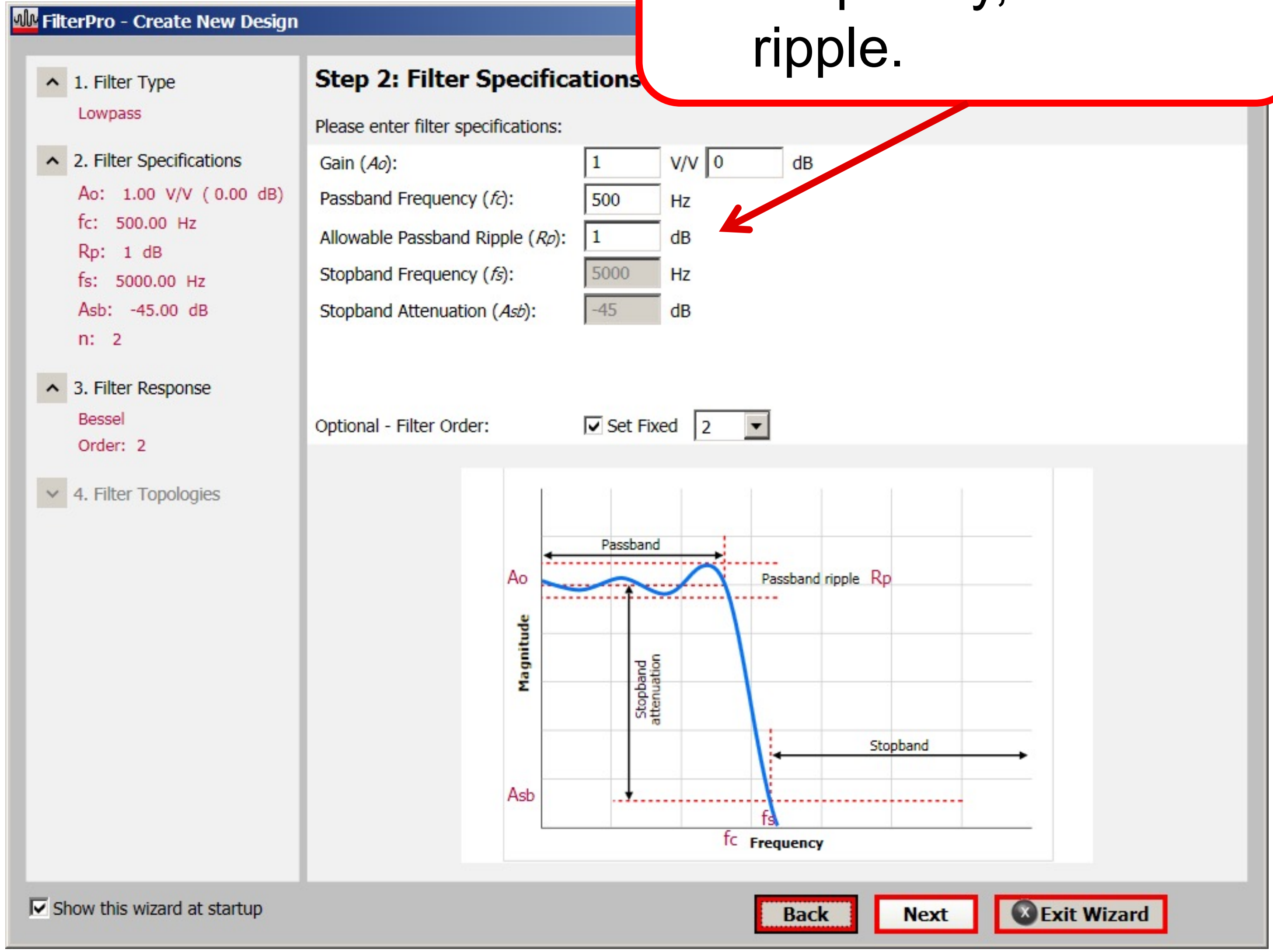
Run from
Texas Instruments > FilterPro Desktop



Designing the Antialiasing filter

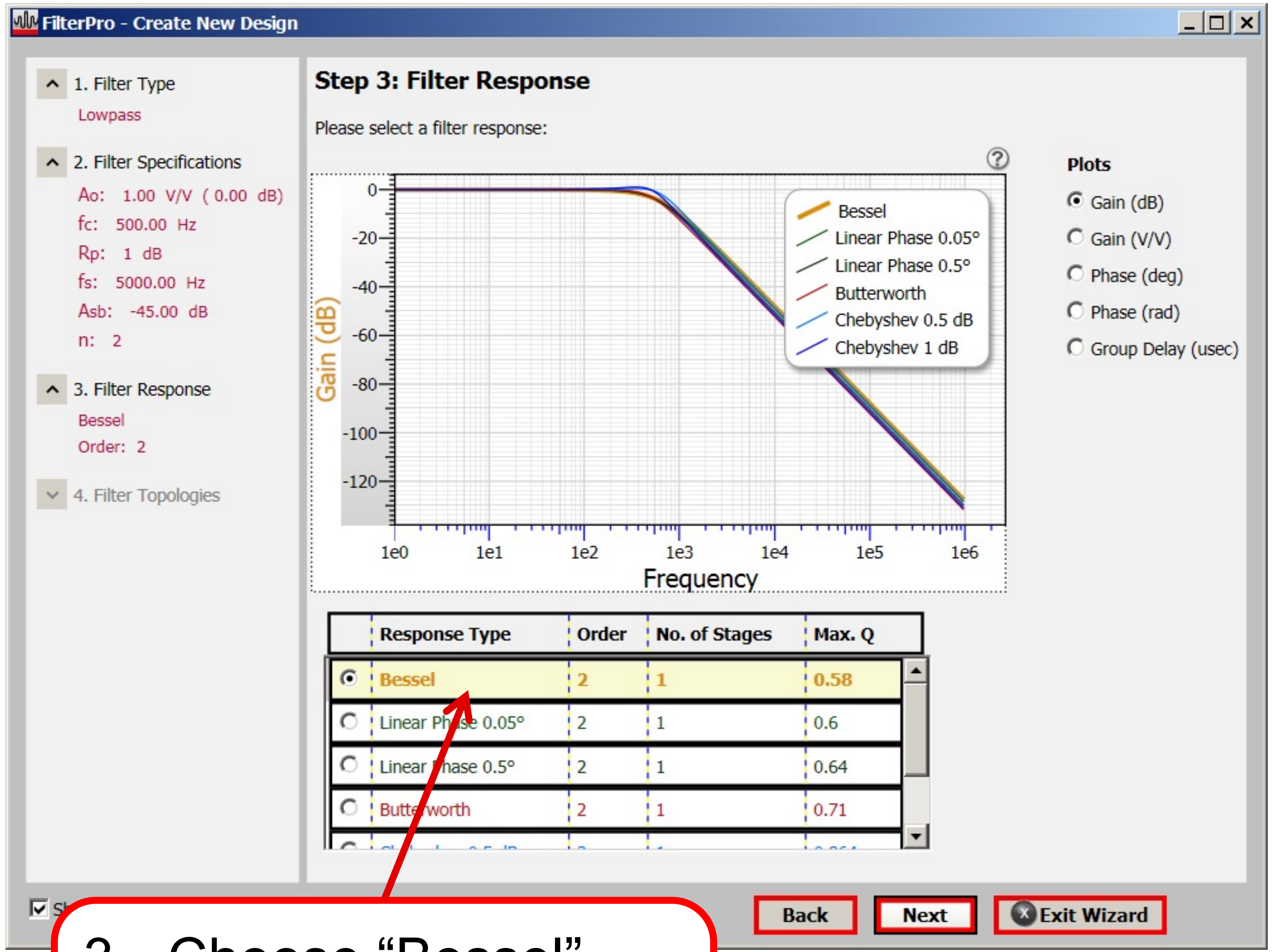


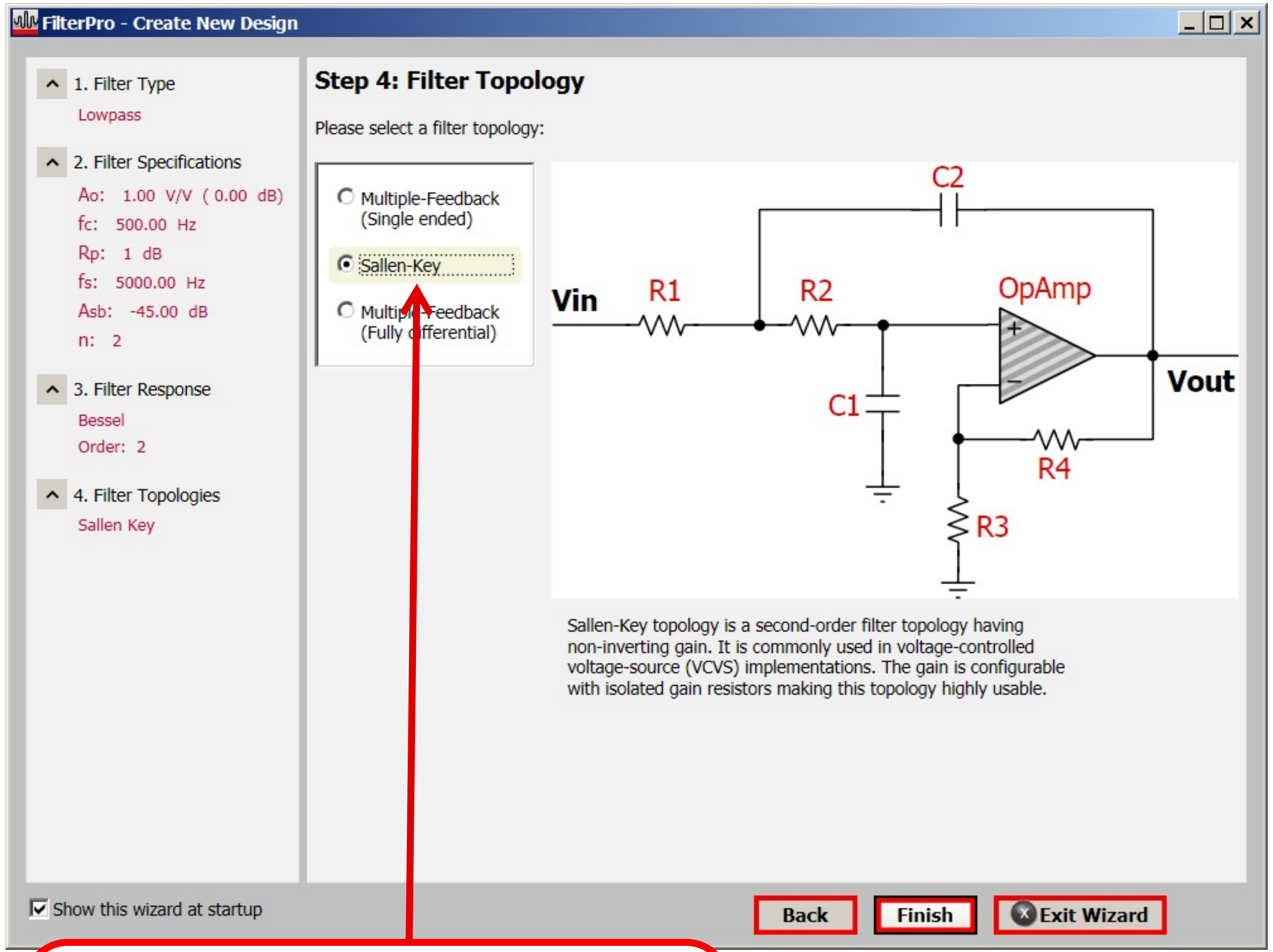
1. Select "Lowpass" filter.



