SAR ADC Reference Drive Hands-on
TI Precision Labs – ADCs

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TEXAS INSTRUMENTS

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Hello and welcome to the TI Precision labs hands-on experiment covering different techniques for driving the ADC reference input. In this experiment we compare and contrast how the performance of an ADC is effected by two different references. One reference has an integrated wide bandwidth buffer and the other reference has a lower bandwidth output. We will look at the systems AC and DC performance with the two different references.
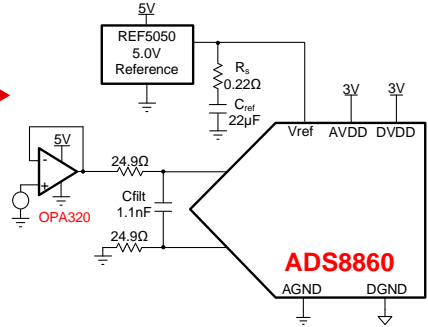
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Required/Recommended Equipment

- Calculation
  - No calculation or simulation for this experiment
  - We will look at the qualitative difference between a reference with high and low bandwidth
- Measurement
  - Measure impact of reference bandwidth on AC performance vs. sampling rate
  - Measure impact of reference bandwidth on DC settling vs. sampling rate
  - PLABS-SAR-EVM-PDK
  - http://www.ti.com/tool/plabs-sar-evm-pdk
  - Download EVM software and purchase EVM

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In the labs lecture we described how the ADC performance is impacted by the bandwidth of the reference buffer. In this experiment, we will look at the difference in performance for a AC and DC input signal. We will also see how sampling rate effects reference settling performance. All measurements will be done on the PLABS-SAR-EVM-PDK. Let's get started.
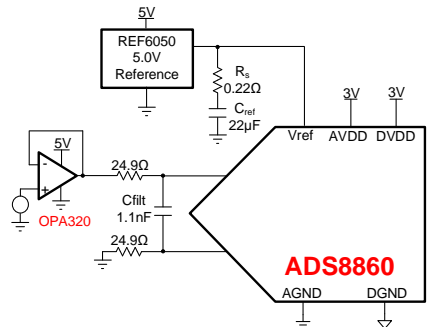
Circuits under test

Circuits are identical except for the reference.

Channel 1: REF5050

5V
REF5050 5.0V Reference
R_s 0.22Ω
C_{ref} 22µF
3V 3V
Vref AVDD DVDD
5V
OPA320
24.9Ω
Cfilt 1.1nF
24.9Ω
ADS8860
AGND   DGND

Channel 2: REF6050

5V
REF6050 5.0V Reference
R_s 0.22Ω
C_{ref} 22µF
3V 3V
Vref AVDD DVDD
5V
OPA320
24.9Ω
Cfilt 1.1nF
24.9Ω
ADS8860
AGND   DGND

ADS8860 Data Sheet (1Msps)

Parameter	Min	Typ	Max	Unit
SNR	92	93		dB
THD (1kHz)		-108		dB

Should meet ADS8860 data sheet specifications

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For this experiment we will measure the AC and DC performance of the ADS8860 with two different references. Both references are low noise precision references, but the REF5050 has a low bandwidth output and the REF6050 has a high bandwidth output. Note that the bandwidth refers to the ability of the reference to respond to transients. The reference input of the ADC has significant fast moving current requirements. In this experiment we will see that the system using the wide bandwidth reference has better AC and DC performance because the reference can respond to the ADCs rapid transient current requirements. For AC performance our goal is to get the ADS8860 to meet data sheet SNR and THD. For DC

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performance we look at settling of the reference after startup. Ideally, the reference is fully settled during the first conversion and the ADC does not have a transient start up error. Notice that Channel 1 is connected to the low bandwidth REF5050 and Channel 2 is connected to the wide bandwidth REF6050. Now let's look at a summary of the experiments that we will do.

Expected results

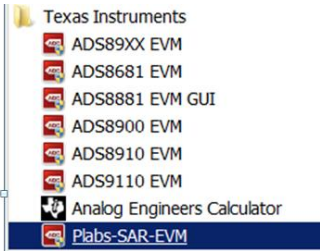|	Reference	Sampling Rate	Measured Results			Example Measurements		
			SNR (dB)	THD (dB)	Reference settling Vin = 4.9V DC	SNR (dB)	THD (dB)	Reference Droop Vin = 4.9V DC (codes)
	Data Sheet Typical Specification	1M	93	-108		93	-108	
1	REF5050	1M				92.2	-91.4	10.9
2	REF5050	500k				92.1	-97.1	5.35
3	REF5050	100k				92.0	-108.2	1.4
4	REF6050	1M				92.6	-108.1	1.15
5	REF6050	500k				92.7	-109.3	0.8
6	REF6050	100k				92.3	-108.1	0.8

