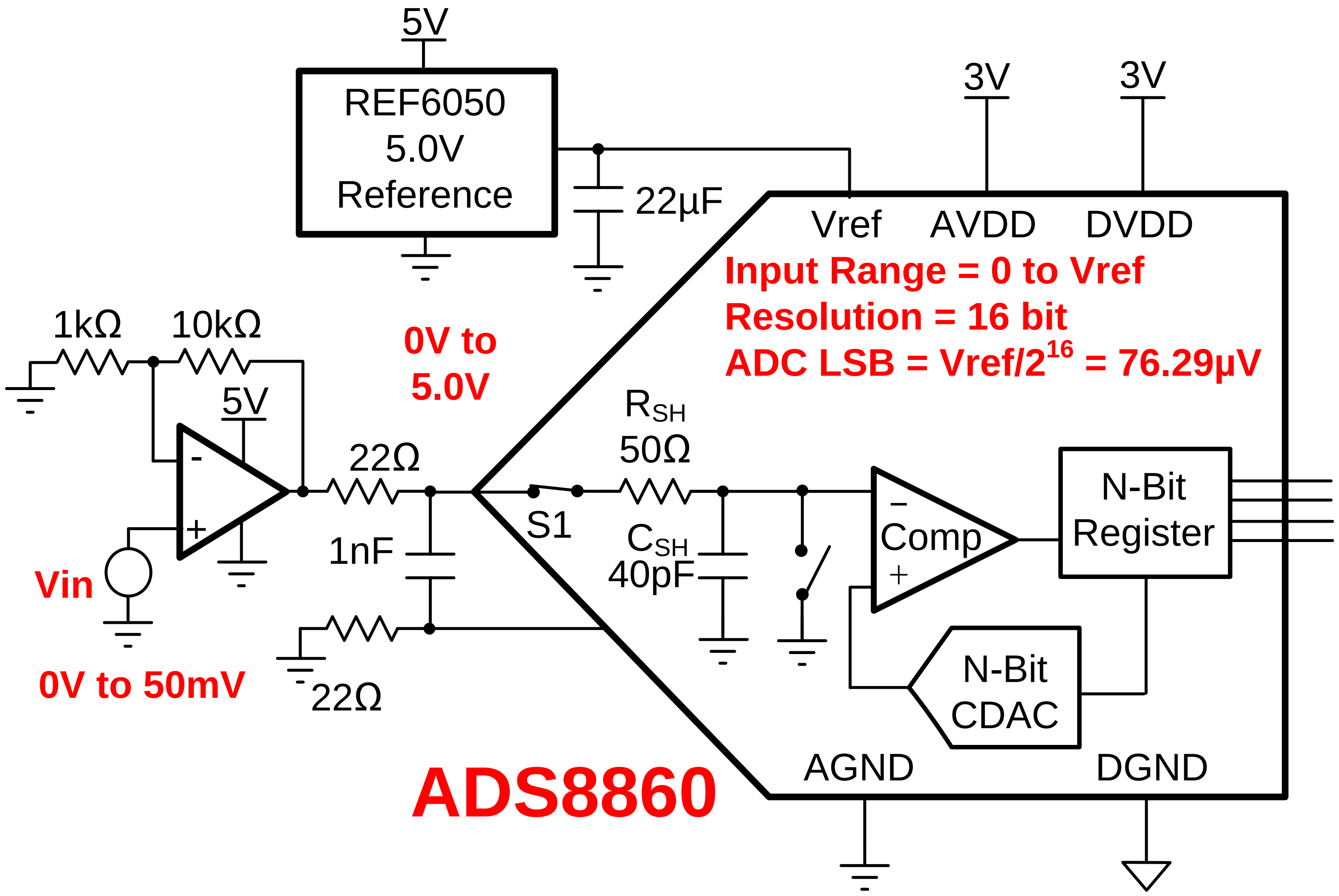
Calculating the total noise for ADC systems

TIPL 4204
TI Precision Labs – ADCs

Created by Art Kay, Dale Li

Presented by Peggy Liska

SNR of Amplifier + ADC: General Equations



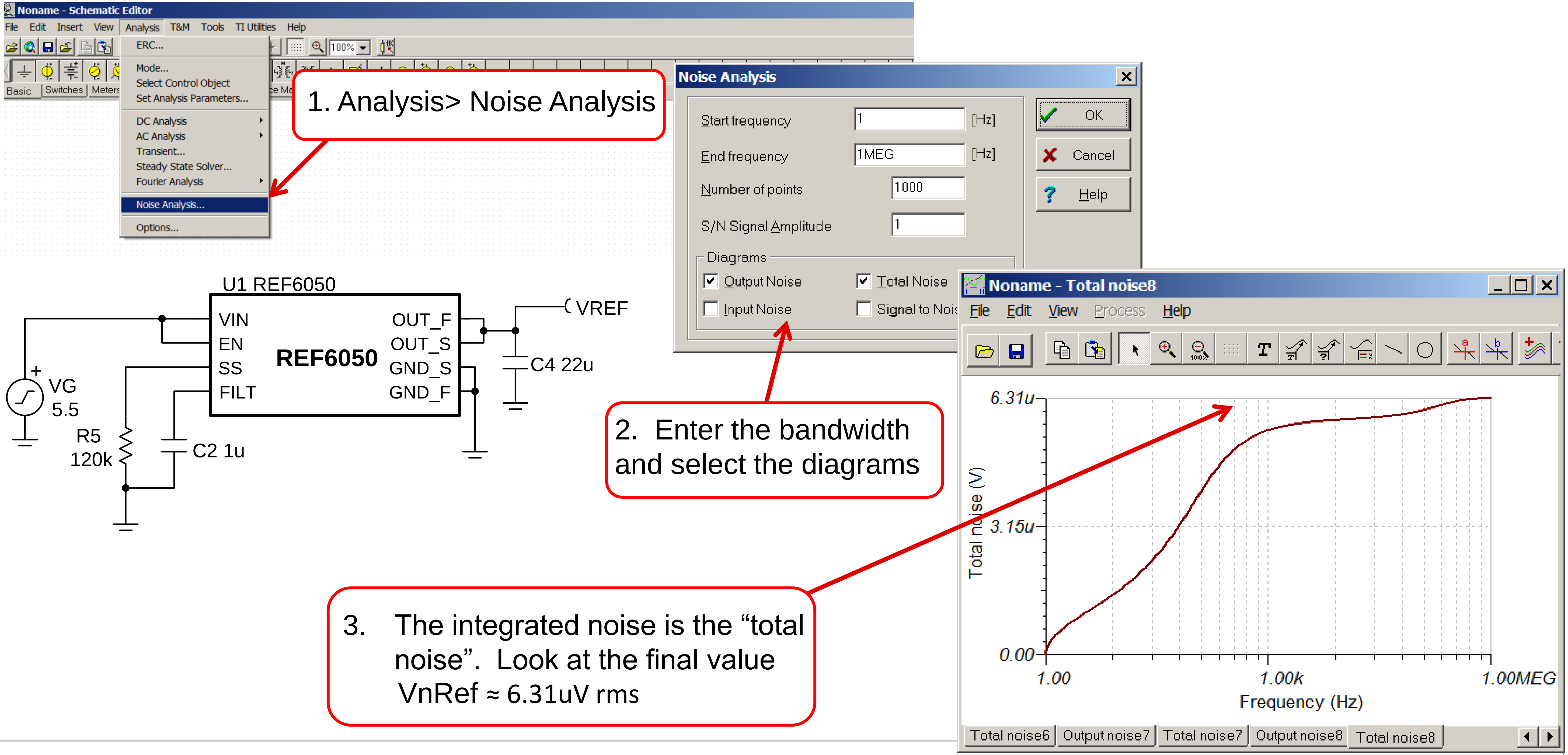
$$SNR_{ADC} = 20 \cdot \log\left(\frac{V_{FSR\_rms}}{V_{nADC}}\right)$$ Solve for noise

$$V_{nADC} = \frac{V_{FSR\_rms}}{10^{\left(\frac{SNR_{ADC}}{20}\right)}}$$ From ADC data sheet

$$V_{nT} = \sqrt{(V_{nADC})^2 + \left(V_{nAmp}\right)^2 + (V_{nRef})^2}$$ Total RMS Noise