2. Enter gain, cutoff frequency, maximum ripple.

Designing the Antialiasing filter



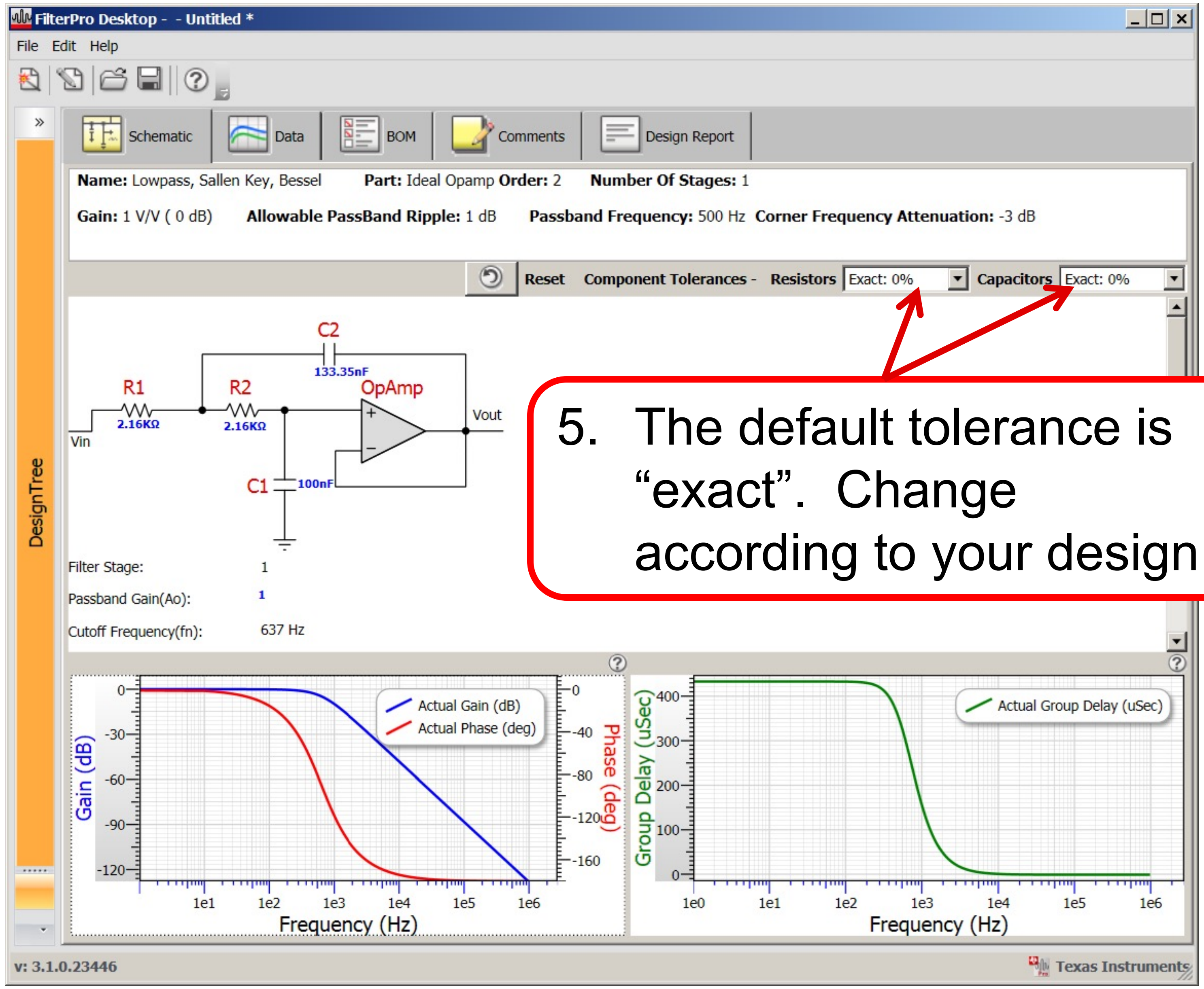


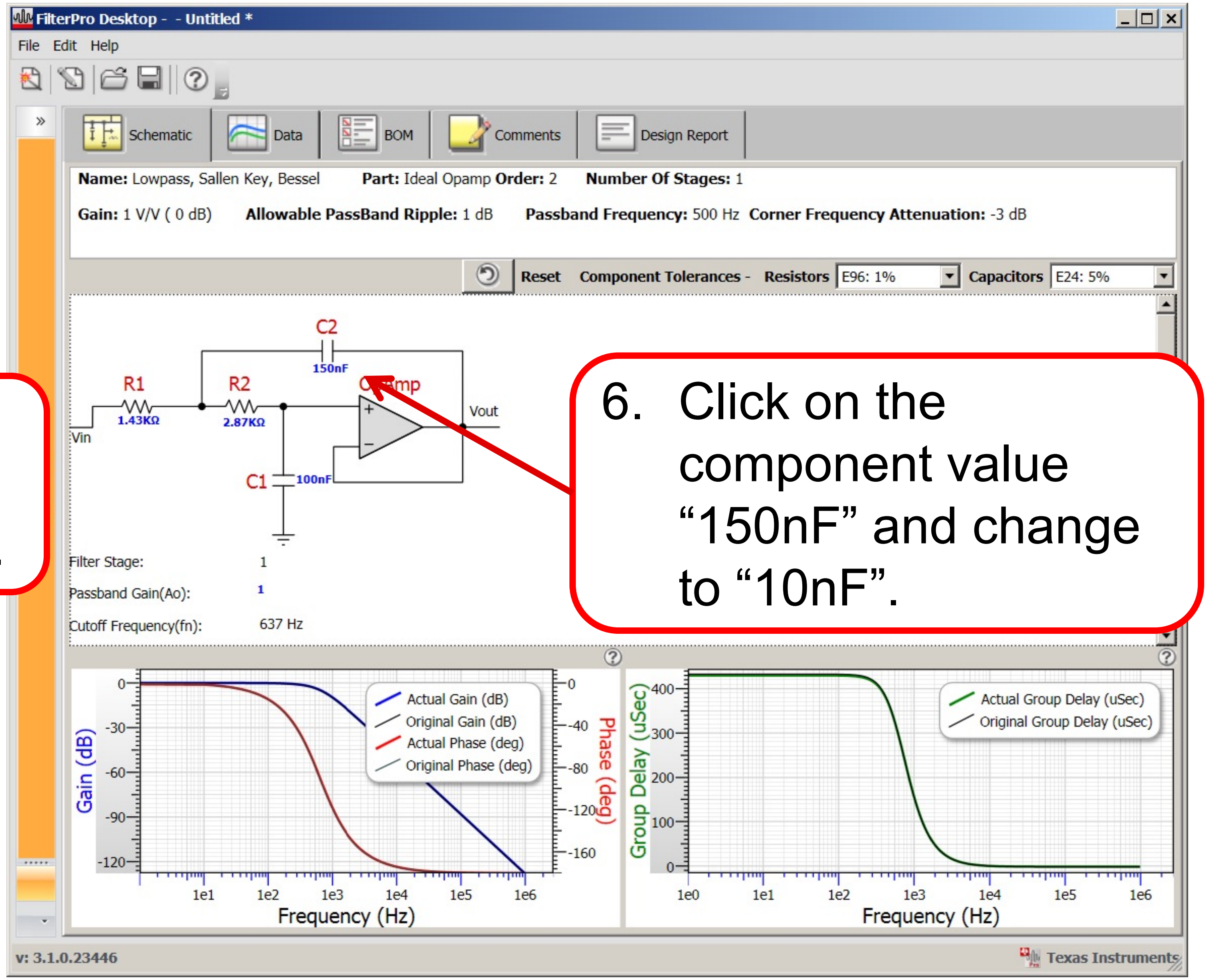
3. Choose "Bessel" type for maximally flat response.

4. Choose "Sallen-Key" topology for non-inverting functionality.

www.ti.com/lit/pdf/sloa049

Designing the Antialiasing filter

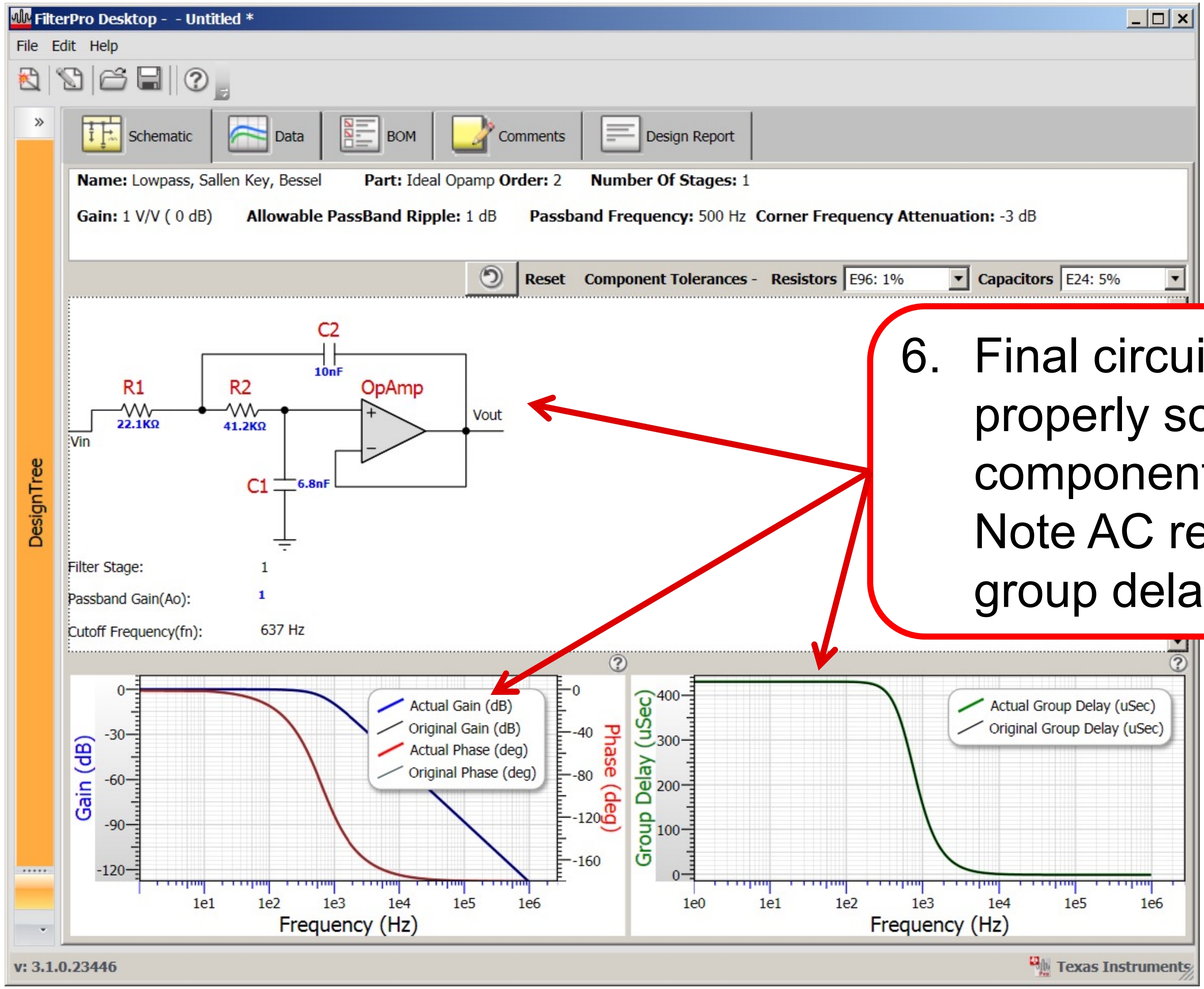




5. The default tolerance is “exact”. Change according to your design.

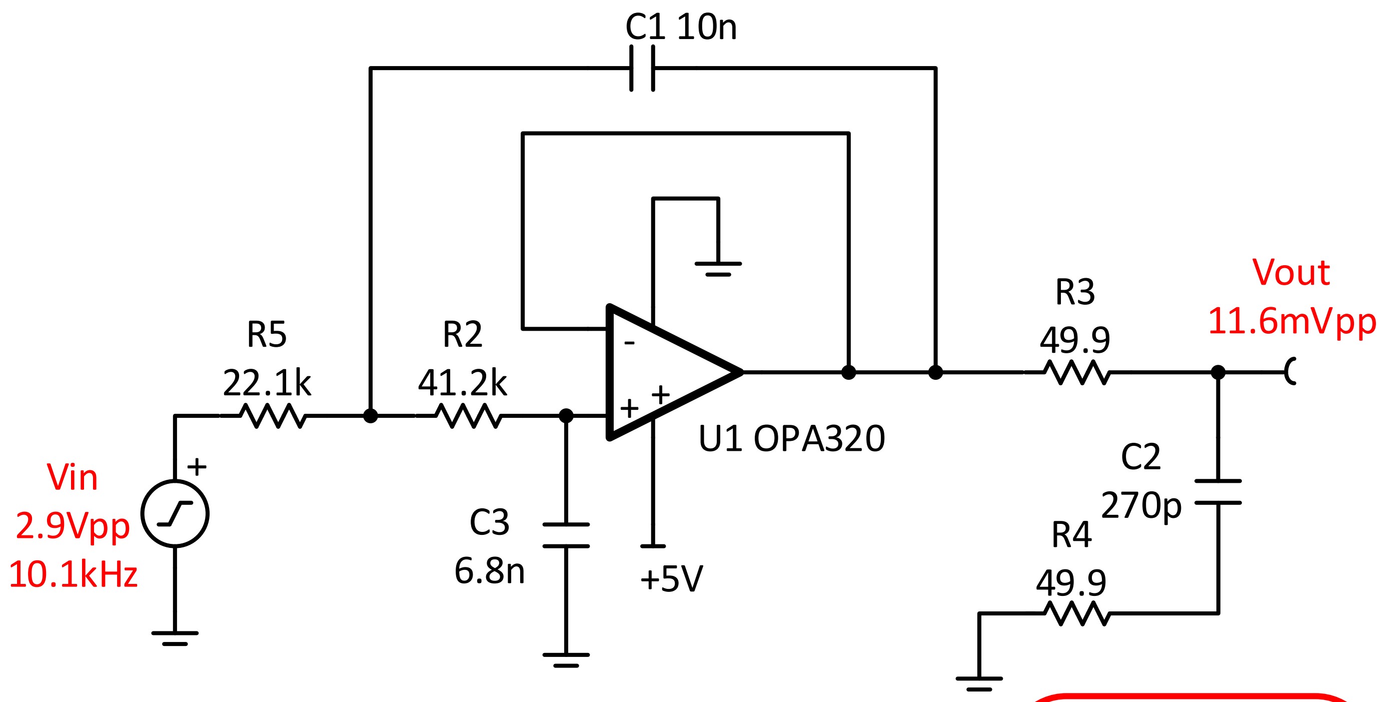
6. Click on the component value “150nF” and change to “10nF”.