The table summarizes the experiments that we will do throughout this experiment. Your measurements will go under the "measured results" section and they should be comparable to the "example measurements" shown at the right. The experiments 1 to 3 are done with the REF5050, and experiments 4 to 6 are done with the REF6050. The experiments will be done at three different sampling rates, and you will see that performance is limited at higher sampling rates for the ADC using REF5050. To test AC performance we will look at SNR and THD, and to test DC performance we will look at reference settling. Print a copy of this table and fill it out as we progress through the experiments. Let's get started.
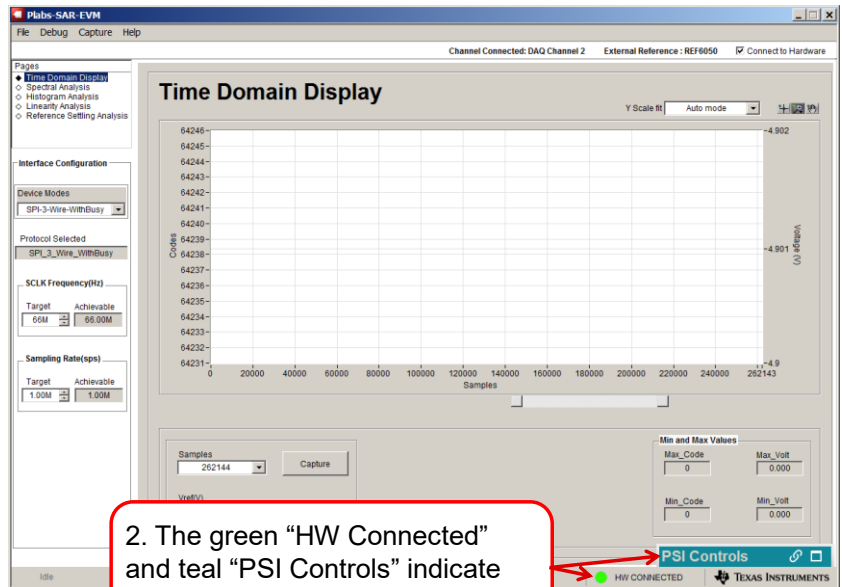
Connect the hardware
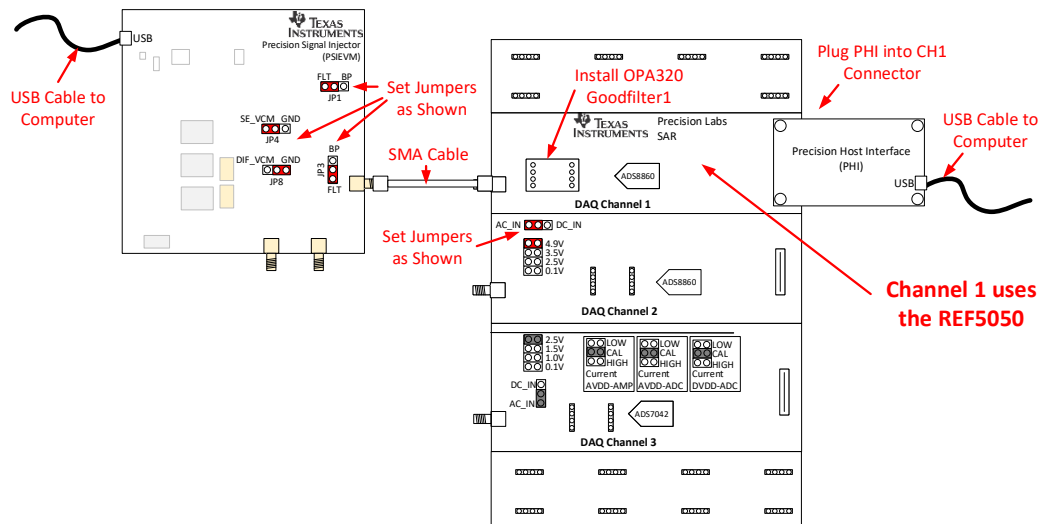
For this experiment we will first use channel 1 on the precision labs hardware. First, set the jumpers as shown here. Connect the PSI to the PLABS board using the SMA cable, and connect the PHI to the PLABS channel 1 connector. Next, connect the USB cables to the computer. Finally, install OPA320_Goodfilter1 in the socket. Be careful to install this amplifier right side up with the label at the bottom of the coupon card. Pause and connect the hardware.

Start & Setup the Plabs-SAR-EVM Software

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

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

Now let's start the software by selecting the "Plabs-SAR-EVM" icon from the "Start > All Programs" menu. Once the software is running you should notice the green "HW connected" message at the bottom of the software. Also if the PSI controls are colored teal the hardware communications is working. Pause and get the EVM software started.