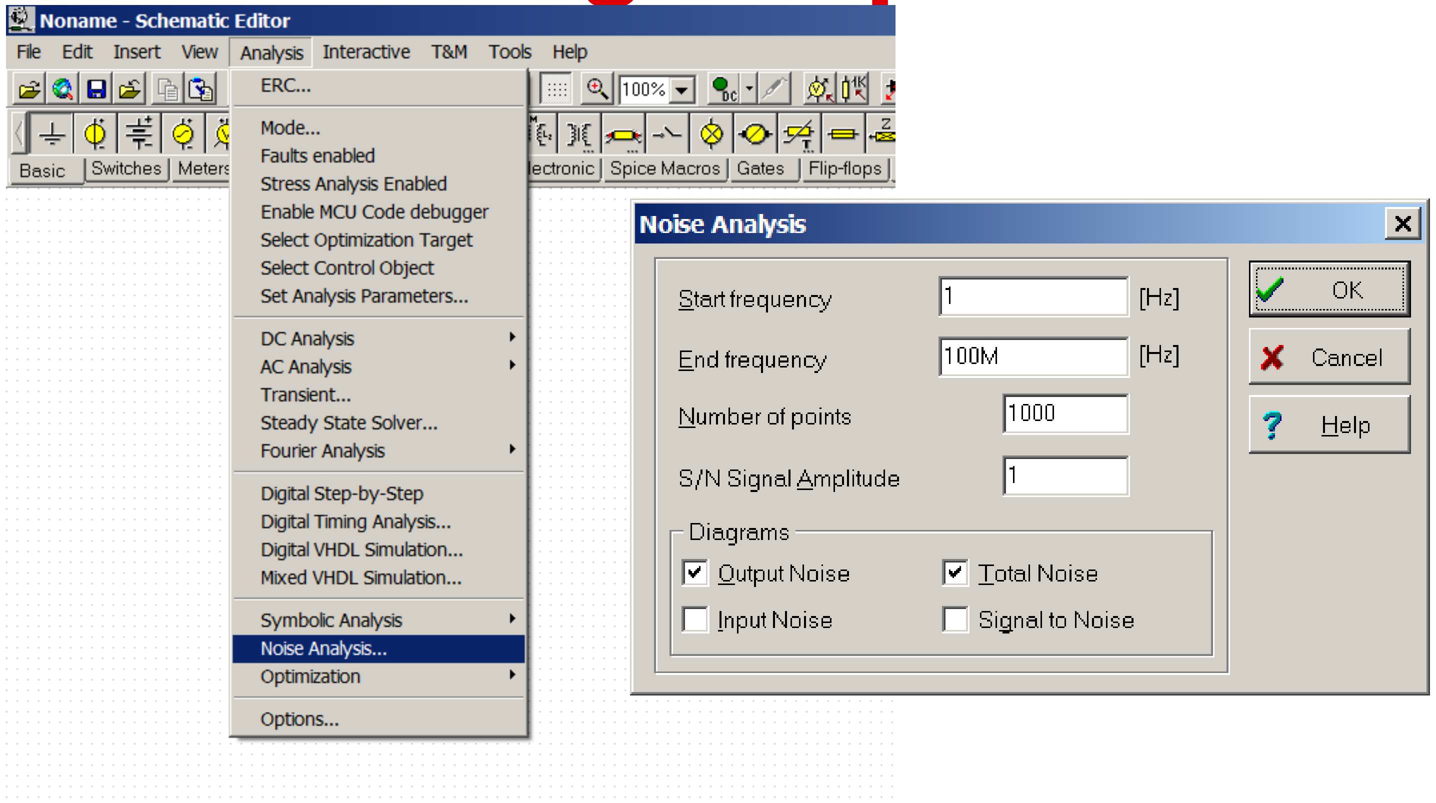
$$SNR_{total} = 20 \cdot \log\left(\frac{V_{FSR\_rms}}{V_{nT}}\right)$$ ADC+Amp+Ref