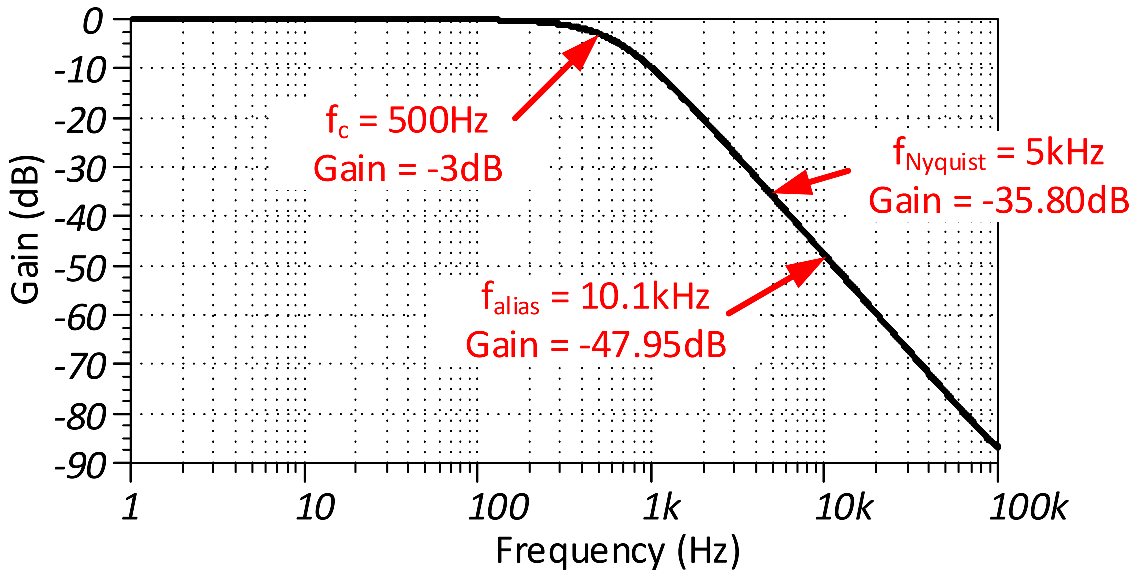
Designing the Antialiasing filter



6. Final circuit with properly scaled component values. Note AC response and group delay below.

Add an Antialiasing Sallen-Key Filter



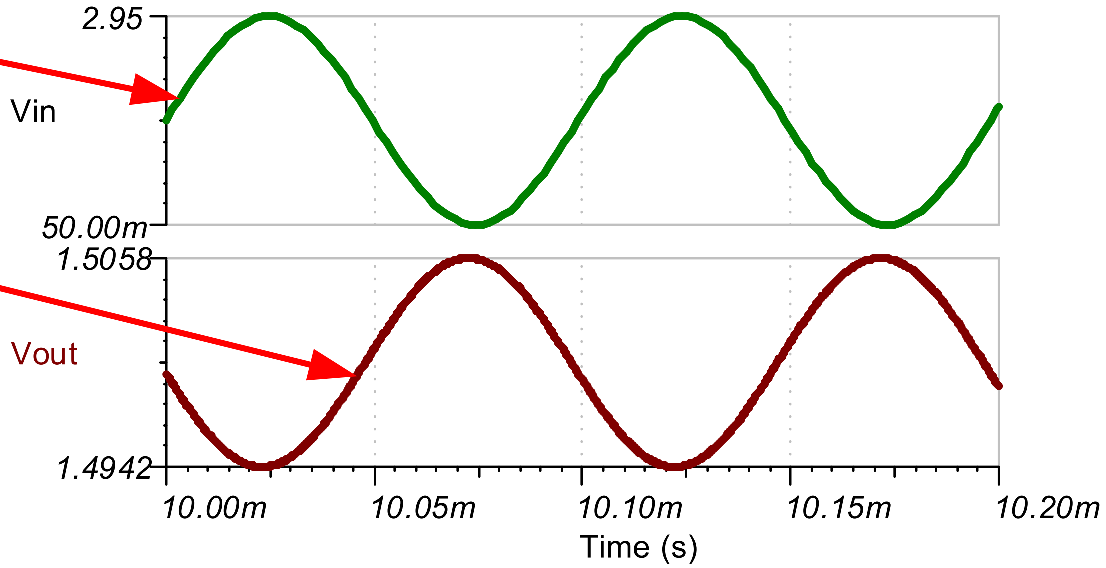


Output at 10.1kHz

$$V_{out} = (2.9V)\cdot\left(10^{\left(\frac{-47.95dB}{20}\right)}\right) = 11.6mV$$

Vin
10.1kHz, 2.9Vpp

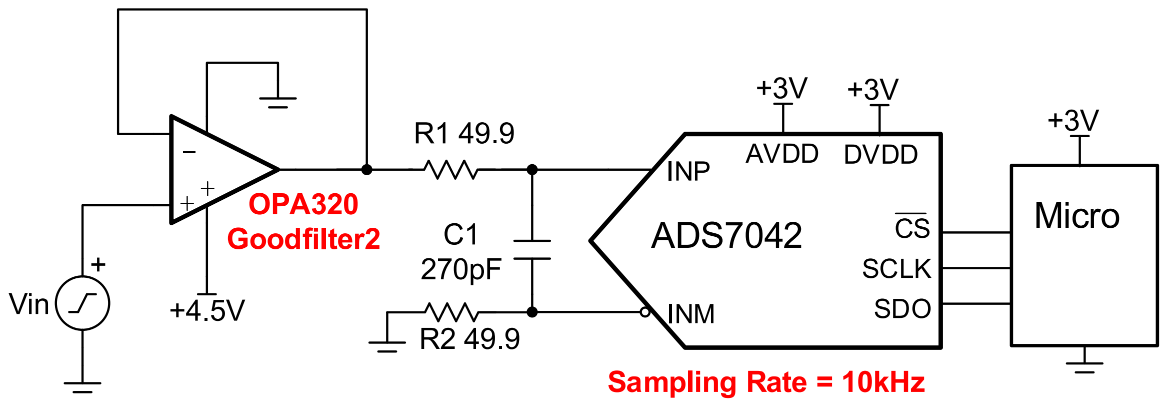
Vout
10.1kHz, 11.6mVpp

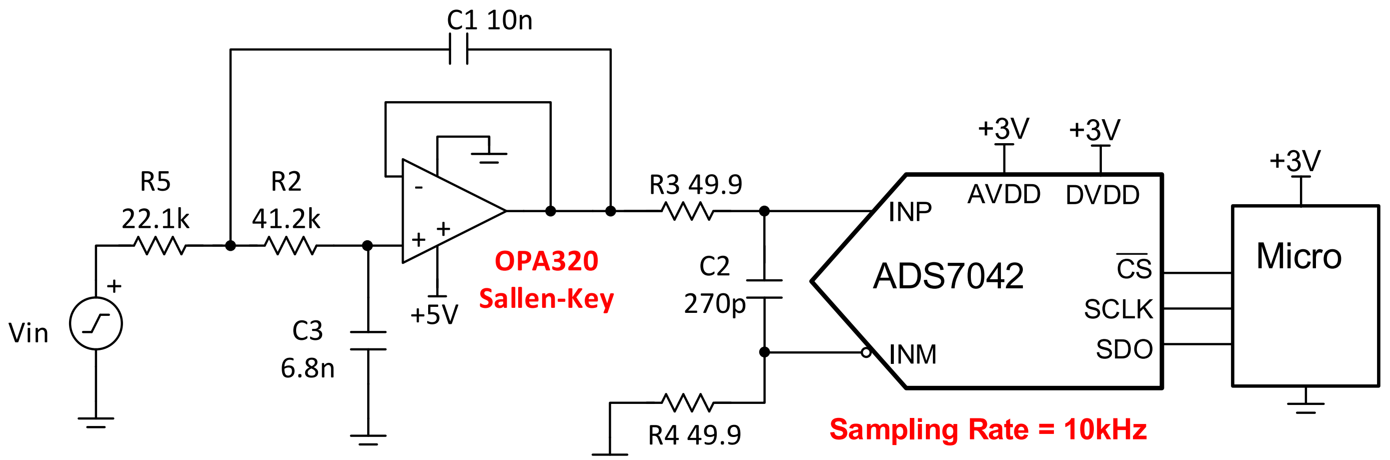


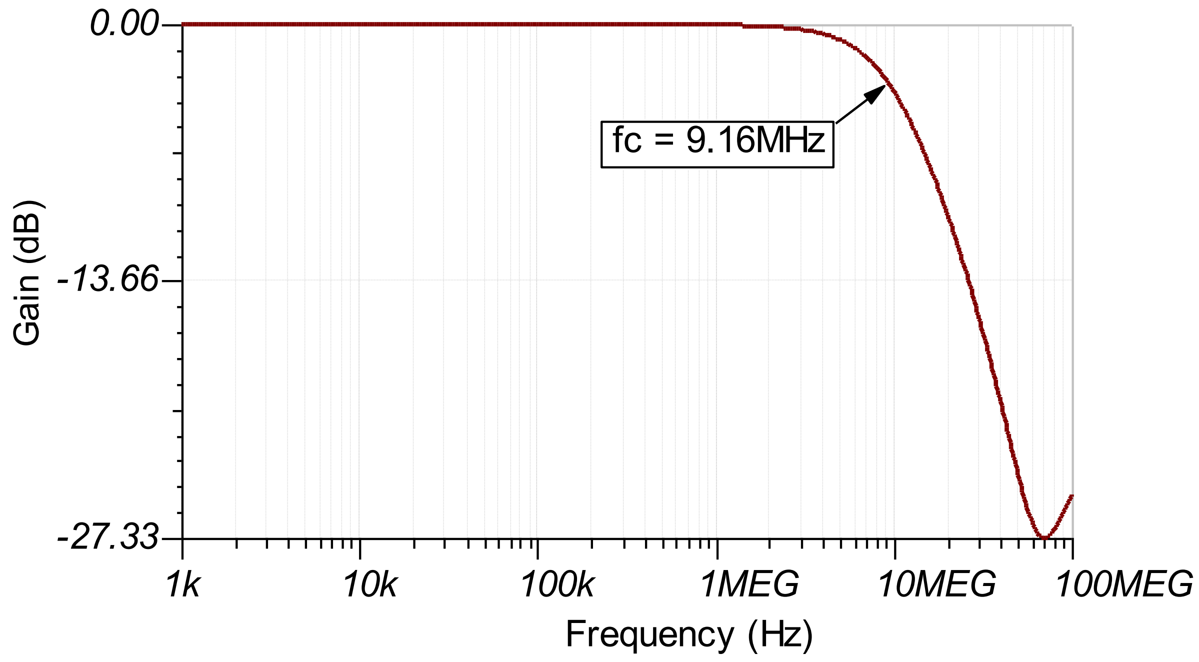
Click here to open TINA file.