REF5050: 1Msps, THD, SNR

	fs	SNR (dB)	THD (dB)
Spec.	1M	93	-108
REF5050	1M	92.2	-91.4

Spectral Analysis

1. Select spectral analysis

2. Sampling Rate 1Msps

3. Press Mark Harmonics

4. Amplitude = 4.9V Offset = 2.5V Frequency = 2kHz Press power on.

5. Press "Capture"
6. Record AC performance

Now let's measure the AC performance for the system using the low bandwidth REF5050. First, select "spectral analysis" on the "pages" menu. Next, make sure the sampling rate is 1Msps. Next check the "mark Harmonics" option. This will zoom in on the distortion components once we capture the waveform. Now enter the amplitude, offset, and frequency into the PSI Controls. In this case the amplitude is near full scale at 4.9V, the offset is half full scale at 2.5V, and the frequency is 2kHz. Press the power button to enable the PSI output. Note that it is colored teal when the output is enabled and red when it off. Next press capture and record the AC performance. When using REF5050 at 1Msps you see that THD is significantly

degraded compared to the data sheet specifications. In this example the THD is -91.4dB whereas the data sheet specification is -108dB. Also, you can see in the FFT that the harmonics are quite large. Pause and measure the AC performance.

REF5050: 500ksps, THD, SNR

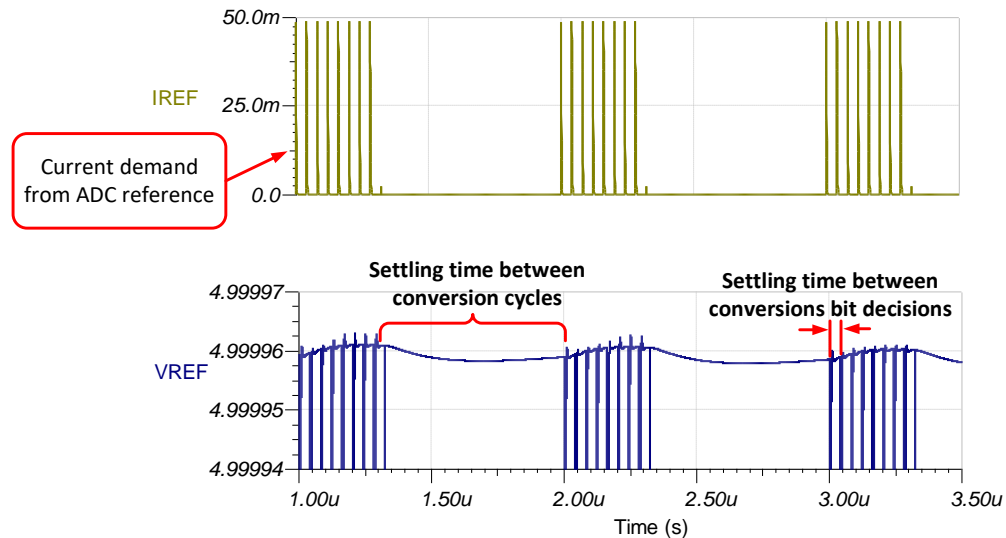|	fs	SNR (dB)	THD (dB)
Spec.	1M	93	-108
REF5050	1M	92.2	-91.4
REF5050	**500k**	**92.1**	**-97.1**
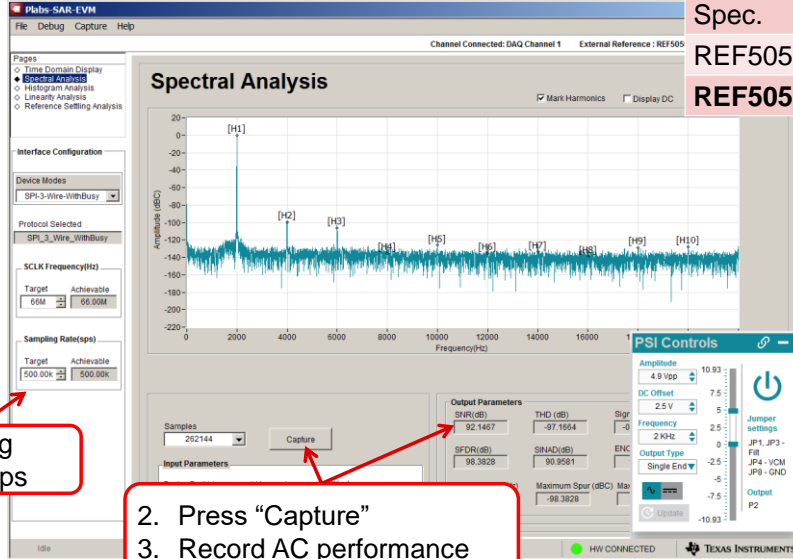
1. Sampling Rate 500ksps
2. Press "Capture"
3. Record AC performance

Here we will make the same measurement at a sampling rate of 500ksps. First, change the sampling rate. Second press capture, and record the AC performance. No other settings need to change. AC performance is improved significantly by reducing the sampling rate. THD improved from -91.4dB to -97.1dB. Note that it still is not equivalent to the data sheet specification of -108dB. Pause and measure the AC performance.