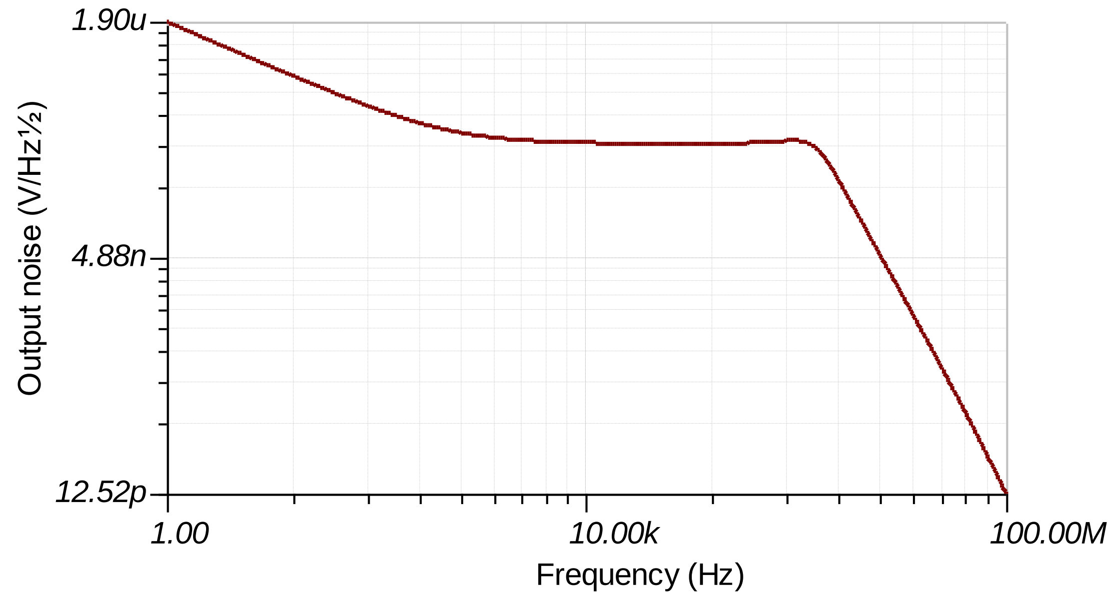
Find the REF6050 Noise

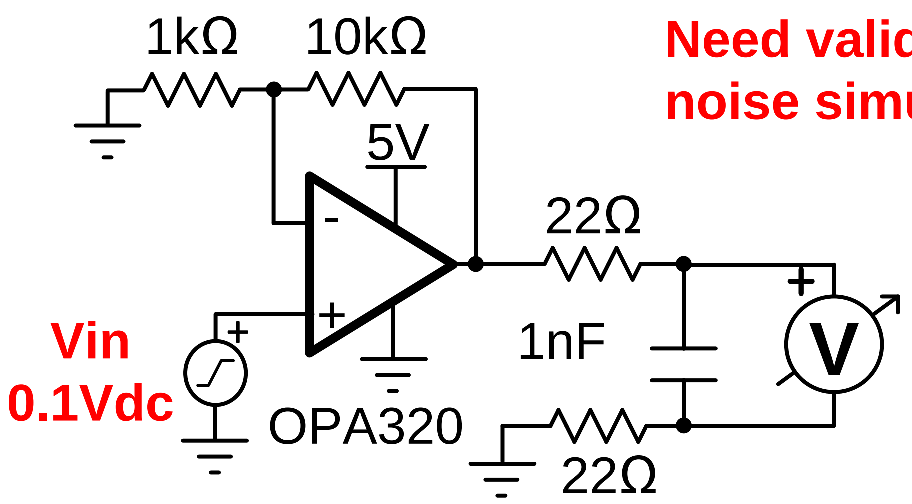


TEXAS INSTRUMENTS

Simulating Amplifier Noise

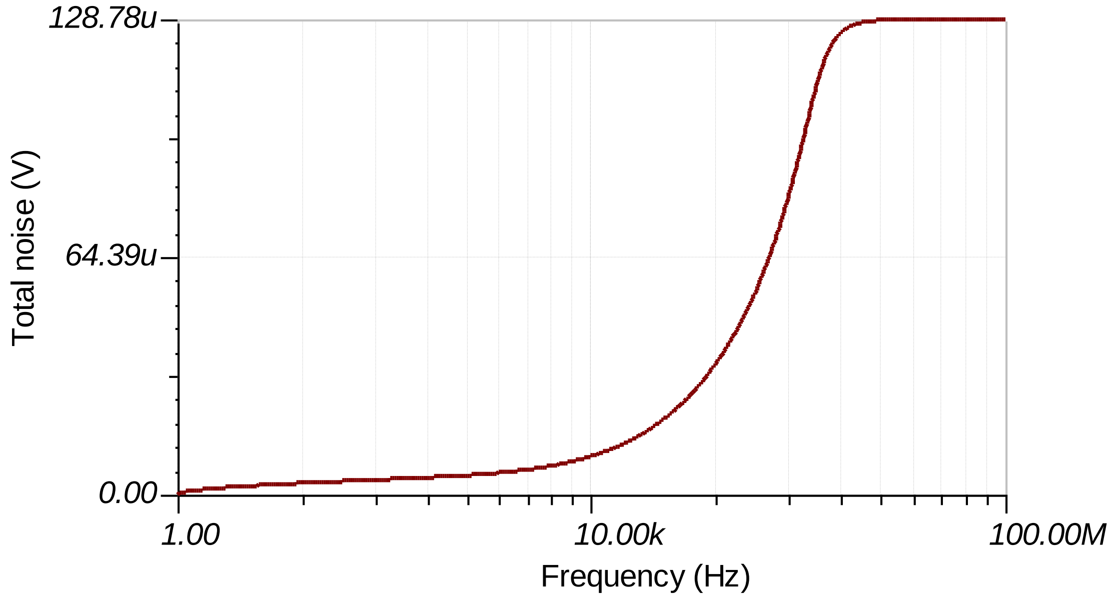




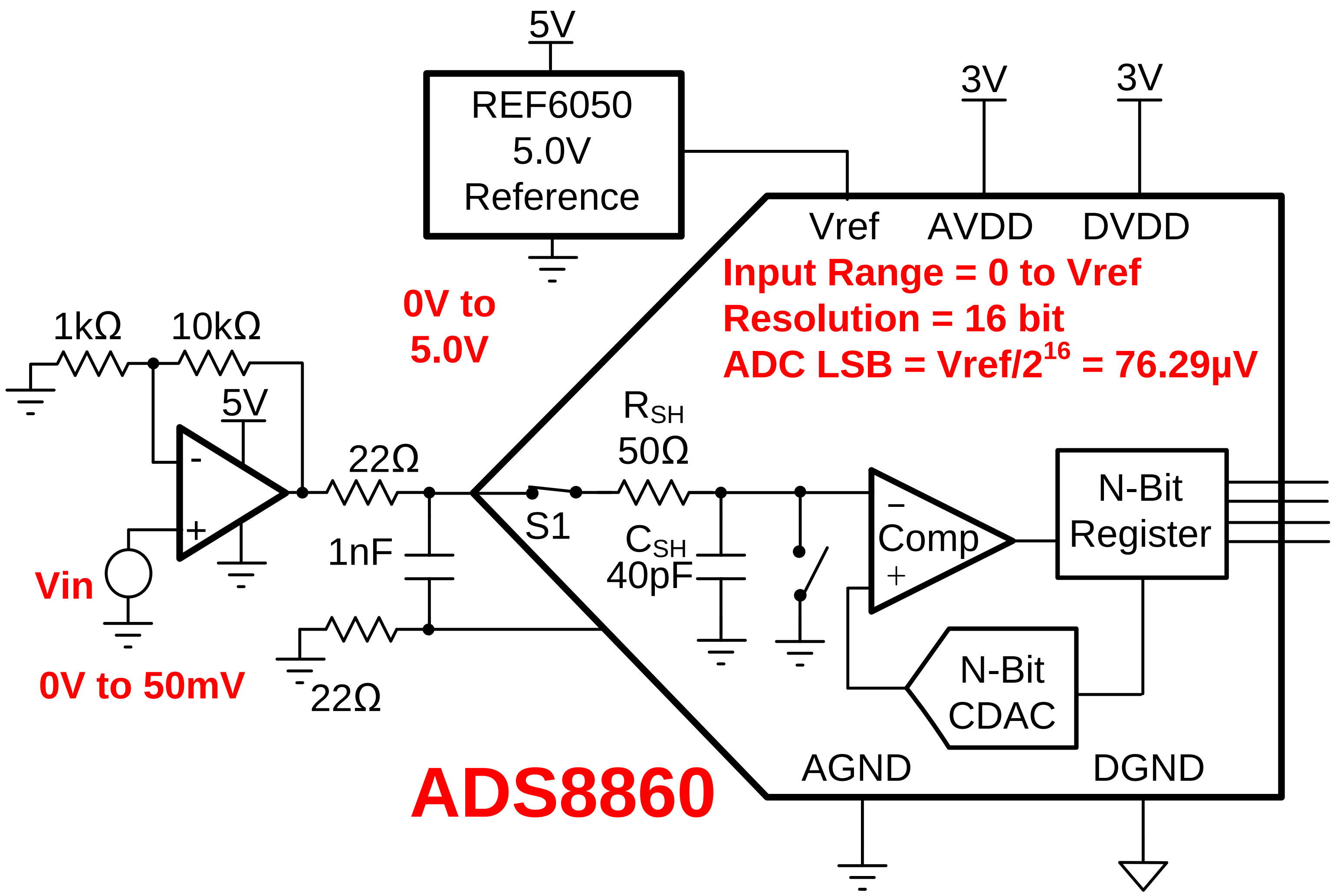


Need valid dc operating point for noise simulation!

V_{outDC} = 11 x 0.1V = 1.1V
E_{nrms} = 128.8µV rms
E_{npp} = 6·128.8µV rms = 773µVpp



SNR of Amplifier + ADC: Example Calculation



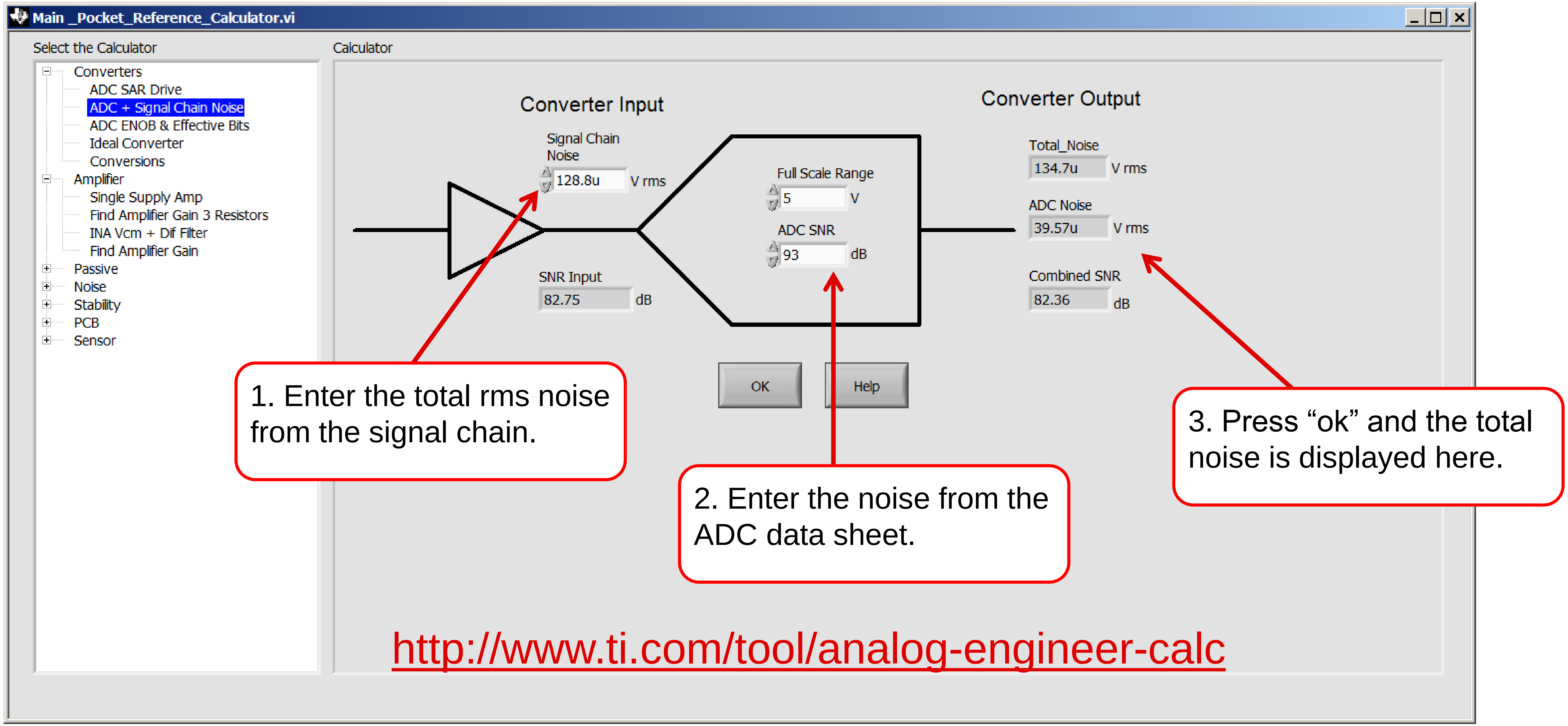
$$V_{FSR\_rms} = V_{FSRpk} \cdot 0.707$$
$$V_{FSR\_rms} = 0.5 \cdot FSR \cdot 0.707$$
$$= 0.5 \cdot 5V \cdot 0.707 = 1.767V$$

$$V_{nADC} = \frac{V_{FSR\_rms}}{10^{\left(\frac{SNR_{ADC}}{20}\right)}} = \frac{1.767V}{10^{\left(\frac{93dB}{20}\right)}} = 39.6\mu V\ rms$$