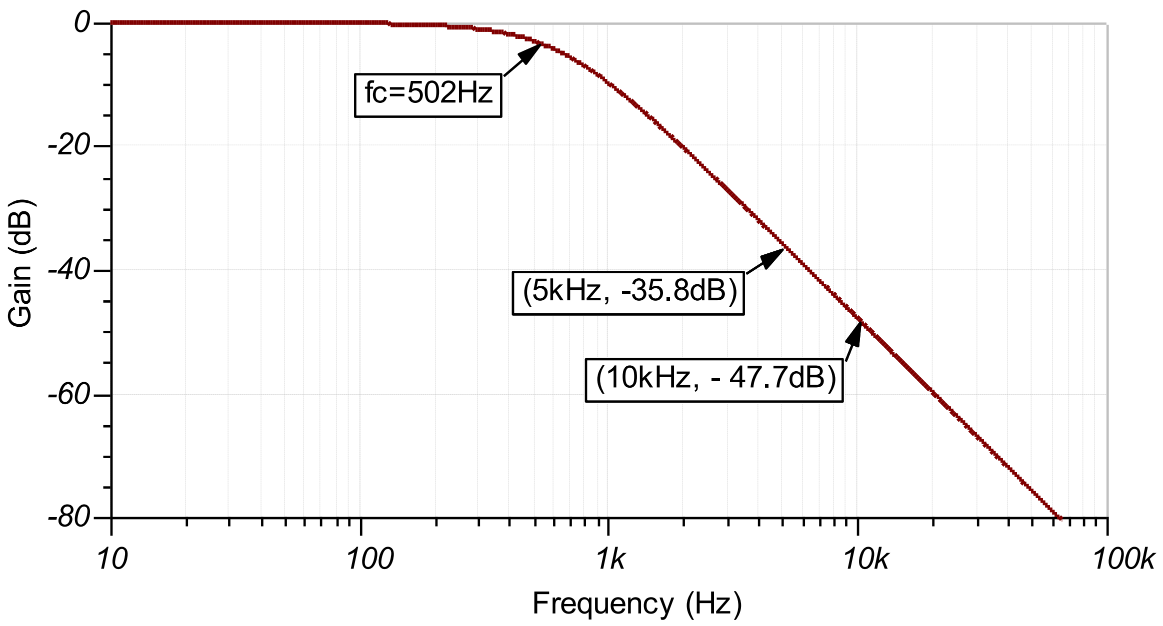
OPA320_SK-Filter.TSC

OPA320_Goodfilter2 vs. Sallen-Key Filter

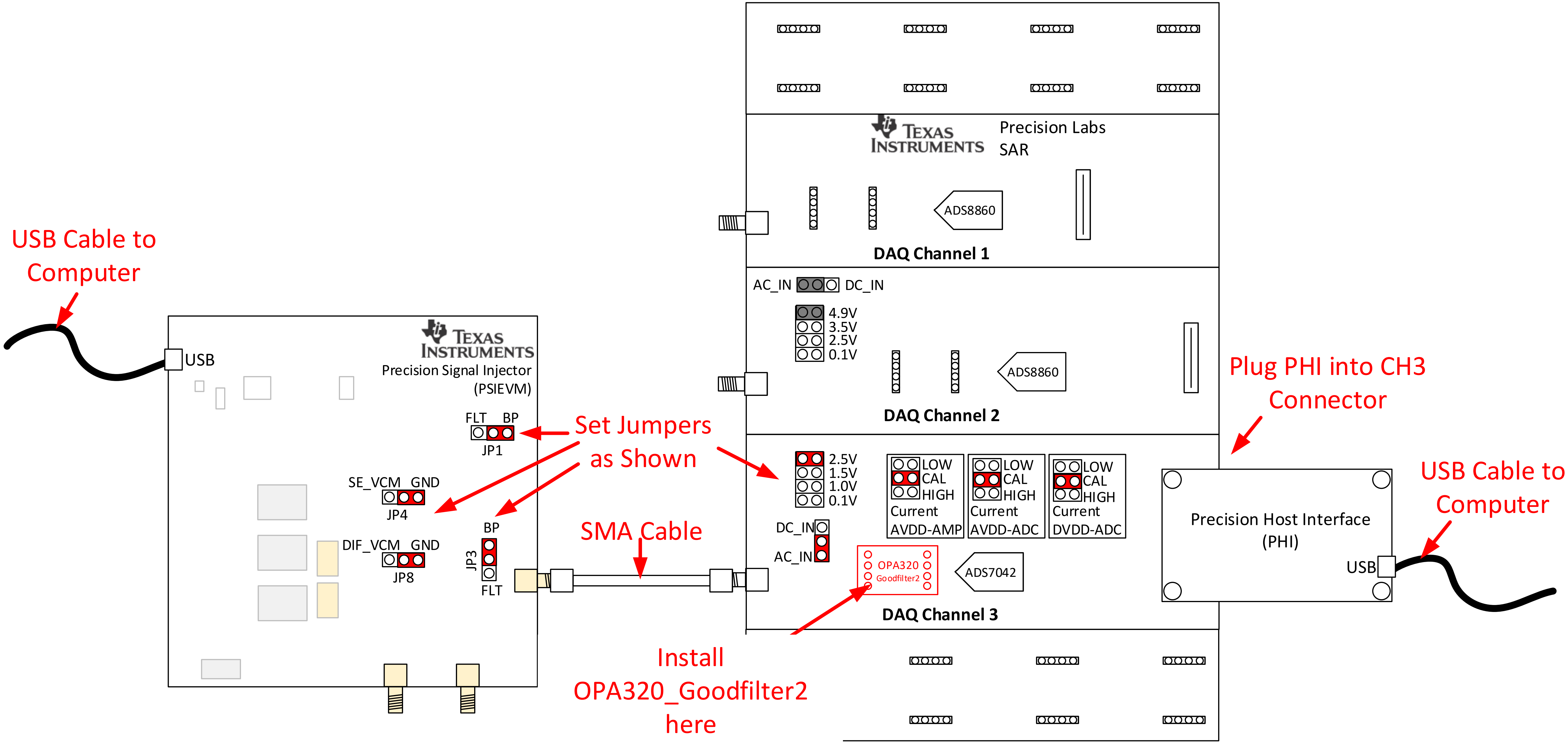




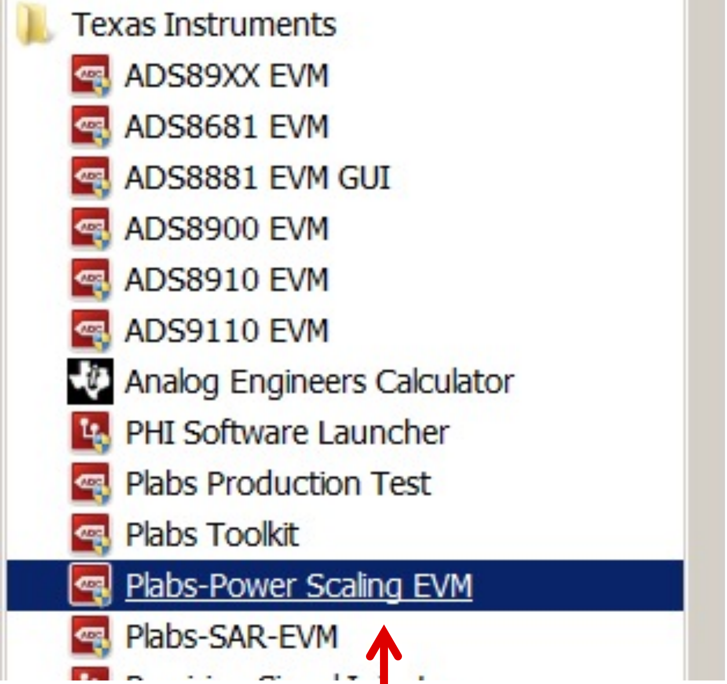




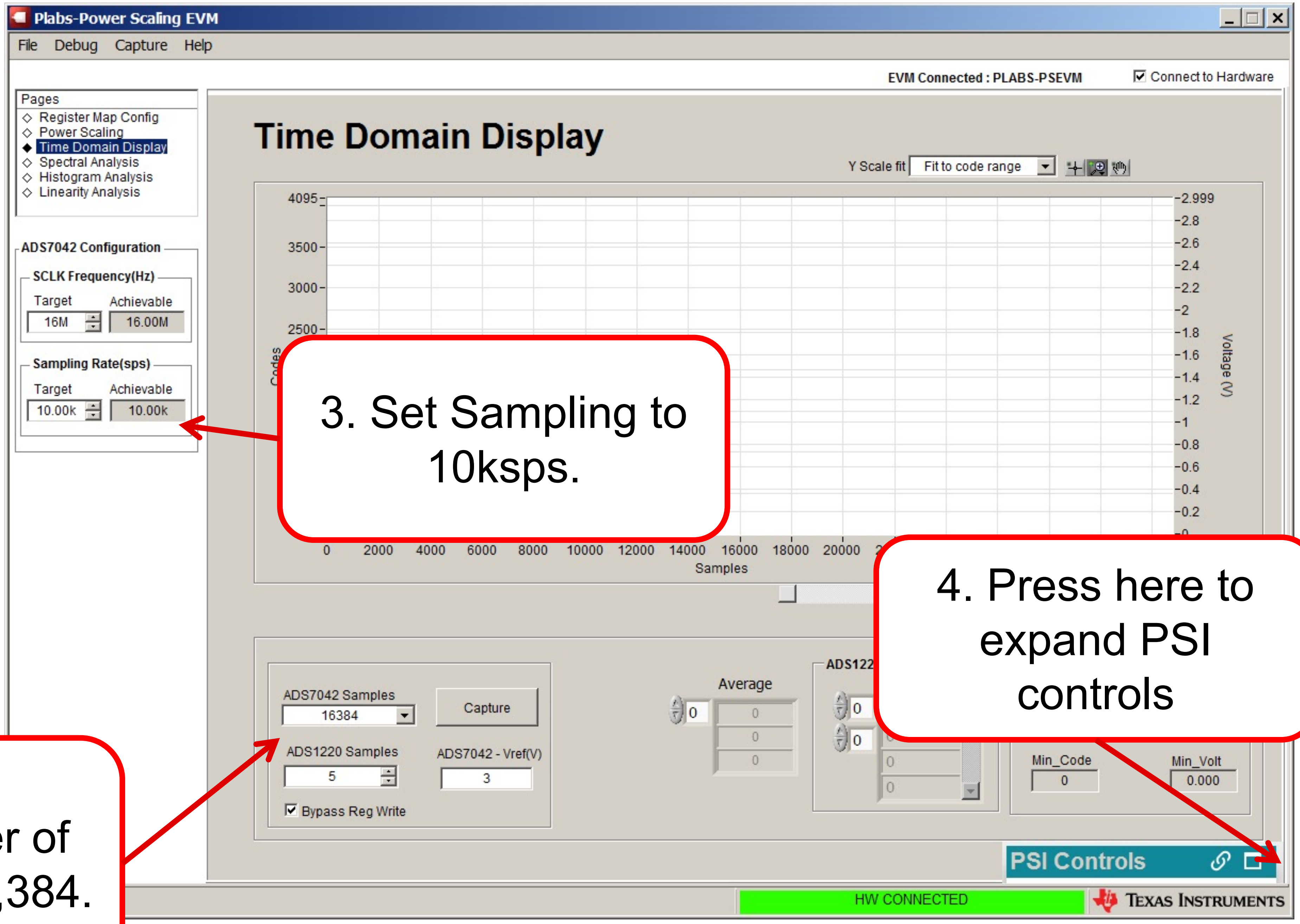
Connect the hardware



Start & Setup the Plabs-Power Scaling EVM Software



1. Select “Plabs-Power Scaling” from “start>All Programs”

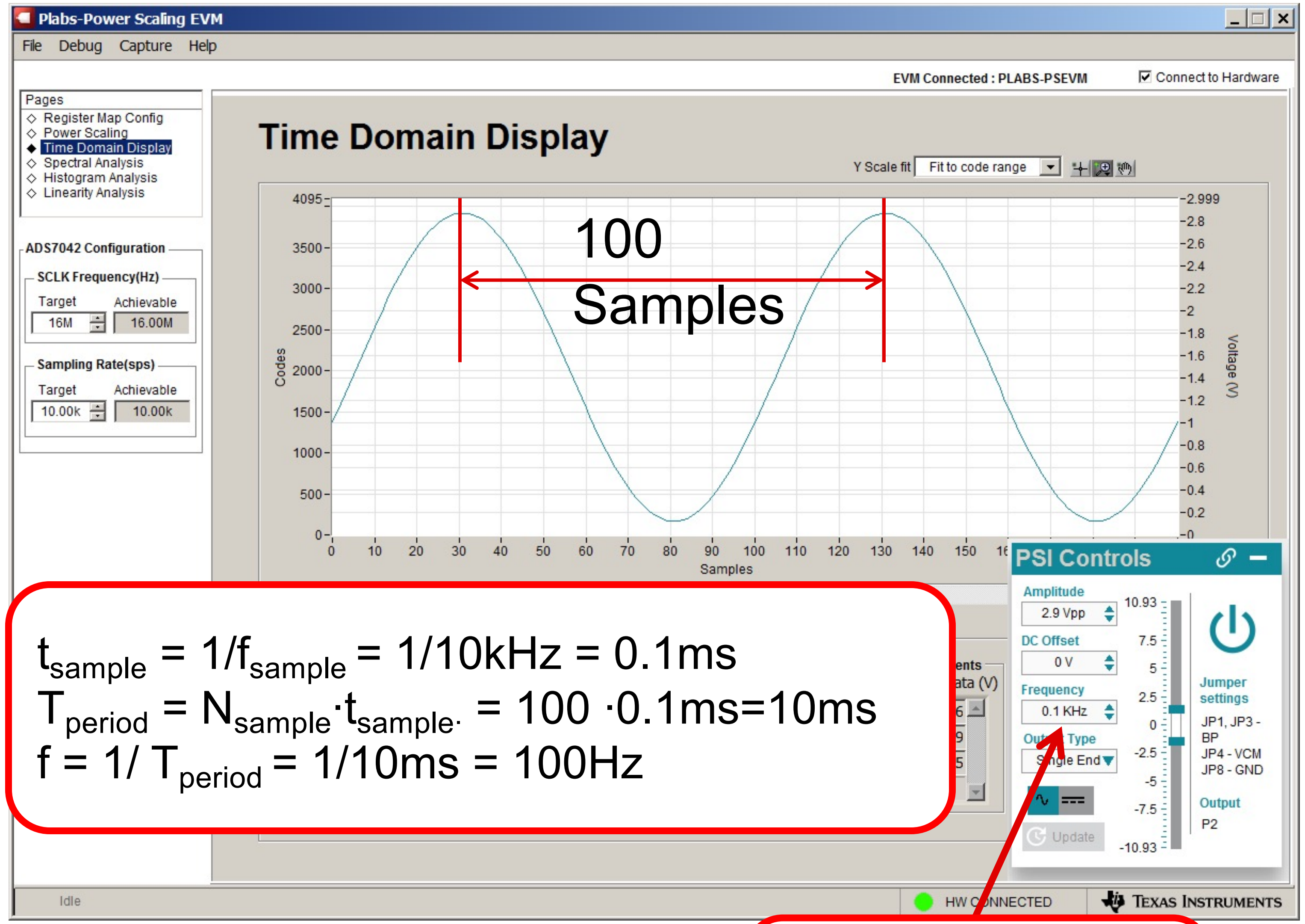


2. Set number of samples to 16,384.

3. Set Sampling to 10ksps.

4. Press here to expand PSI controls

Time domain for 0.1kHz and 10.1kHz look the same



$t_{sample} = 1/f_{sample} = 1/10kHz = 0.1ms$

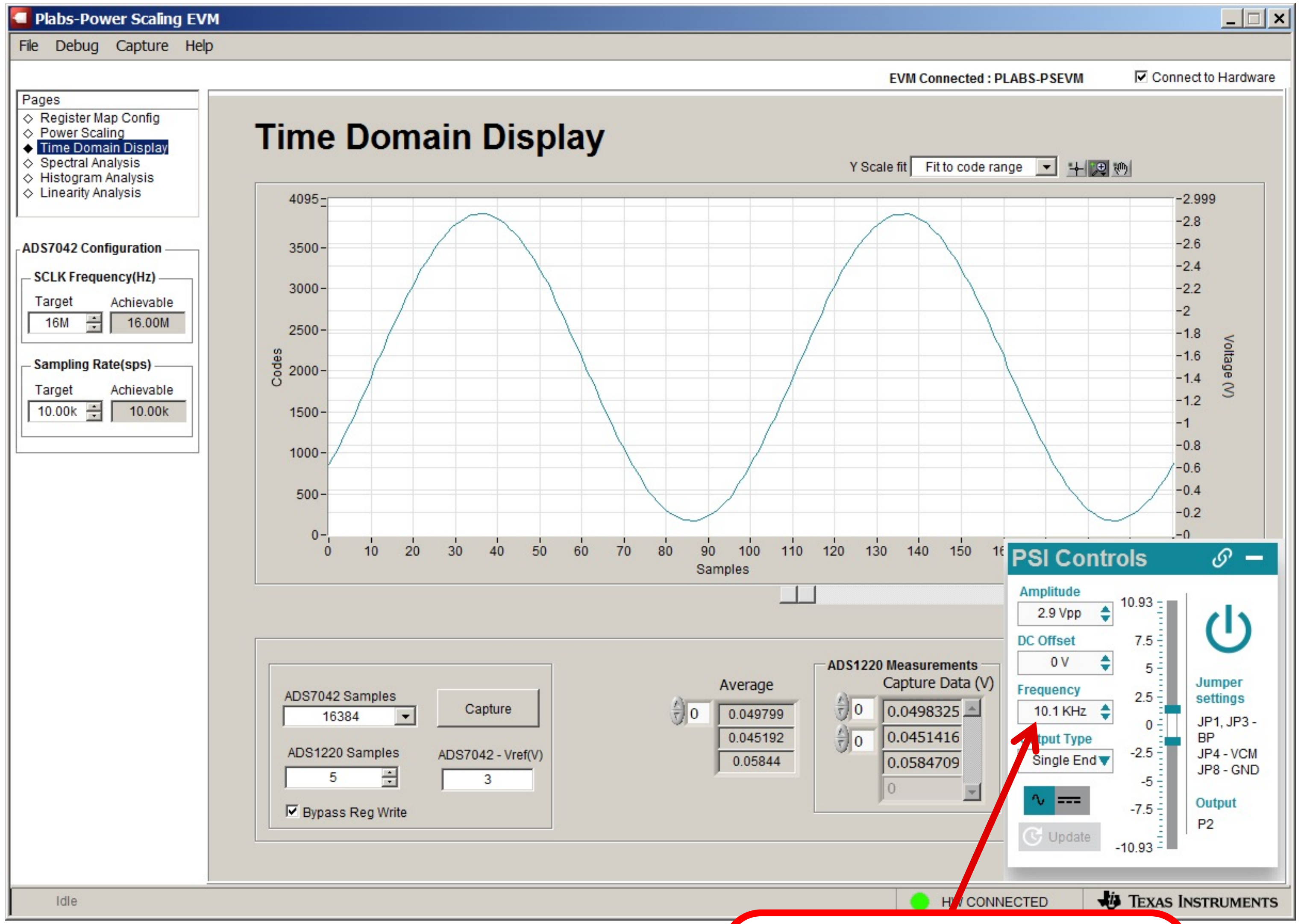
$T_{period} = N_{sample} \cdot t_{sample} = 100 \cdot 0.1ms = 10ms$