REF5050: 100ksps, THD, SNR

	fs	SNR (dB)	THD (dB)
Spec.	1M	93	-108
REF5050	1M	92.2	-91.4
REF5050	500k	92.1	-97.1
REF5050	**100k**	**92.0**	**-108.2**
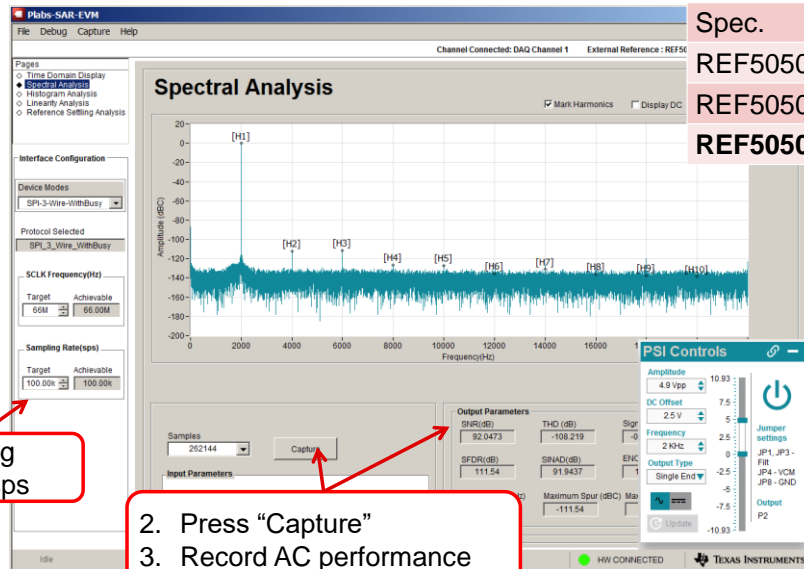
1. Sampling Rate 100ksps

2. Press "Capture"
3. Record AC performance

Here we will make the same measurement at a sampling rate of 100ksps. First, change the sampling rate. Second press capture, and record the AC performance. The AC performance here is now equivalents to the data sheet specification of -108dB. Further reductions in sampling rate will have little to no effect on performance. Pause and measure the AC performance.

Reducing sampling rate improves performance

IREF — Current demand from ADC reference

VREF

Settling time between conversion cycles

Settling time between conversions bit decisions

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In the previous slide you noticed that the data converter AC performance improved as sampling rate decreased. This is because the reference has time to fully settle when the sampling rate is decreases. Looking at this graph, you can see at the top of the graph the current drawn by the ADC reference input. There is a large rapid 50mA current transient for each bit decision. Each group of current transients represents one conversion cycle. In this example, we see three conversion cycles. The bottom graph shows the reference voltage output. You can see corresponding transients in the voltage for each current transients. Between each current transient, the reference needs to replenish the charge on the