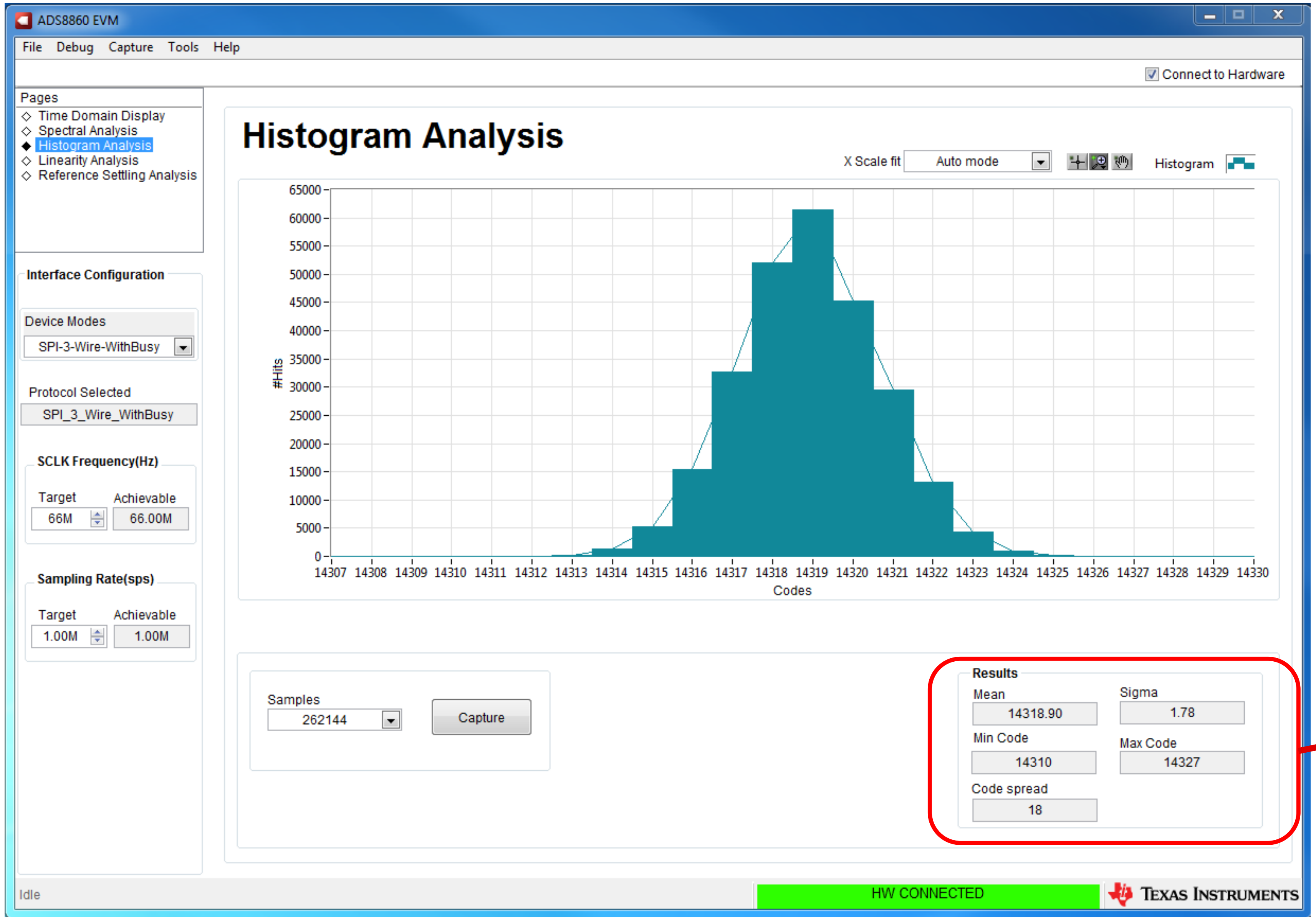
$$V_{nT} = \sqrt{(V_{nADC})^2 + \left(V_{nAmp}\right)^2 + (V_{nRef})^2}$$
$$= \sqrt{(36.9\mu V)^2 + (128.8\mu V)^2 + (6.3\mu V)^2} = 134\mu V\ rms$$

$$SNR_{total} = 20 \cdot \log\left(\frac{V_{FSRrms}}{V_{nT}}\right) = 20 \cdot \log\left(\frac{1.767V}{134\mu V}\right) = 82.4\ dB$$

Signal Chain Noise: Analog Engineer's Calculator



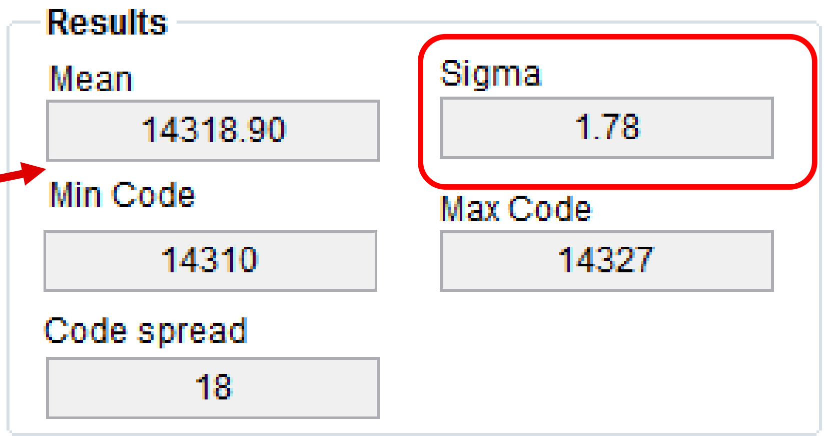
SNR of Amplifier + ADC: Measured Result



$$LSB = \frac{FSR}{2^N} = \frac{5V}{2^{16}} = 76.29\mu V$$

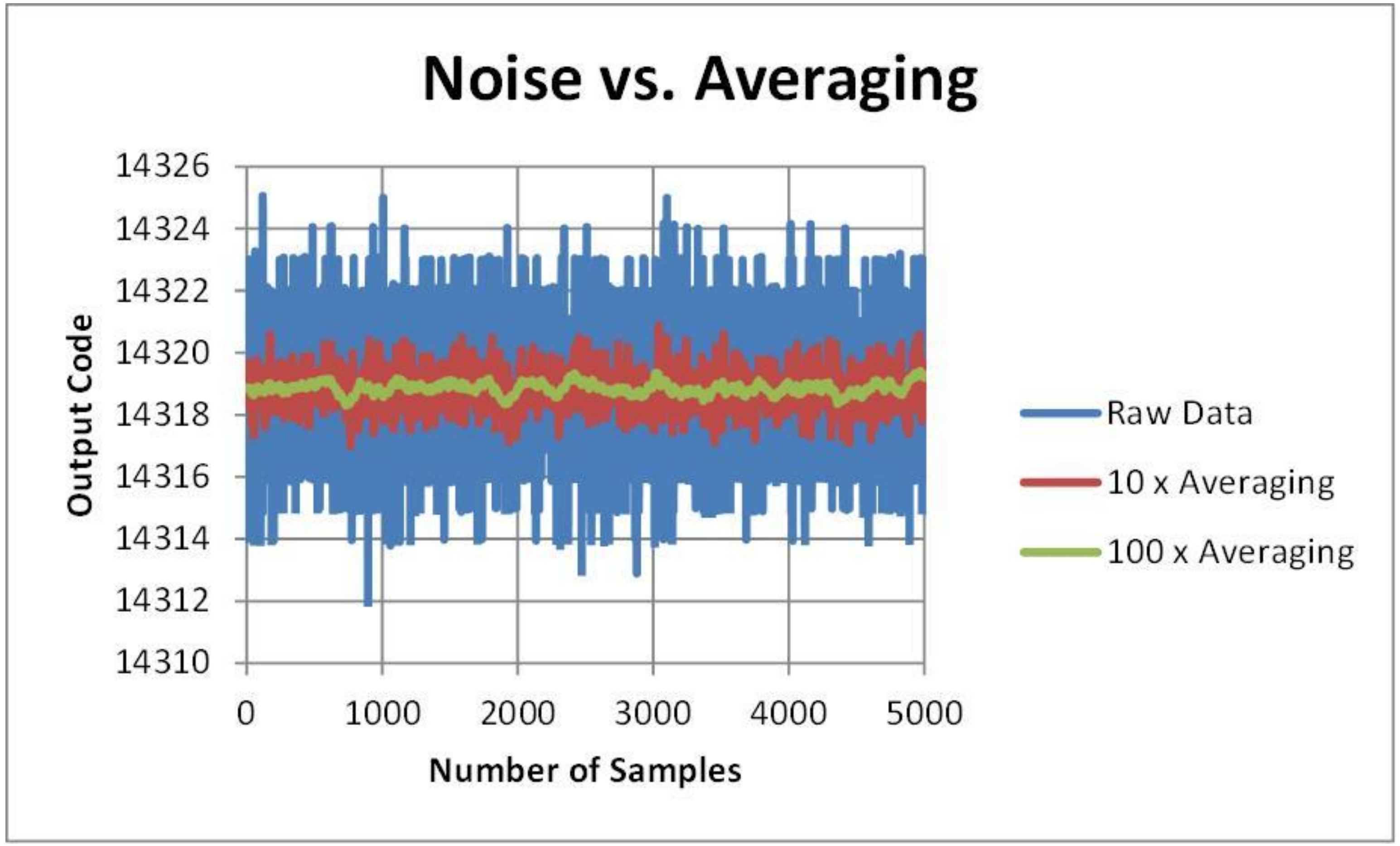
$$V_{nTmeas} = \sigma_{adc} \cdot LSB = 1.78 \cdot 76.29\mu V = 136\mu V\ rms$$

$V_{nTCalc} = 134\mu V\ rms$ *from the previous slide*



rms noise is one sigma

Averaging to Reduce Noise



Measured vs. Calculated Averaging

	Measured RMS codes	Calculated RMS codes
Standard Deviation Raw Data	1.80	na
Standard Deviation 10 x Averaging	0.59	0.57
Standard Deviation 100 x Averaging	0.18	0.18

$$\mathrm{V_{nAvg}} = \frac{V_n}{\sqrt{N}}$$

Where
V_n *is the RMS noise*
N *is the number of averages*
V_{nAvg} *is the RMS noise after averaging*

$$\mathrm{V_{nAvg}} = \frac{V_n}{\sqrt{N}} = \frac{1.8\ codes}{\sqrt{10}} = 0.57\ codes$$

$$SNR_{avg} = 20 \cdot \log\left(\frac{\mathrm{V}_s}{V_n/\sqrt{N}}\right) = 20 \cdot \log\left(\frac{\mathrm{V}_s}{V_n}\right) + 10 \cdot \log(N)$$

Thanks for your time!
Please try the quiz.