$f = 1/T_{period} = 1/10ms = 100Hz$

$f_{input} = 0.1kHz$

Vin = 2.9V

Offset = 0V

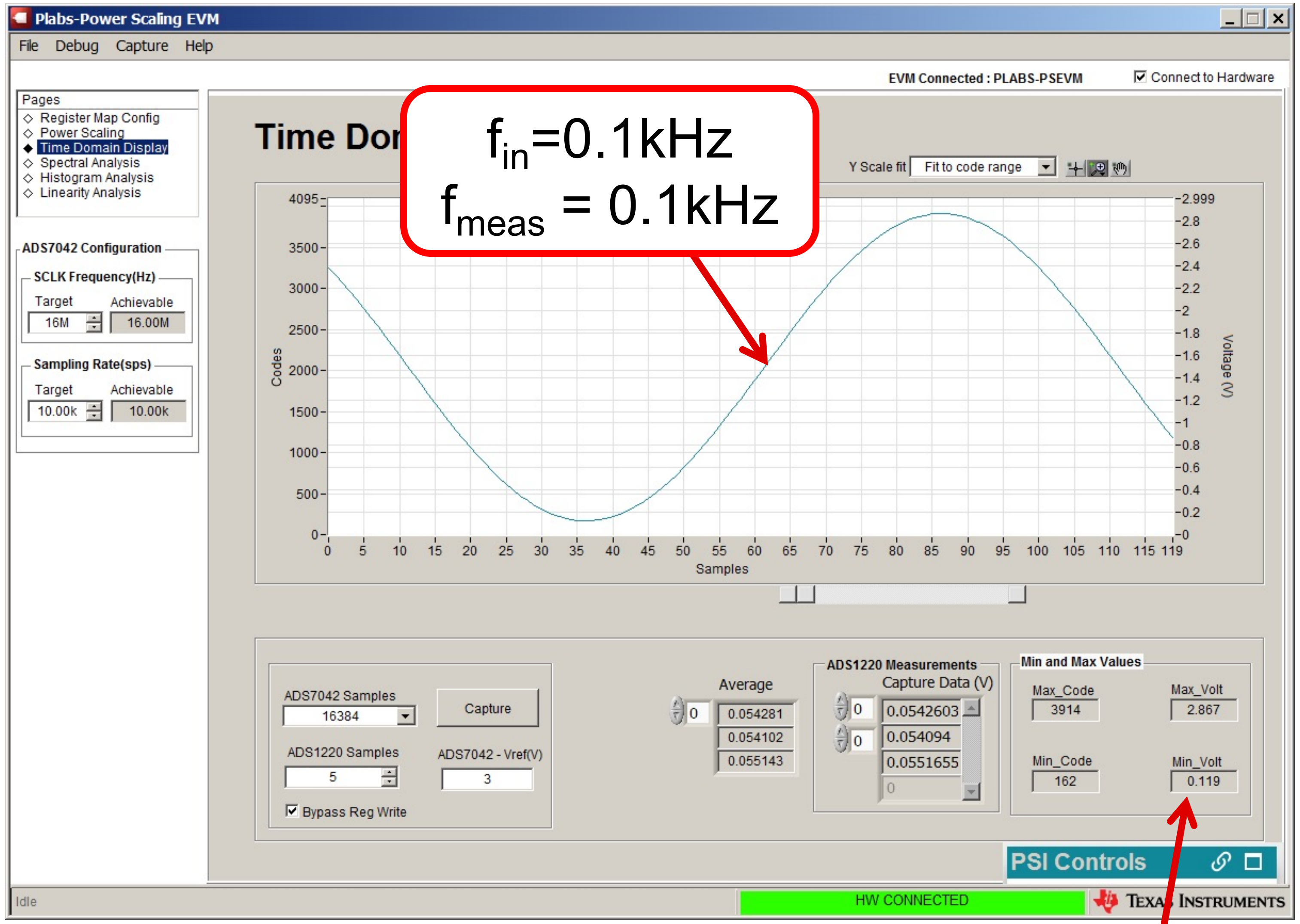


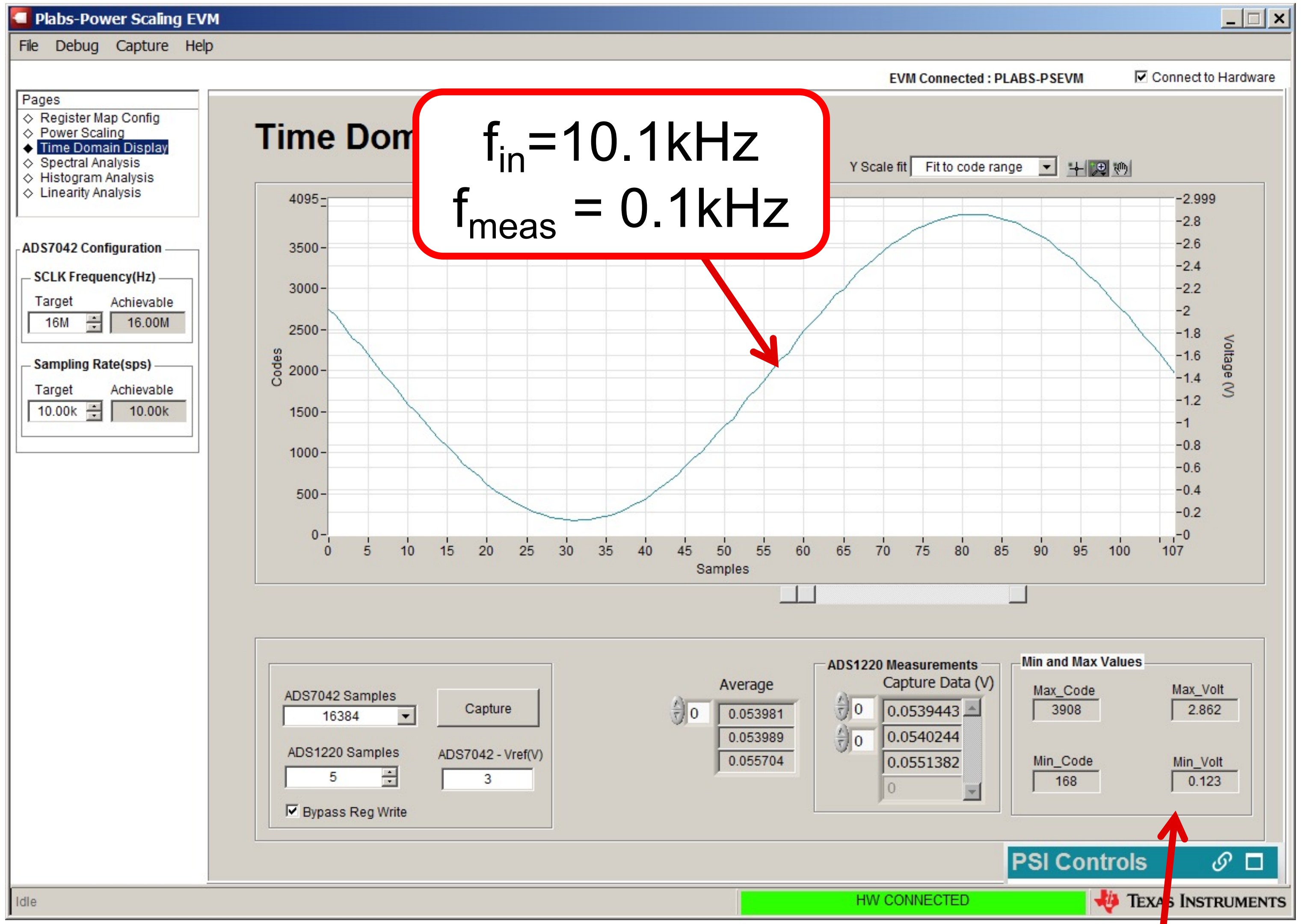
$f_{input} = 10.1kHz$

Vin = 2.9V

Offset = 0V

Time domain for 0.1kHz and 10.1kHz look the same

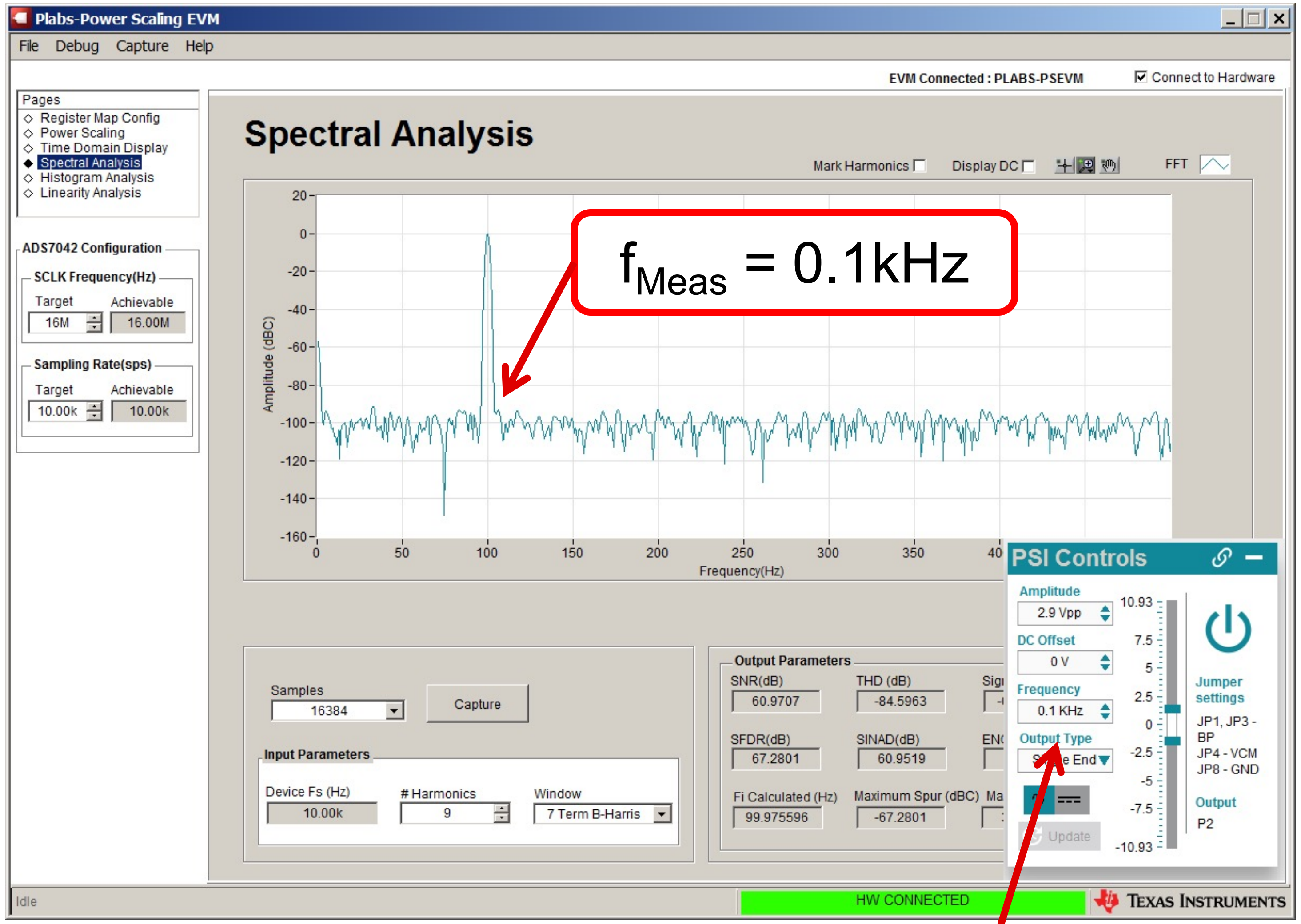




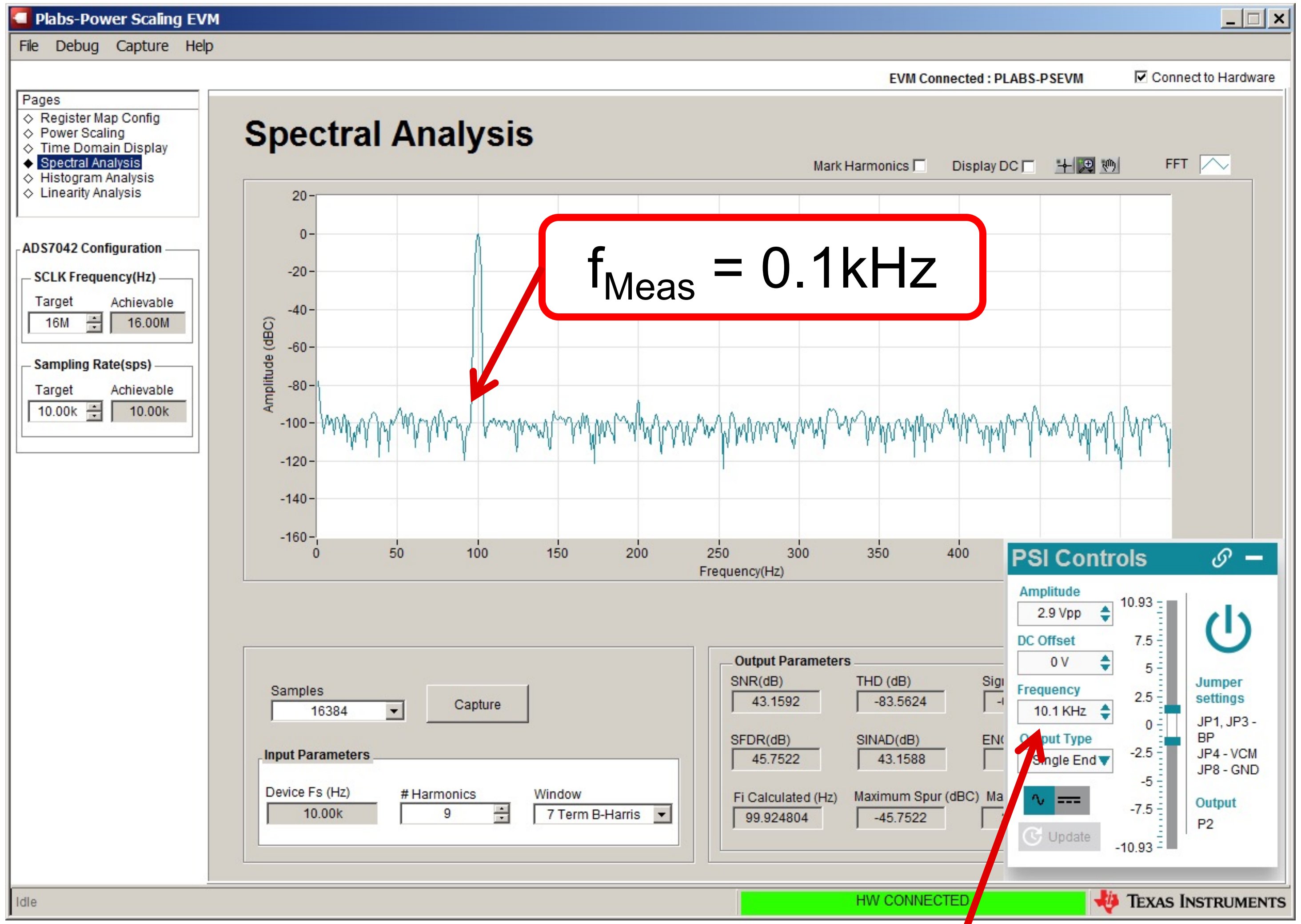
Vpp = 2.867 - 0.119 = 2.748V

Vpp = 2.852 - 0.123 = 2.729V

Frequency domain for 0.1Hz and 10.1kHz the same

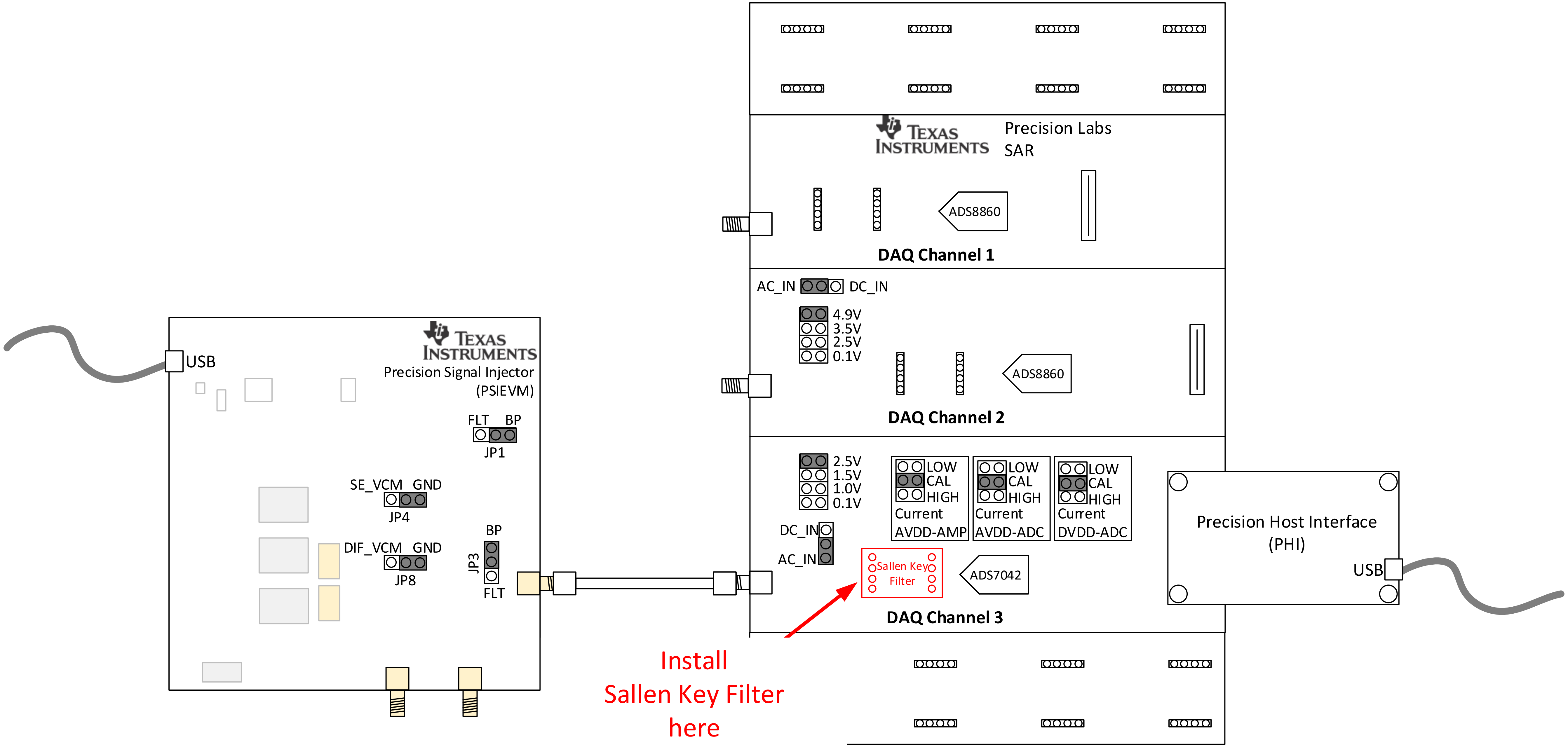


f_{input} = 0.1kHz

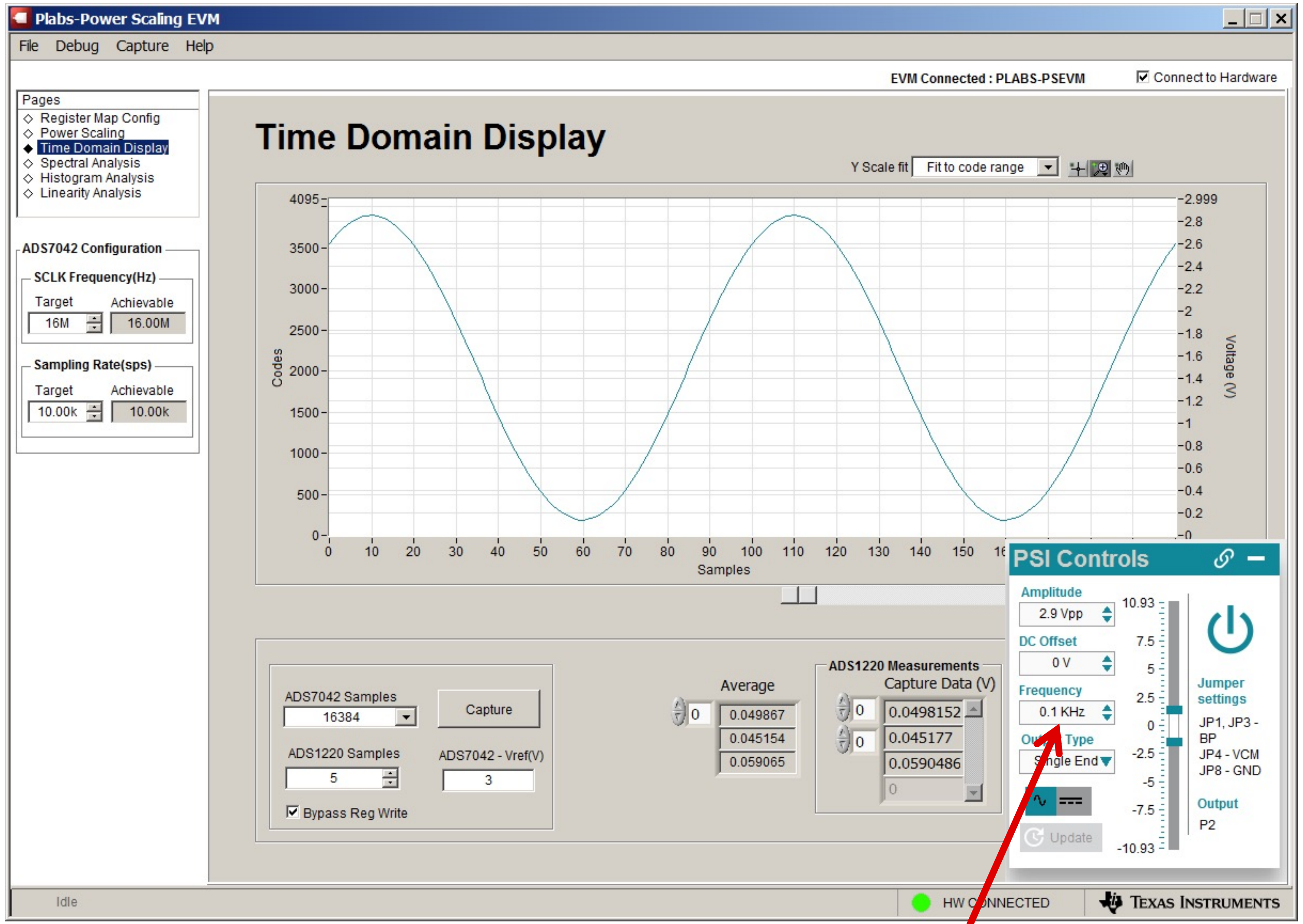


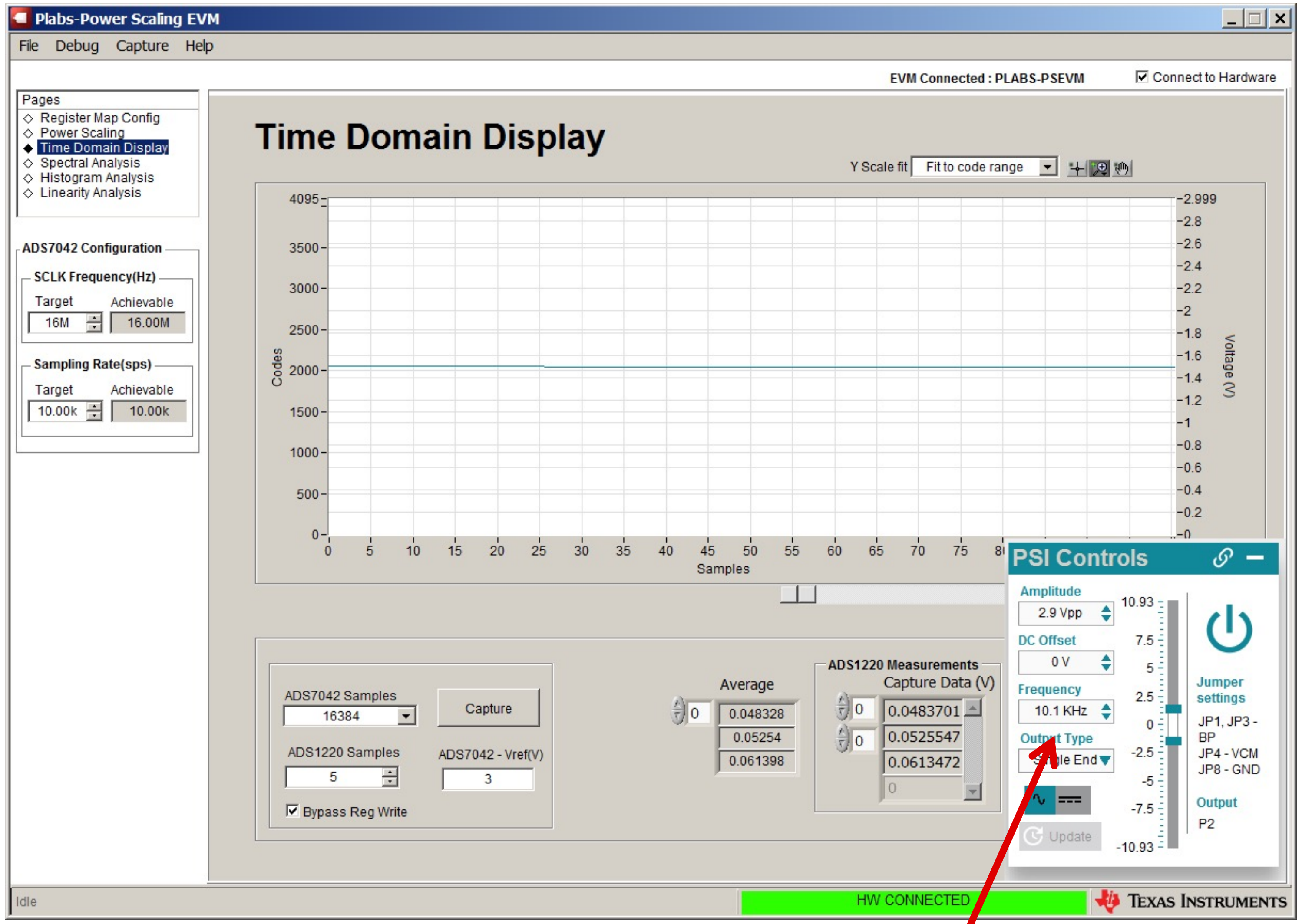
f_{input} = 10.1kHz

Install the Sallen Key Filter



Antialiasing filter with 0.1kHz and 10.1kHz Input