decoupling capacitor and settle to within half of one LSB. Increasing the conversion time increases the time between each bit decision and between each conversion cycle. This provides more time to charge the reference capacitors and substantially improves the settling on the reference. Good reference settling will improve the data converters AC and DC performance.
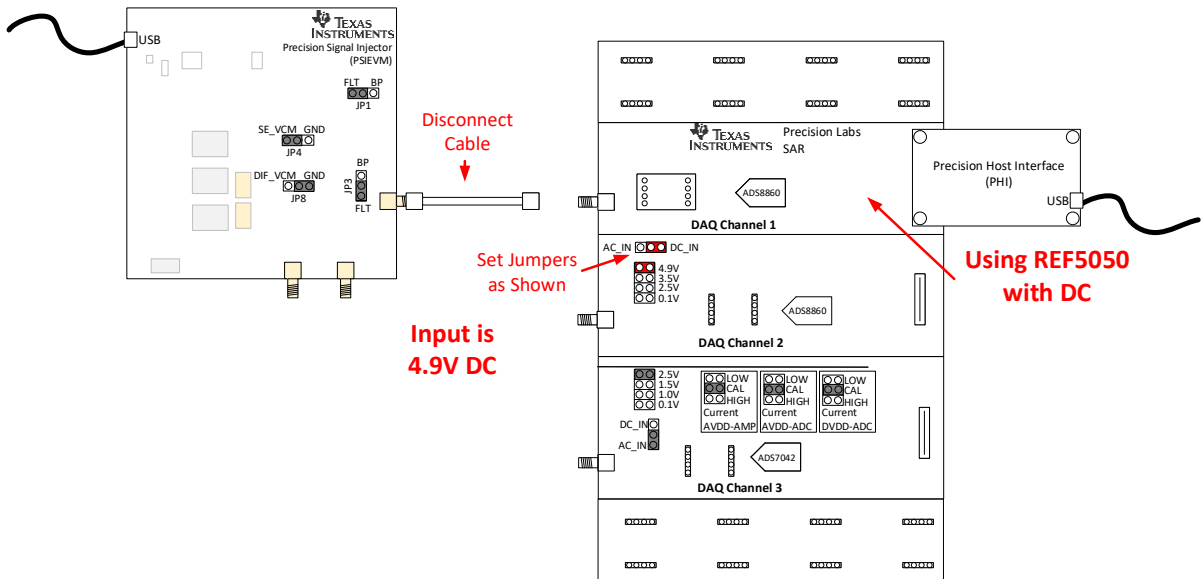
Reference Settling Test – How it works
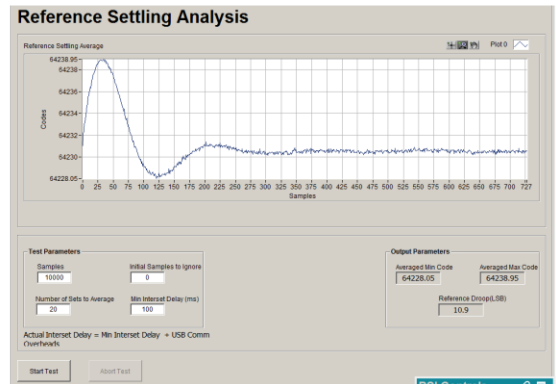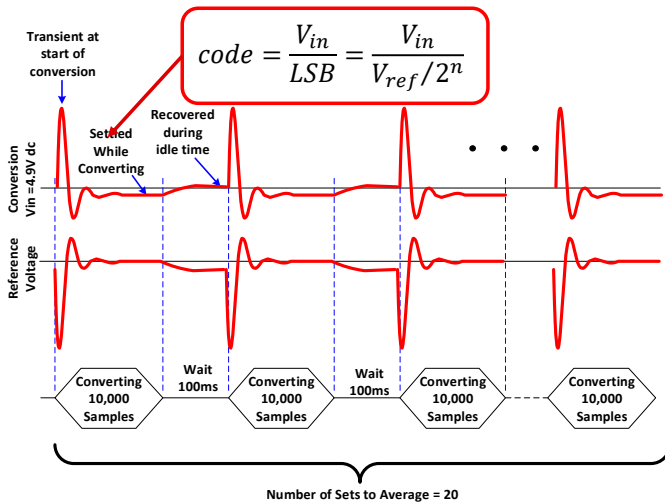
Next we are going to see how DC performance is impacted by the bandwidth of the reference. To do this we will alternate between converting and having an idle wait time. For a data converter with a constant DC input the reference voltage will go through a transient behavior when conversions start and eventually settle to a steady state value after many conversions. If the conversions are paused for an idle period, the reference will recover to it's initial state. Then once the conversions resume the initial transient behavior will repeat itself. Thus if you have a system that "goes to sleep", when it wakes up and begins converting there will be a transient on the reference that introduces and error for the initial samples. We

will see that the magnitude and length of this transient is minimized when a wide bandwidth reference like the REF6050 is used.

From a practical perspective this reference settling is an issue in systems that use a "sleep mode" for power saving. This is because the system measured results will have an error during the initial transient. A similar behavior will also happen in multiplexed systems when transitioning from between channels that are at significantly different voltage levels. In this case the different conversion results from the two different channels will cause a significant shift in the ADC reference load current requirement. The shift in load applied to the reference will cause a reference voltage transient similar to the "sleep mode" case.

In this figure you can see the reference voltage and conversion result. Notice that the conversion result will be the inversion of the reference voltage because the conversion result is calculated by dividing by the reference voltage over 2 to the "n" power. We will measure reference settling by just looking at the conversion result.

Hardware change

For this experiment we will make a few minor changes to the hardware. First disconnect the SMA cable from the PSI. Next change the jumper to DC_IN and make sure that the voltage jumper is set to 4.9V. So for this experiment, the AC signal is disconnected and we connect the on-board 4.9V DC source. Pause and change the hardware.

REF5050: 1Msps, Settling

	fs	Droop (LSB)
REF5050	1M	10.9

Now we can measure reference settling for the REF5050 at 1Msps. First set the sampling rate to 1Msps. Next, set the number of averages to 20. This will take 20 measurements and average them to minimize the noise. Third set the "minimum interset delay" to 100ms. This is just the idle time between each set of 10,000 samples. Fourth, press "start test". This will take a little time as we are averaging 20 readings. Once this is complete you will see the "reference droop" in LSB. This is the magnitude of the transient error on the reference. In this case the error is 10.9 LSB. You can see most of this happens in the first 500 samples. Pause and measure reference settling.