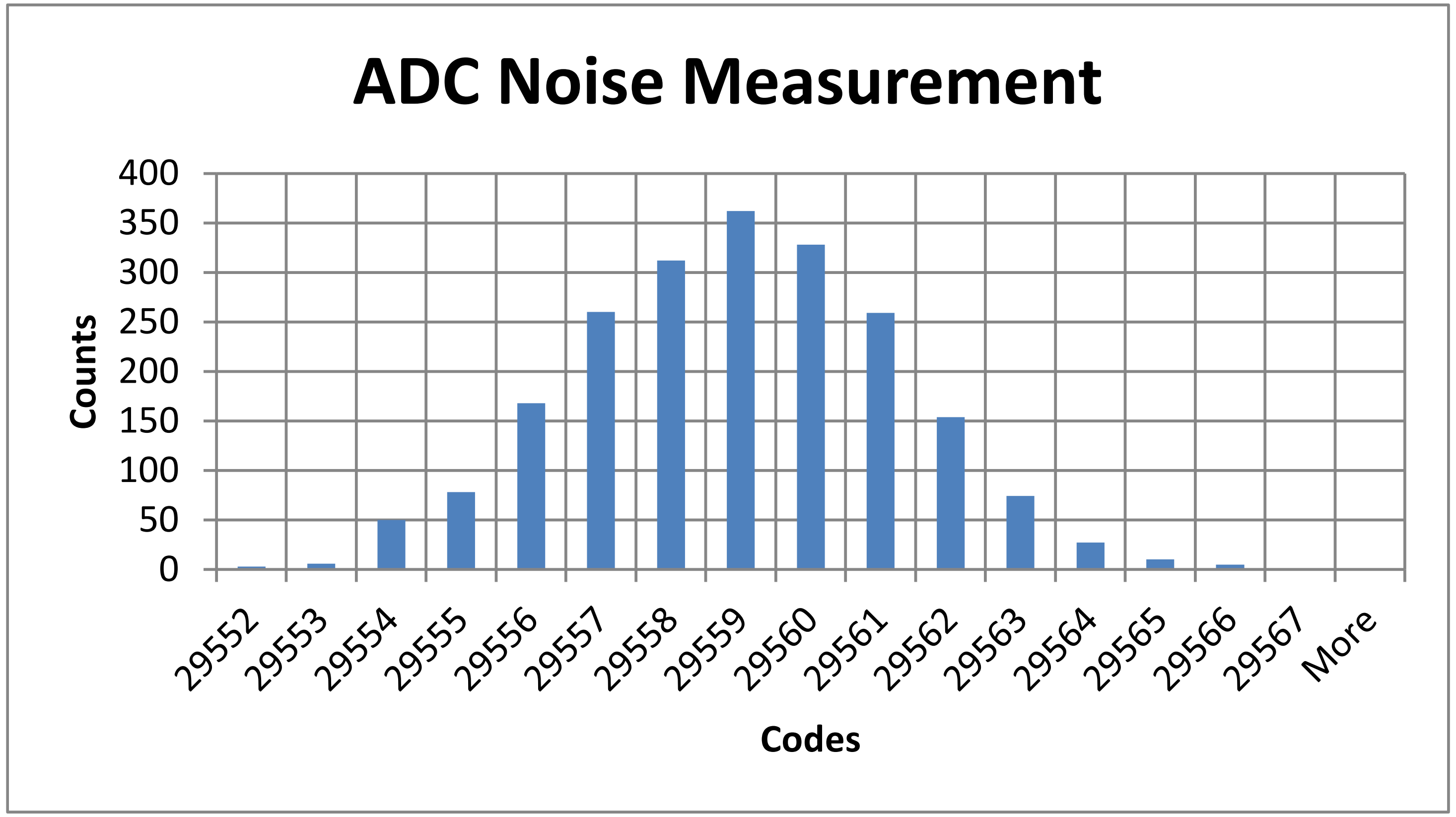
Quiz: Calculating the total noise for ADC systems

TIPL 4204
TI Precision Labs – ADCs

Created by Art Kay

Quiz: Calculating the total noise for ADC systems

1. The histogram below was measured with a data converter:
   a) What is the RMS noise voltage?
   b) Assume the output is averaged using a 8 point rolling average. What is the averaged noise?



FSR = ±5V
Resolution = 18
Standard Deviation=σ = 2.25 codes
Mean = 29558.4

Quiz: Calculating the total noise for ADC systems

2. For the attached Excel file:

   a) Graph the raw data, 8 point rolling average, and 128 point rolling average.

   b) Calculate RMS noise in codes.

   c) Calculate RMS noise in volts. Assume FSR = ±5V and resolution is 18 bits.

   d) Compare theoretical to measured averaging.

Click on this embedded file, for the Excel file used for this problem.

Microsoft Excel Worksheet

Quiz: Calculating the total noise for ADC systems

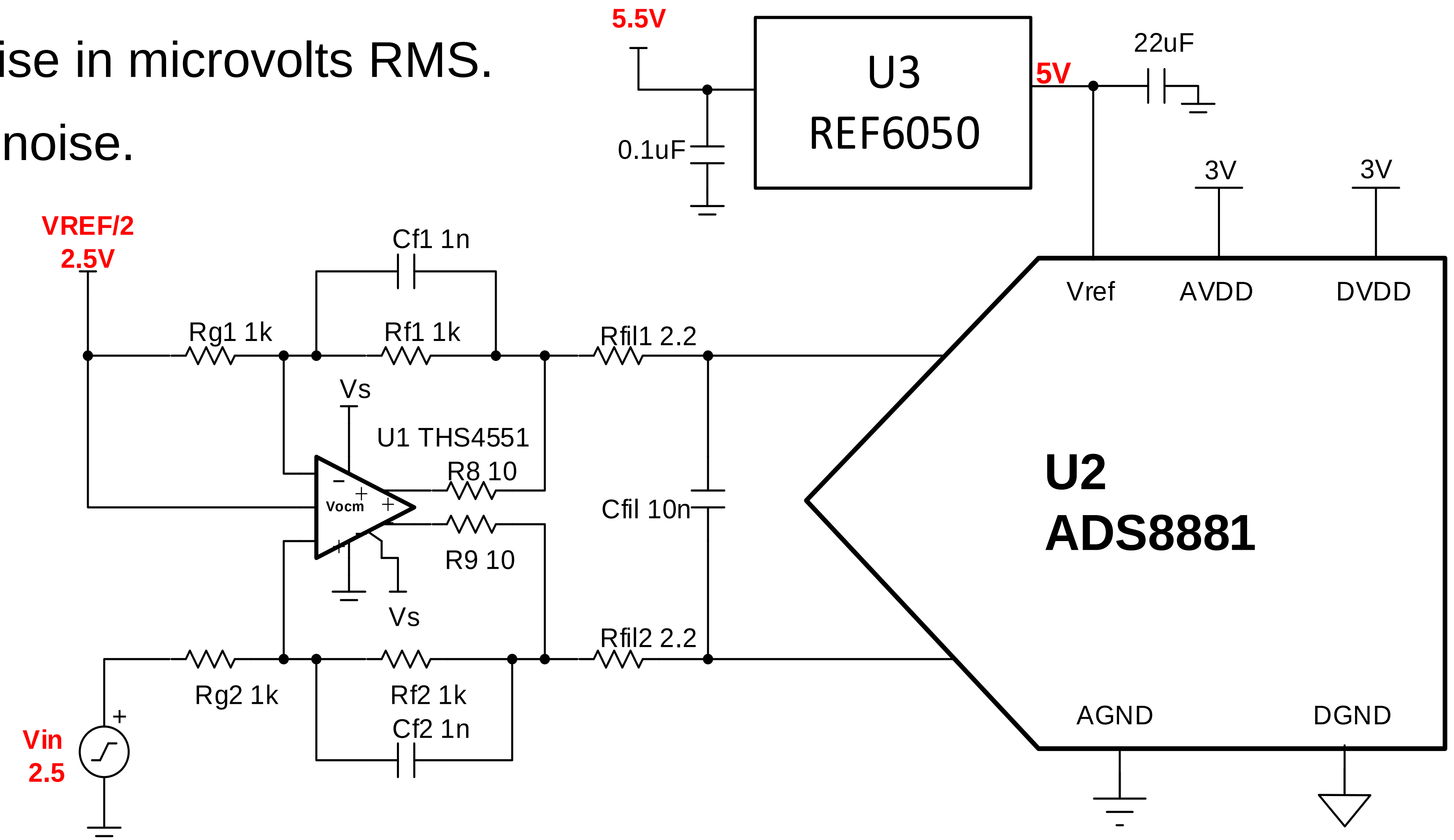
3. For the circuit below.

   a) Find the total RMS amplifier noise.

   b) Find the total RMS reference noise.

   c) Calculate the total ADC Noise in microvolts RMS.

   d) Find the total RMS system noise.