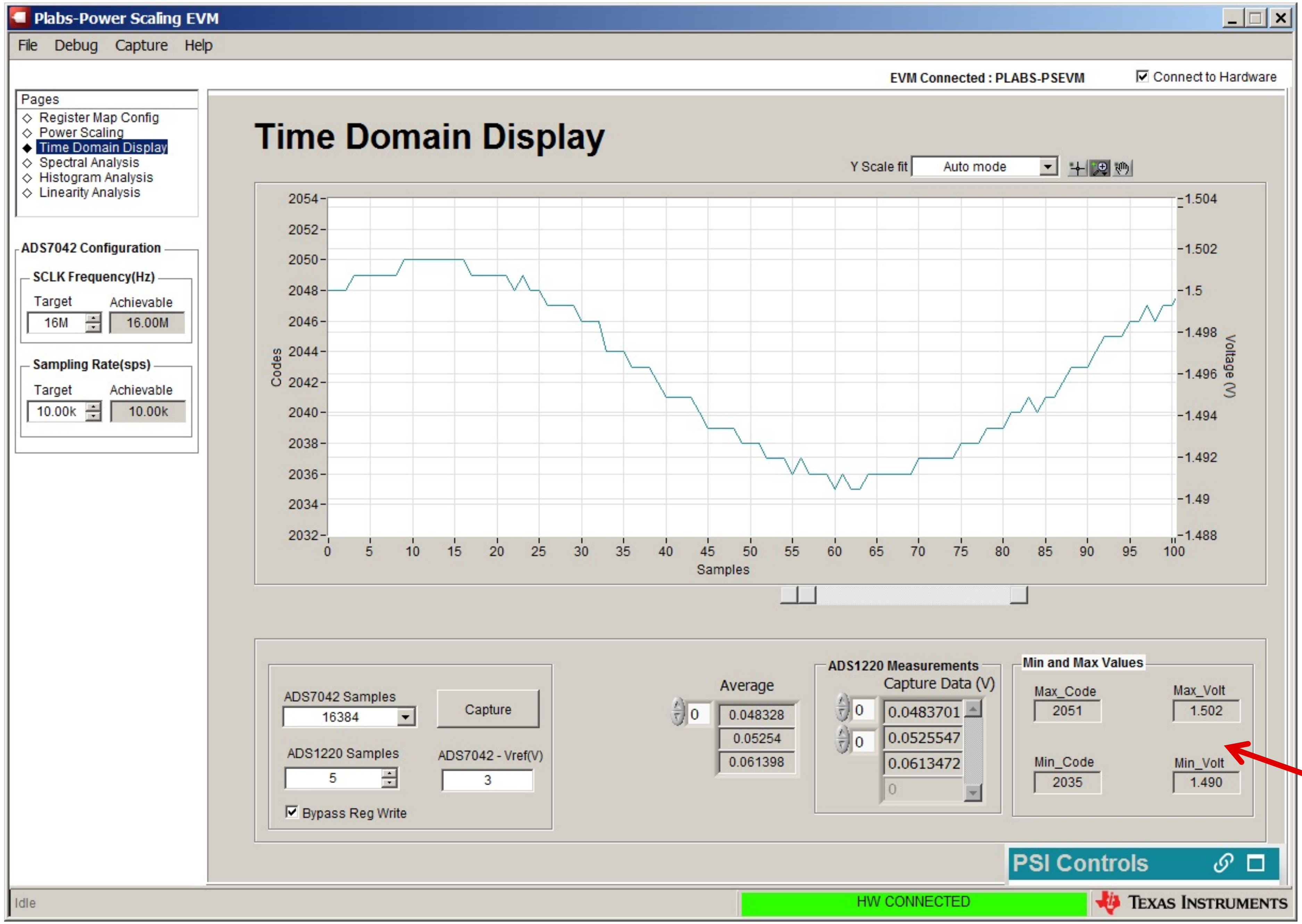


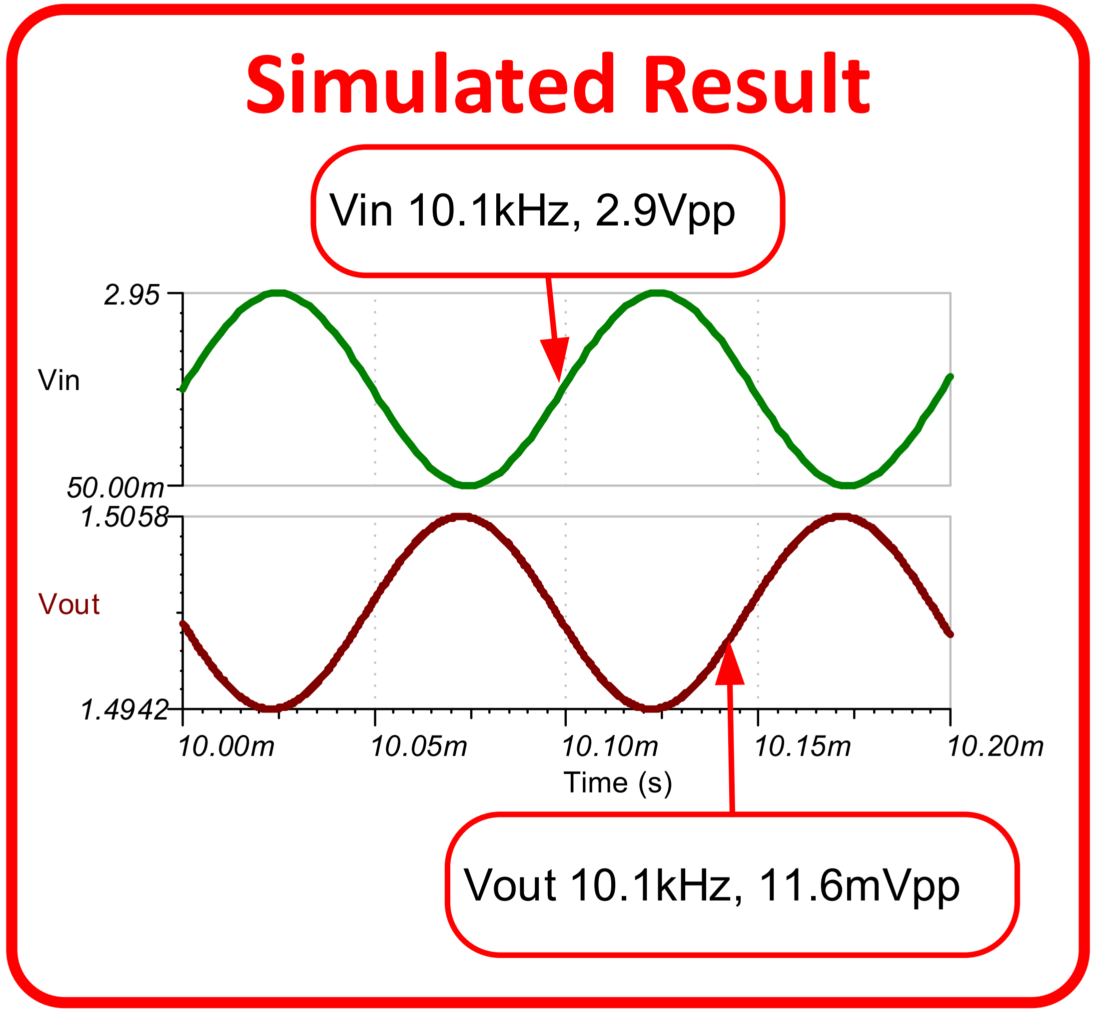


f_{input} = 0.1kHz
Vin = 2.9V
Offset = 0V

f_{input} = 10.1kHz
Vin = 2.9V
Offset = 0V

Zoom in on Alias





$$Vpp = 1.502 - 1.490 = 0.012V$$

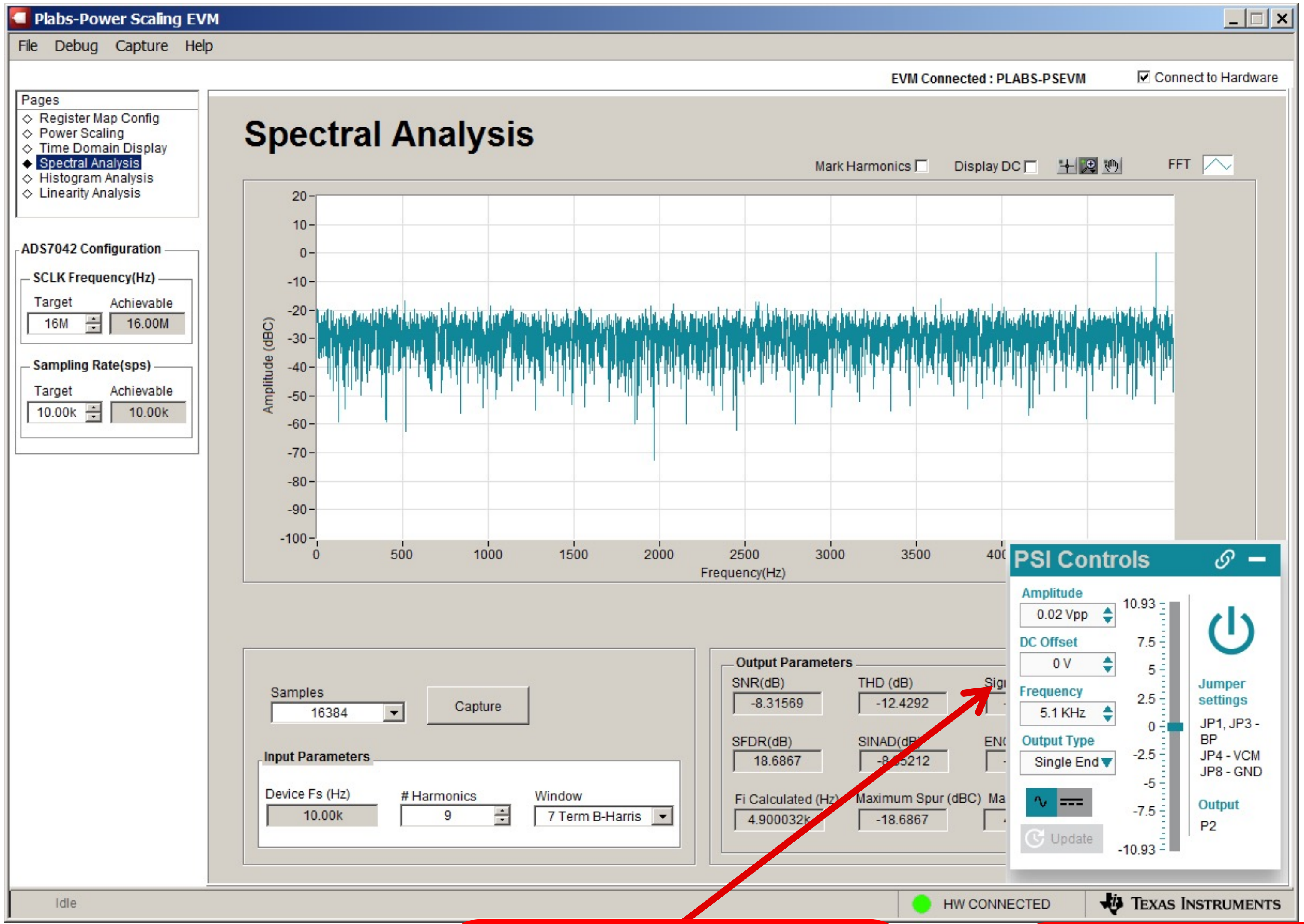
Measured vs Expected Results

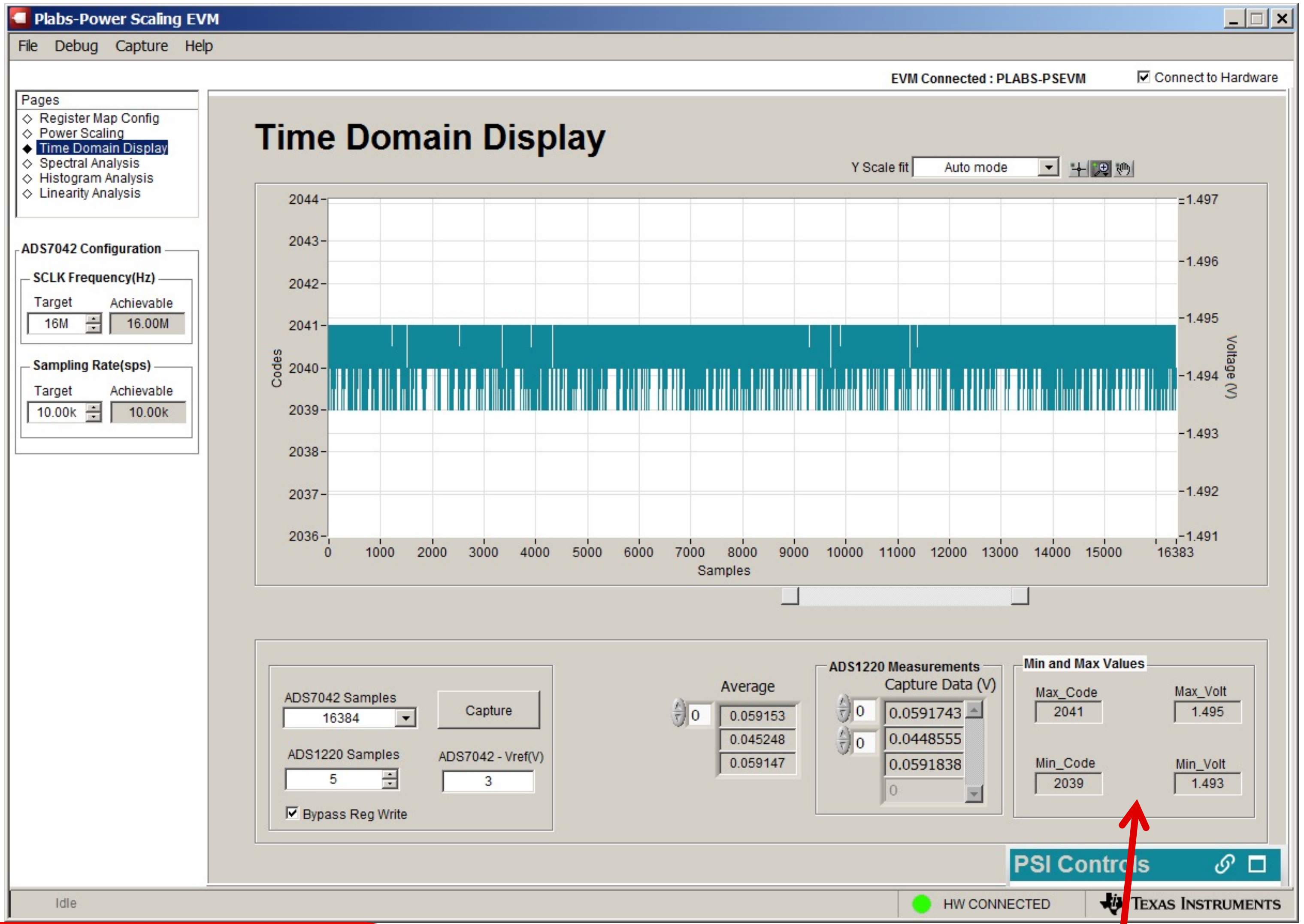
Your results should show the same trend as the expected result but the specific values will differ.

fsamp = 10kHz

Device				Expected		Example Measurements		Your Measurements	
	Device	f_{in} (kHz)	V_{in} (V)	f_{meas} (kHz)	V_{adc} (Vpp)	f_{meas} (kHz)	V_{adc} (Vpp)	f_{meas} (kHz)	V_{adc} (Vpp)
1	OPA320 Good filter2	0.1	2.9	0.1	2.9	0.1	2.748		