Zoom in on Settling
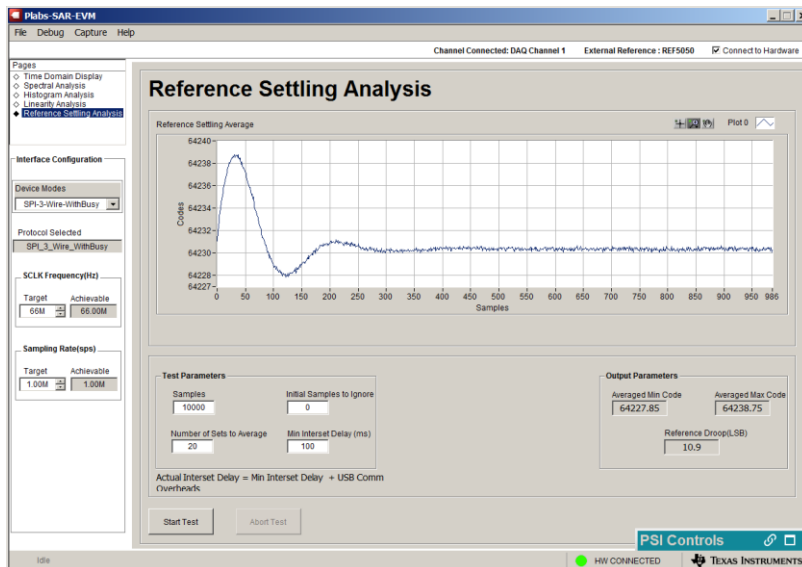
Right click and drag to zoom in on the transient. Now you can see more clearly that this is a normal second order kind of overshoot and ringing. From this picture it is clear that you will not get the best accuracy until after 300 samples. Pause and zoom in on the settling.

REF5050: 500ksps, Settling

	fs	Droop (LSB)
REF5050	1M	10.9
REF5050	**500k**	**5.35**

Now let's look at reference settling with the sampling rate set to 500ksps. First set sampling to 500ksps. Next, press start test. After this test completes you will see that the reference droop is significantly better for the 500ksps case. The droop went from 10.9 LSB to 5.35 LSB. Ideally, we would like this error to be less than 1 LSB. So, this is an improvement but still not ideal. Pause and measure settling at 500ksps.