Solutions

Quiz: Calculating the total noise for ADC systems

1. The histogram below was measured with a data converter:
   a) What is the RMS noise voltage? **ANS: 85.83µV rms**
   b) Assume the output is averaged using a 8 point rolling average. What is the averaged noise? **ANS: 30.35µV**

FSR = ±5V
Resolution = 18
Standard Deviation=σ = 2.25 codes
Mean = 29558.4

RMS Noise Voltage

$$LSB = \frac{FSR}{2^N} = \frac{2 \cdot 5V}{2^{18}} = 38.15\mu V$$

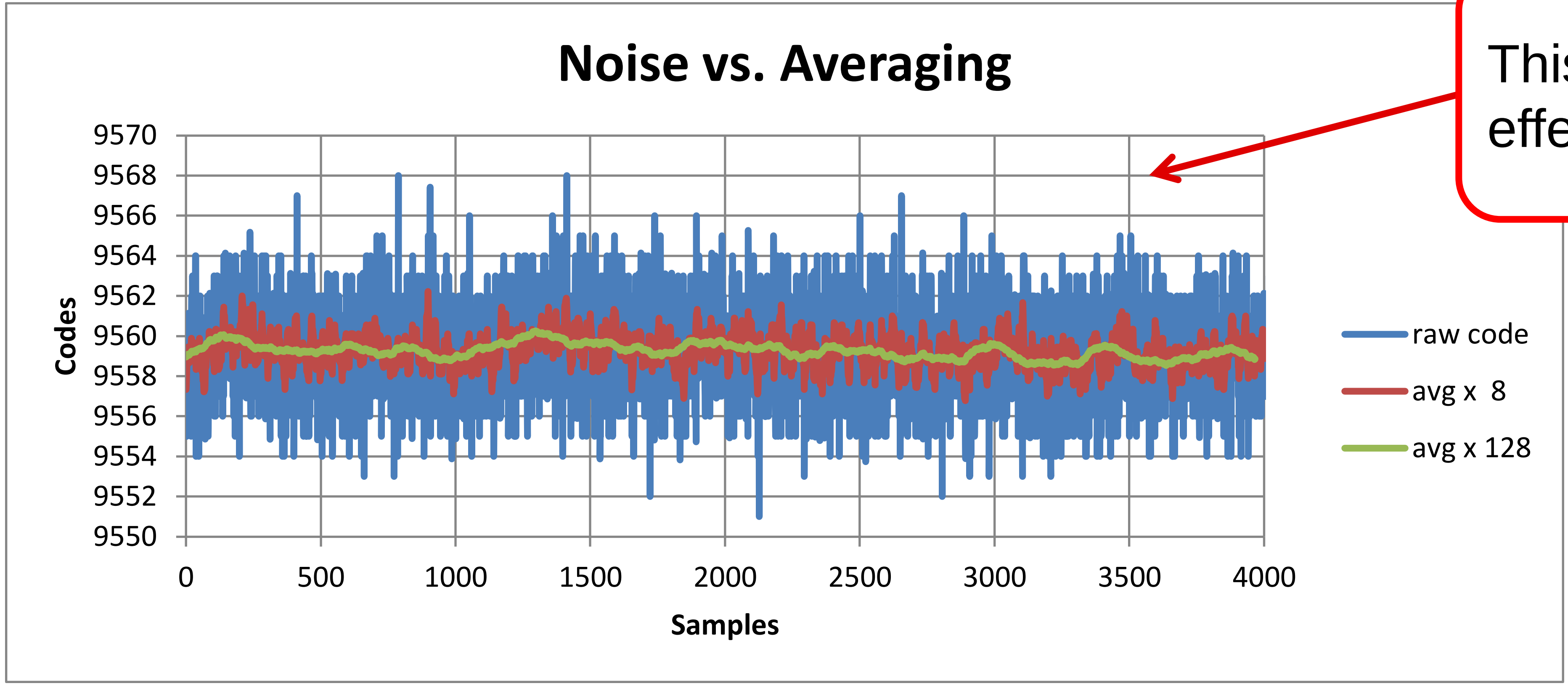
$$V_n = LSB \cdot \sigma = (38.15\mu V) \cdot (2.25) = 85.83\mu V\ rms$$

Output With 8 point rolling average

$$V_{nAvg} = \frac{V_n}{\sqrt{N}} = \frac{85.83\mu V}{\sqrt{8}} = 30.35\mu V$$

Quiz: Calculating the total noise for ADC systems

2. For the attached Excel file:
   a) Graph the raw data, 8 point rolling average, and 128 point rolling average.



This graph shows the raw data and the effect of averaging (8x and 128x).

Click on this embedded file, for the Excel file used for this problem.

Microsoft Excel Worksheet

Quiz: Calculating the total noise for ADC systems

2. For the attached Excel file:
   - b) Calculate RMS noise in codes.
   - c) Calculate RMS noise in volts. Assume FSR = ±5V and resolution is 18 bits.
   - d) Compare theoretical to measured averaging.

Find Measured Stdev

In Excel use "=AVERAGE()" and select the appropriate number of samples.

Find Theoretical Stdev

$$\sigma_{codeAvg} = \frac{\sigma_{codeRaw}}{\sqrt{N}} = \frac{2.2284}{\sqrt{8}} = 0.7878$$

Find Stdev in Volts

$$LSB = \frac{10V}{2^{18}} = 38.14\mu V$$

$$\sigma_{volts} = LSB \cdot \sigma_{codes} = (38.14\mu V\ ) \cdot (2.228)$$

$$\sigma_{volts} = 84.97\mu V\ rms$$

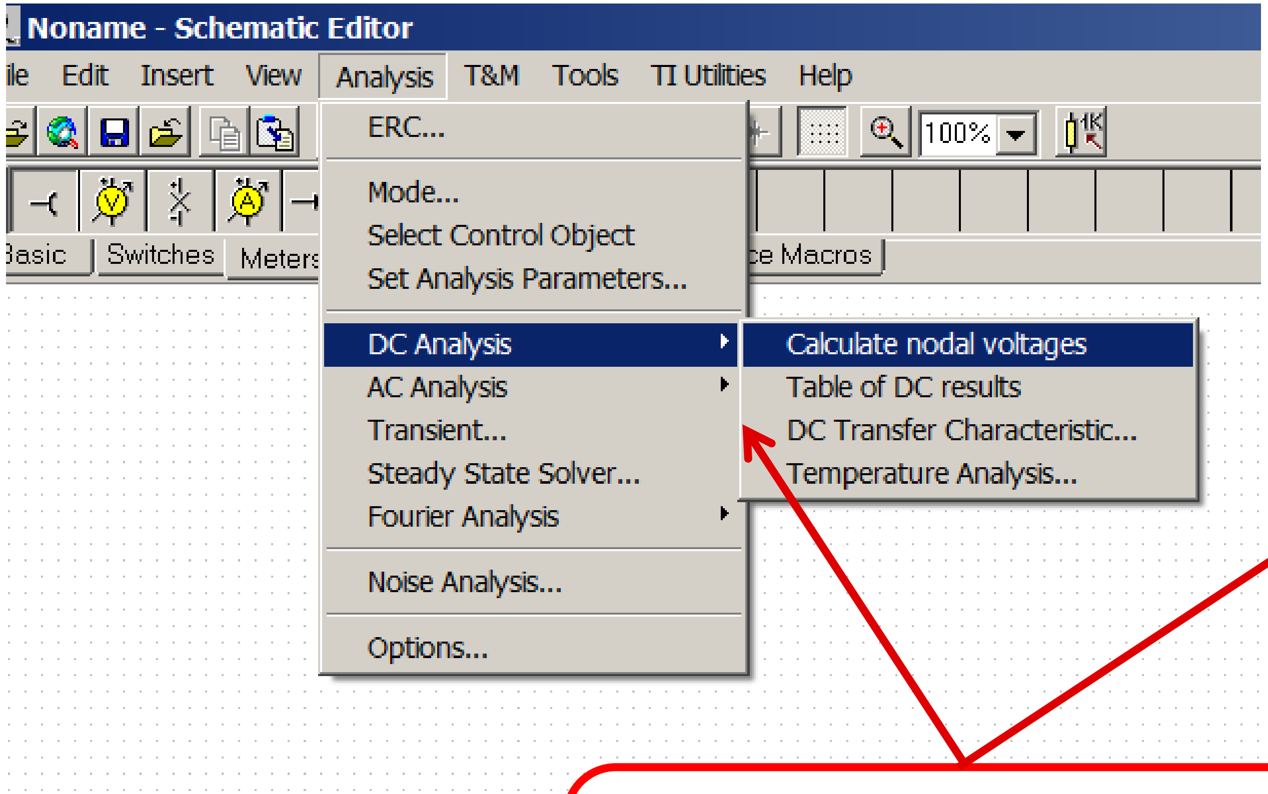
Number Averages	Measured Stdev	Theoretical Stdev	Stdev in Volts (measured)
-na-	2.228437	-na-	84.97µV
8	0.82137	0.787872	31.32µV
16	0.355782	0.196968	13.57µV