2	OPA320 Good filter2	10.1	2.9	0.1	2.9	0.1	2.729		
3	Sallen-Key	0.1	2.9	0.1	2.9	0.1	2.711		
4	Sallen-Key	10.1	2.9	0.1	11.6m	0.1	12m		
5	Sallen-Key (test design)	5.1	0.02	4.9	0.0				
6	Sallen-Key (test design)	5.1	2.9	4.9	44.4m				

Check Antialiasing Filter Near Nyquist (Vin = 20mV)





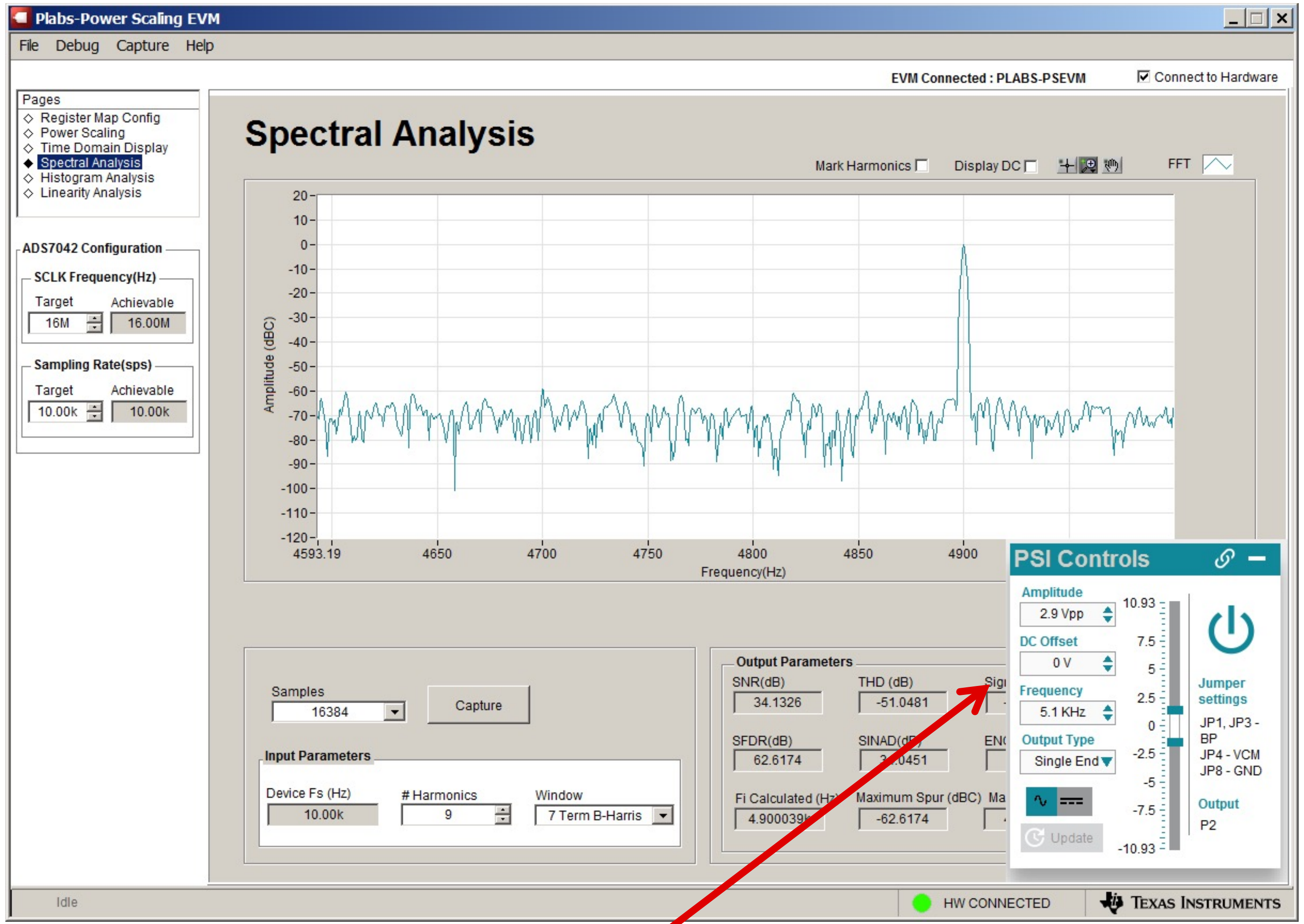
f_{input} = 5.1kHz
Vin = 0.02V
Offset = 0V

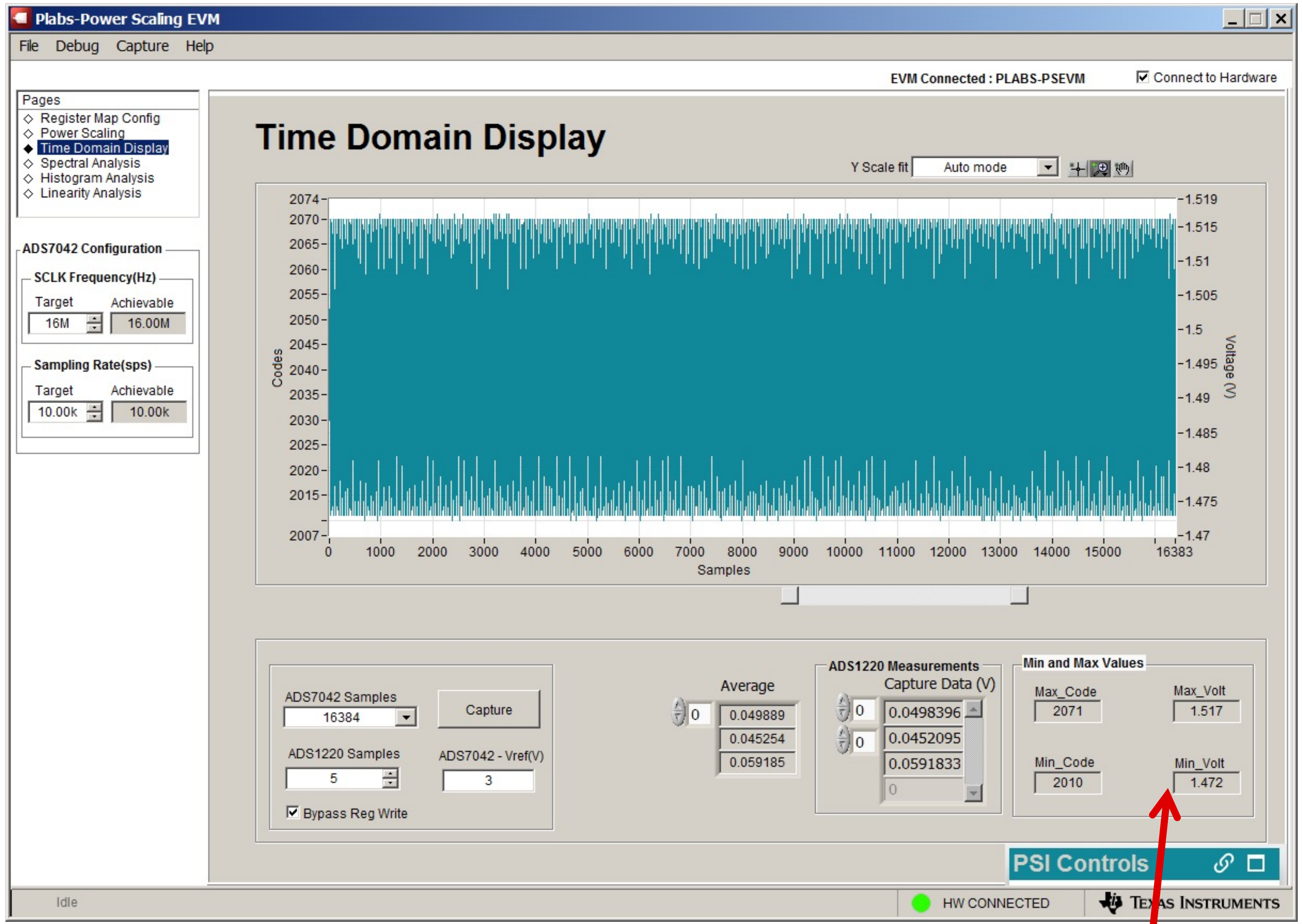
Expected Output at 5.1kHz

$$V_{out} = (20mV)\cdot\left(10^{\left(\frac{-36.1dB}{20}\right)}\right) = 313\mu V$$

Vpp = 1.495 – 1.493 = 2mV

Check Antialiasing Filter Near Nyquist (Vin = 2.9V)





f_{input} = 5.1kHz
Vin = 2.9V
Offset = 0V

Expected Output at 5.1kHz

$$V_{out} = (2.9V) \cdot \left(10^{\left(\frac{-36.1dB}{20}\right)} \right) = 45.4mV$$

Vpp = 1.517 – 1.472 = 0.045V

Measured vs Expected Results

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

fsamp = 10kHz

Device				**Expected**		**Example Measurements**		**Your Measurements**	
	Device	f_{in} (kHz)	V_{in} (V)	f_{meas} (kHz)	V_{adc} (Vpp)	f_{meas} (kHz)	V_{adc} (Vpp)	f_{meas} (kHz)	V_{adc} (Vpp)
1	OPA320 Good filter2	0.1	2.9	0.1	2.9	0.1	2.748		
2	OPA320 Good filter2	10.1	2.9	0.1	2.9	0.1	2.729		
3	Sallen-Key	0.1	2.9	0.1	2.9	0.1	2.711		
4	Sallen-Key	10.1	2.9	0.1	11.6m	0.1	12m		
5	Sallen-Key (test design)	5.1	0.02	4.9	0.0	-na-	2m		
6	Sallen-Key (test design)	5.1	2.9	4.9	44.4m	4.9	45m		

Thanks for your time!