REF5050: 100ksps, Settling

|	fs	Droop (LSB)
REF5050	1M	10.9
REF5050	500k	5.35
REF5050	**100k**	**1.4**

Now let's check settling at 100ksps. First set the sampling rate to 100ksps. Second press "start test". After the test completes you will see that the reference droop is about 1.4 LSB. Although this isn't perfect, it is pretty close to the goal of less than 1 LSB. Thus, here we can see that the dc performance is also improved by reducing the sampling rate. This reference settling is especially important when a multiplexer is used as each time the input steps the reference will have to settle again. We will perform the same set of tests with the REF6050, and you will see that the droop for this reference is good at the entire range of sampling rates. Pause and measure settling at 100ksps.
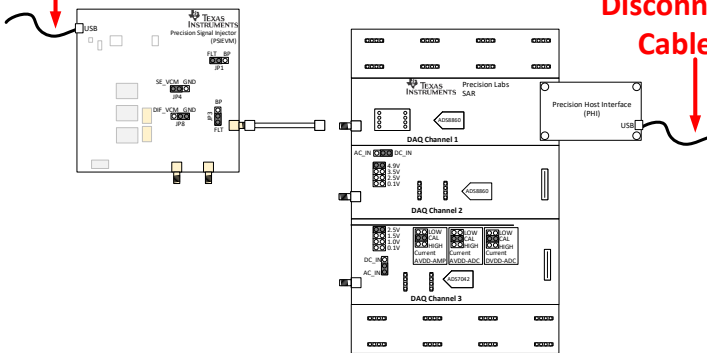
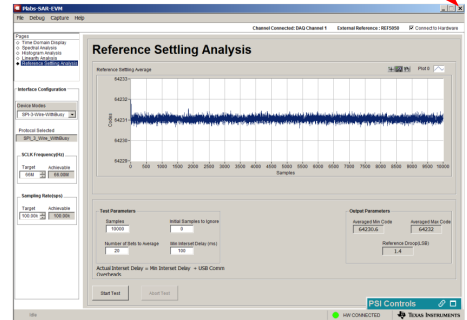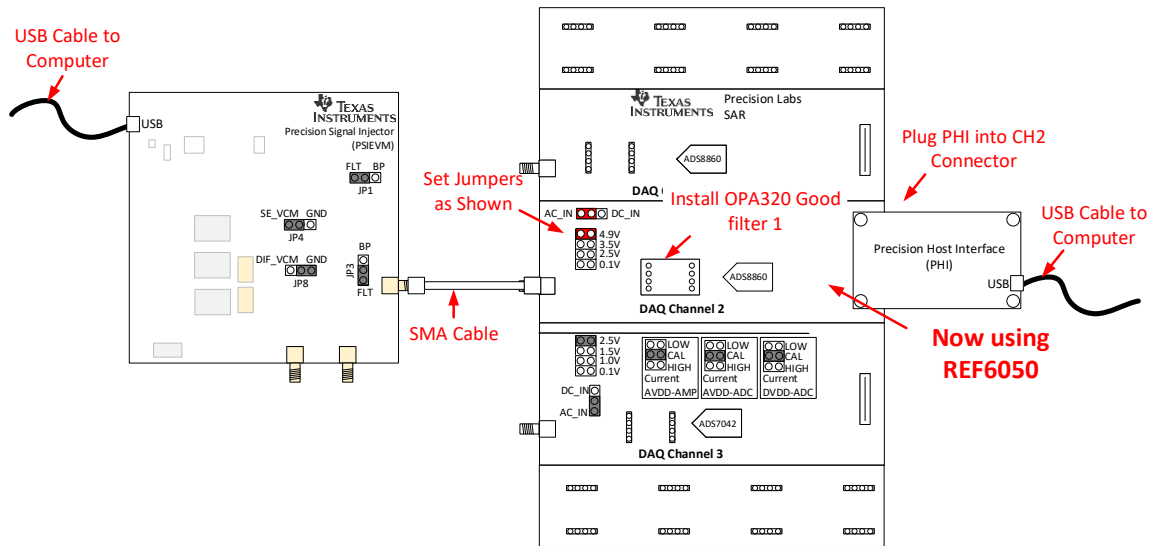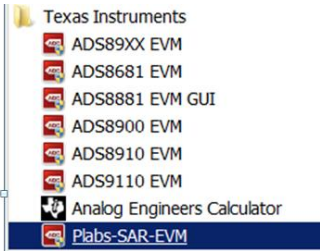Now we are going to switch to another channel. To do this we need to disconnect power to both the PSI and PHI by disconnecting the USB cable. Also, close the software should be closed by clicking the "x" in the corner.

Connect the hardware

USB Cable to Computer

Set Jumpers as Shown

SMA Cable

Plug PHI into CH2 Connector

Install OPA320 Good filter 1

USB Cable to Computer

Now using REF6050

Now we will switch to channel 2 on the precision labs hardware. First, set the jumpers as shown here. Note that we are changing back to an AC input with the jumper settings. Connect the PSI to the PLABS board using the SMA cable, and connect the PHI to the PLABS channel 2 connector. Next, connect the USB cables to the computer. Finally, install OPA320_Goodfilter1 in the socket. Be careful to install this amplifier right side up with the label at the bottom of the coupon card. Pause and connect the hardware.

Start & Setup the Plabs-SAR-EVM Software

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

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

Now we can re-start the software by selecting the "Plabs-SAR-EVM" icon from the "Start > All Programs" menu. Once the software is running you should notice the green "HW connected" message at the bottom of the software. Also if the PSI controls are colored teal the hardware communications is working. Pause and get the EVM software started.

REF6050: 1Msps, 500ksps, 100ksps: SNR, THD

1. Select spectral analysis

2. Sampling Rate 1Msps, 500ksps, 100ksps

3. Press Mark Harmonics

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

5. Press "Capture"
6. Record AC performance

	fs	SNR (dB)	THD (dB)
Spec.	1M	93	-108
REF6050	1M	92.6	-108.1
REF6050	500k	92.7	-109.3
REF6050	100k	92.3	-108.1

Now we will repeat the SNR and THD measurements for the REF6050. Remember the REF6050 has a wide bandwidth integrated buffer so we expect the system using this device to have good performance up to the full 1Msps sampling rate. To perform this test first select "Spectral Analysis" under "Pages". Next select the sampling rate. For this test we will use 1Msps, 500ksps, and 100ksps sampling rates. Let's start with 1Msps. Next check the "Mark Harmonics" check box. This will zoom in on the distortion components in the FFT. Next configure the PSI. Set the amplitude to 4.9V, the offset to 2.5V, and the frequency to 2kHz. Finally, press capture and record the AC performance. Pause and measure SNR and THD at all three sampling rates.