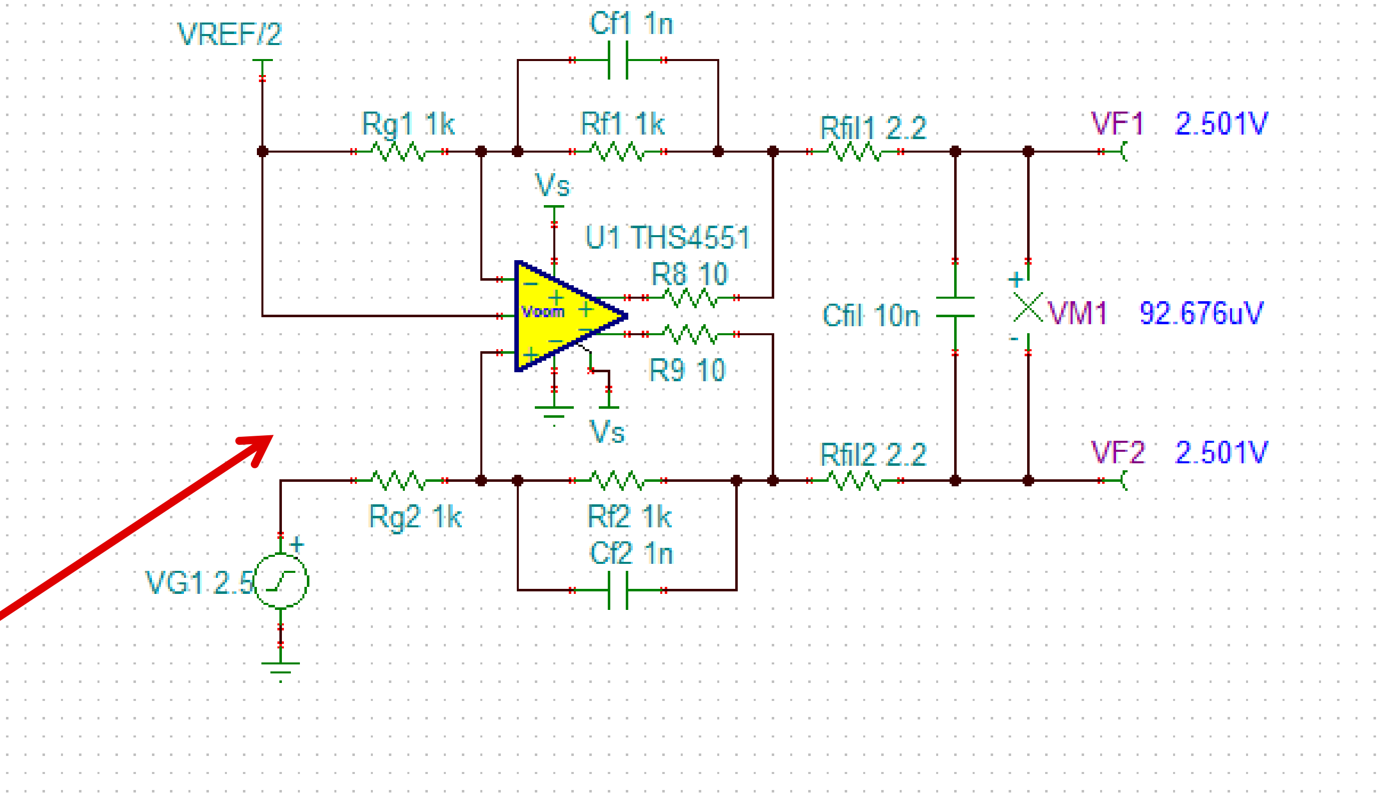
Comparing measured vs. theoretical you can see that the measured averaging is not as effective as theory predicted. This is not an uncommon result and is related to fact that the signal is not fully Gaussian; e.g. the signal has some drift with temperature and time. Also, the maximum reduction of noise is limited by the ADC resolution.

Quiz: Calculating the total noise for ADC systems

3. For the circuit below.

   a) Find the total RMS amplifier noise.





Check nodal voltages to make sure you are in the linear range.

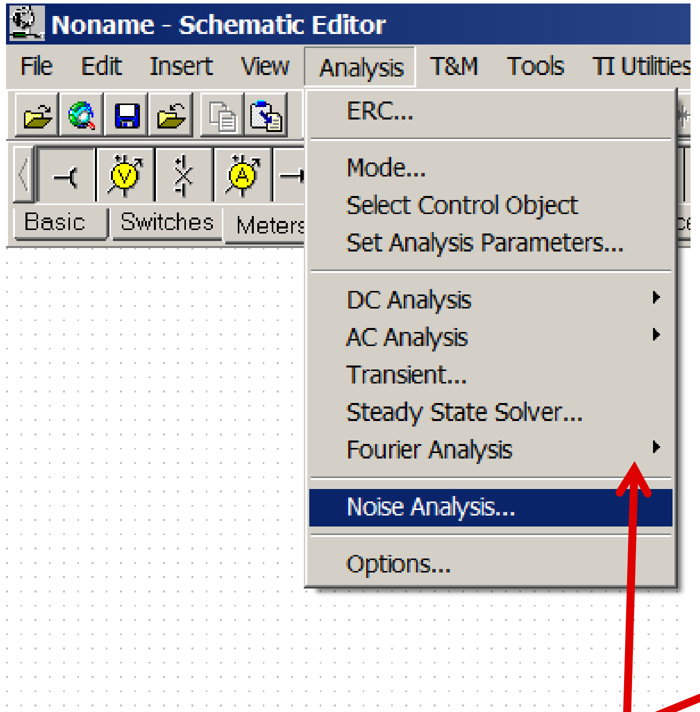
Click on this imbedded file, for the TINA file used for this problem.

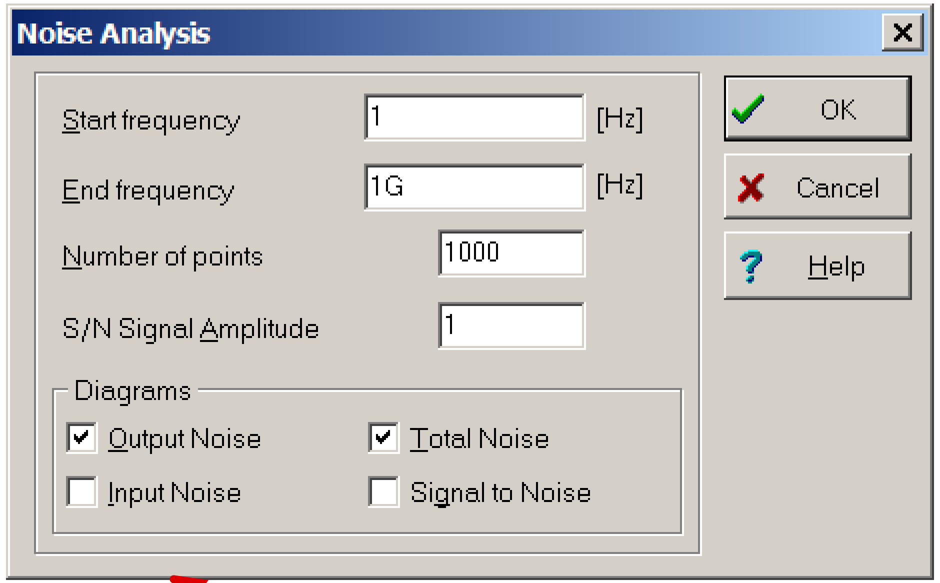
THS4551 Noise.TSC

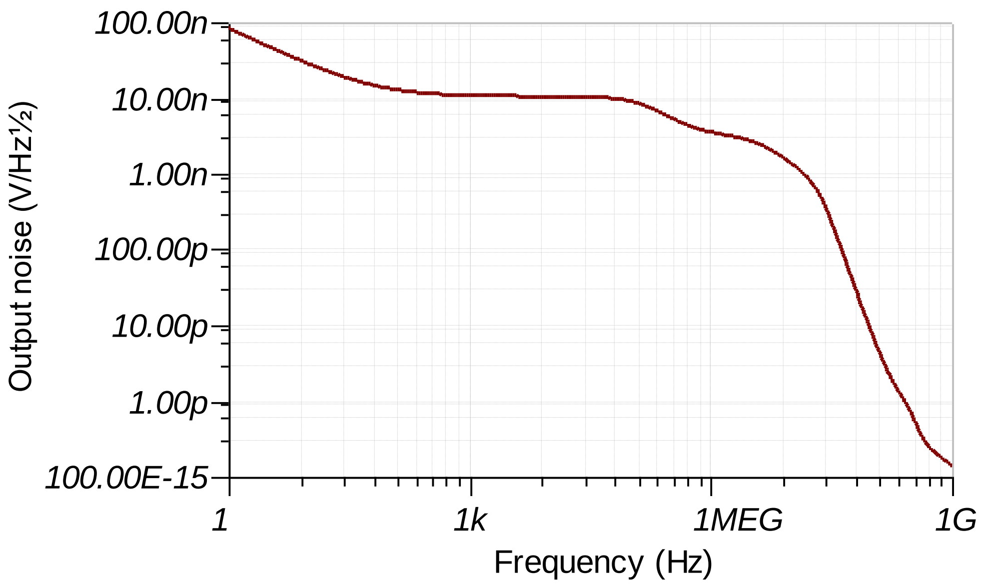
Quiz: Calculating the total noise for ADC systems

3. For the circuit below.

   a) Find the total RMS amplifier noise.