The table to the right compares the SNR and THD specification to the measured performance at the different sampling rates. As expected, the measured performance is very close to the specified performance for all the different sampling rates tested. This is because the wide bandwidth reference in the REF6050 settles quickly allowing for low distortion signal capture.   Next we will look at the DC performance with the REF6050.
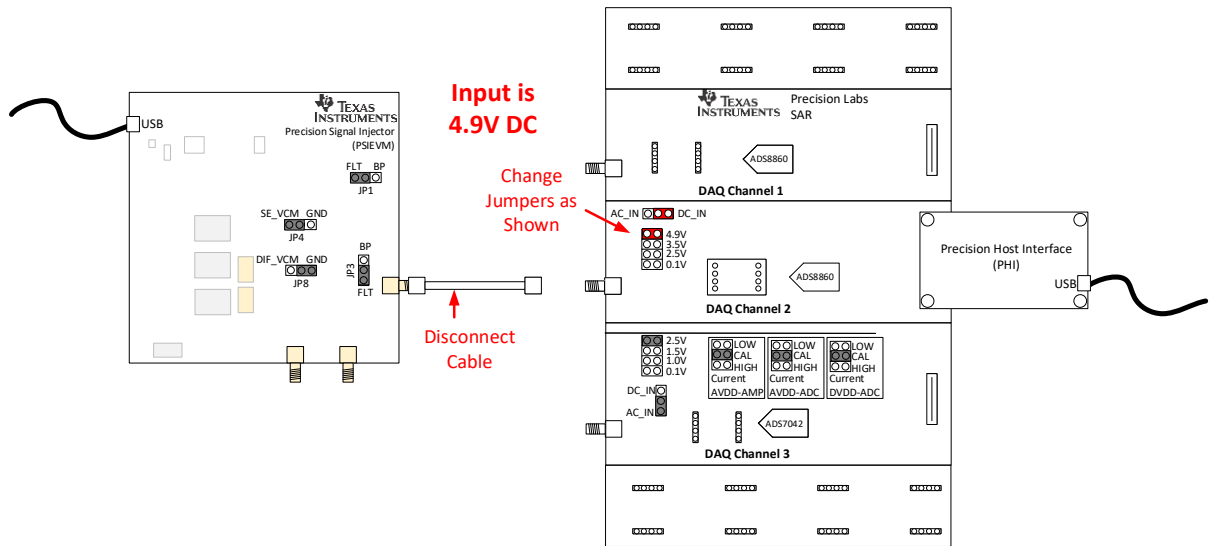
For this experiment we will make a few minor changes to the hardware. First disconnect the SMA cable from the PSI. Next change the jumper to DC_IN and make sure that the voltage jumper is set to 4.9V. So for this experiment, the AC signal is disconnected and we connect the on-board 4.9V DC source. Pause and change the hardware.

REF6050: 1Msps, 500ksps, and 100ksps settling

	fs	Droop (LSB)
REF6050	1M	1.15
REF6050	500k	0.8
REF6050	100k	0.8

Reference Settling Analysis

1. Select "reference settling"
2. Sampling Rate 1Msps, 500ksps, and 100ksps
3. Number of sets to average to 20.
4. Min Interset delay (ms) to 100
5. Start test
6. Reference droop

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Here we will check the reference settling for the REF6050 by applying a DC 4.9V input and measuring the conversions. When we performed the same experiment using the REF5050 the performance was degraded at higher sampling rates. For this experiment first select "Reference Settling" under "Pages". Next, select the sampling rate. Here we will run the experiment for 1Msps, 500ksps, and 100ksps. Let's start with 1Msps. Next enter the number of data sets that we will average to 20. Next set the "Interset" delay to 100ms. This is the delay between each set of points being measured. Finally, press "Start test" and measure the reference droop. The figure shown shows the results for 1Msps. Repeat the experiment for

500ksps, and 100ksps. Pause and measure droop at all three sampling rates.

The table to the right shows the settling performance for the REF5050 system. Ideally the droop should be less than 1 LSB. As expected, the measured performance is very close to this target droop error. This is because the wide bandwidth reference in the REF6050 responds quickly to the transient current requirements and holds the reference voltage constant. Now let's compare all the measured results.

Expected results

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

Reference		Sampling Rate	Measured Results			Example Measurements		
			SNR (dB)	THD (dB)	Reference settling Vin = 4.9V DC	SNR (dB)	THD (dB)	Reference Droop Vin = 4.9V DC (codes)
	Data Sheet Typical Specification	1M	93	-108		93	-108	
1	REF5050	1M				92.2	-91.4	10.9
2	REF5050	500k				92.1	-97.1	5.35
3	REF5050	100k				92.0	-108.2	1.4
4	REF6050	1M				92.6	-108.1	1.15
5	REF6050	500k				92.7	-109.3	0.8
6	REF6050	100k				92.3	-108.1	0.8

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The table summarizes the measured results for all tests in this experiment. Your measured results should be close to the example measurements. Again note that both the AC and DC performance for the REF6050 is good for all the sampling rates whereas the performance for the REF5050 is only good at lower sampling rates.

Thanks for your time!

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That concludes the hands-on experiment. I hope this was useful to you. Thanks for your time.