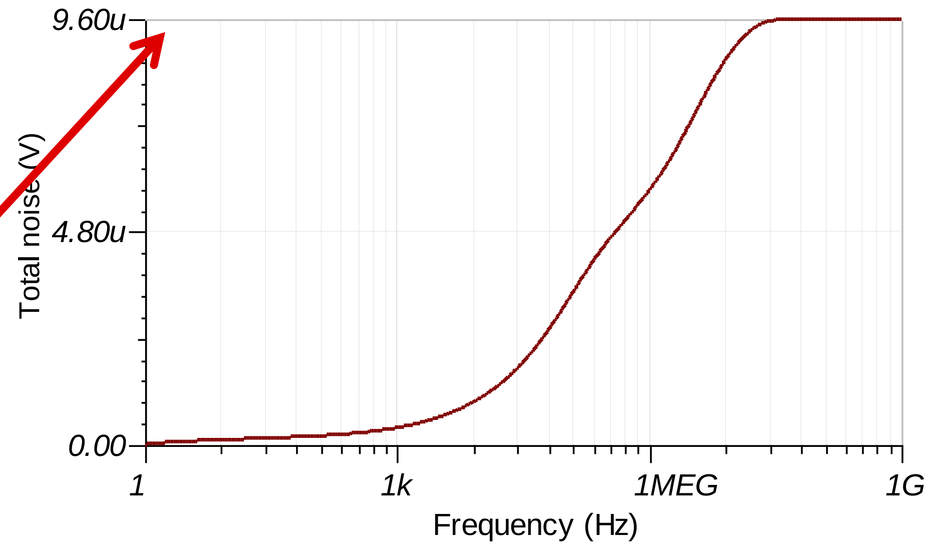






Run “Noise Analysis”. This is a wide bandwidth amplifier so use 1GHz end frequency. Select “Output Noise” and “Total Noise” Diagrams.

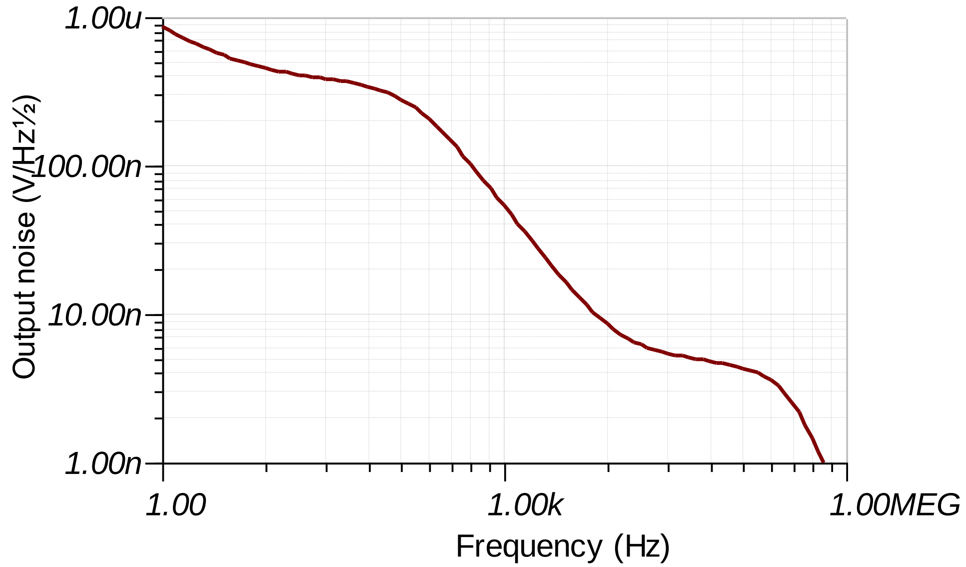
Integrated noise converges to 9.6uV rms.

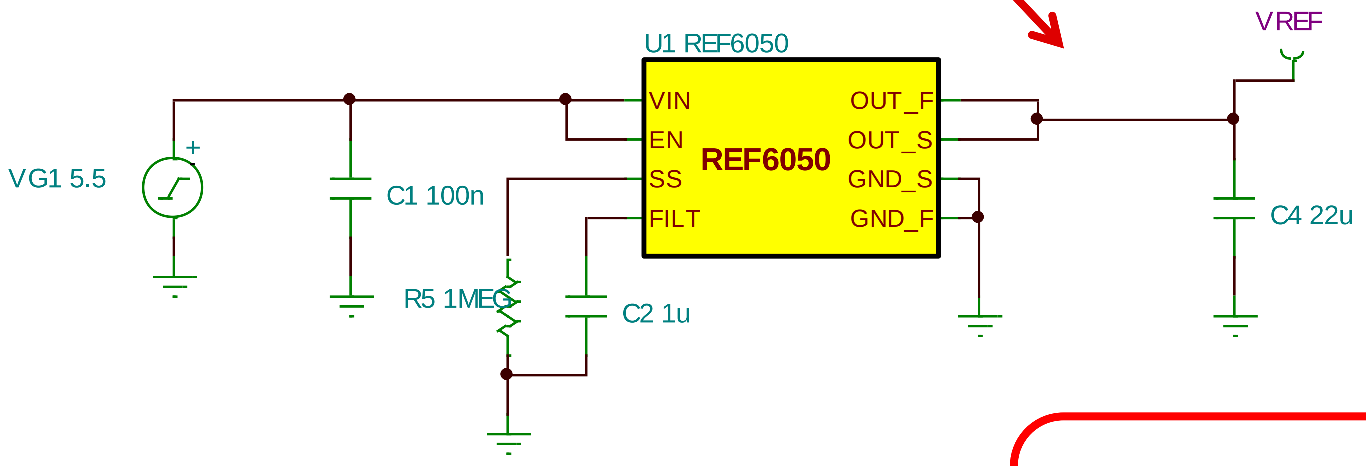


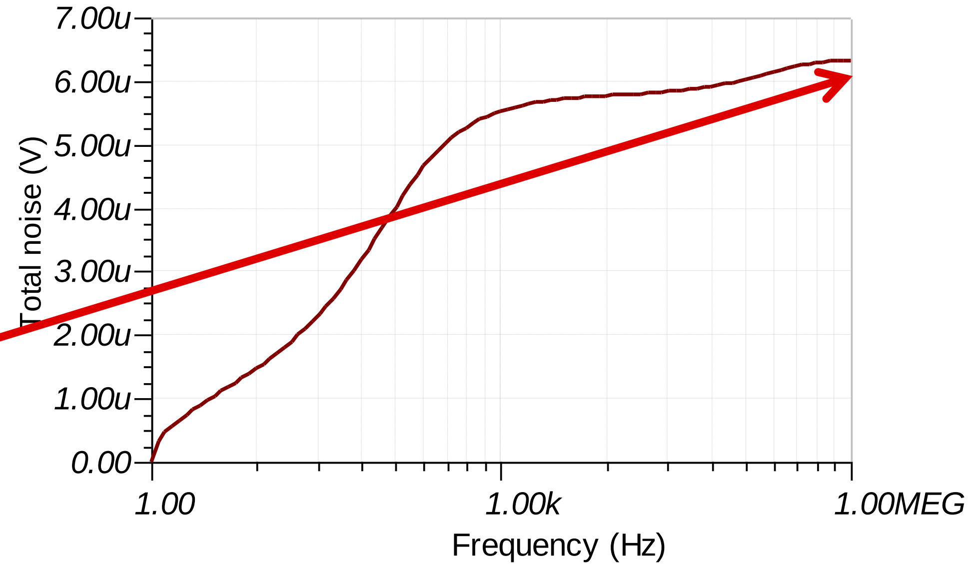
Quiz: Calculating the total noise for ADC systems

3. For the circuit below:
   b) Find the total RMS reference noise

Use the same method as the amplifier to test dc operation, and simulate noise.







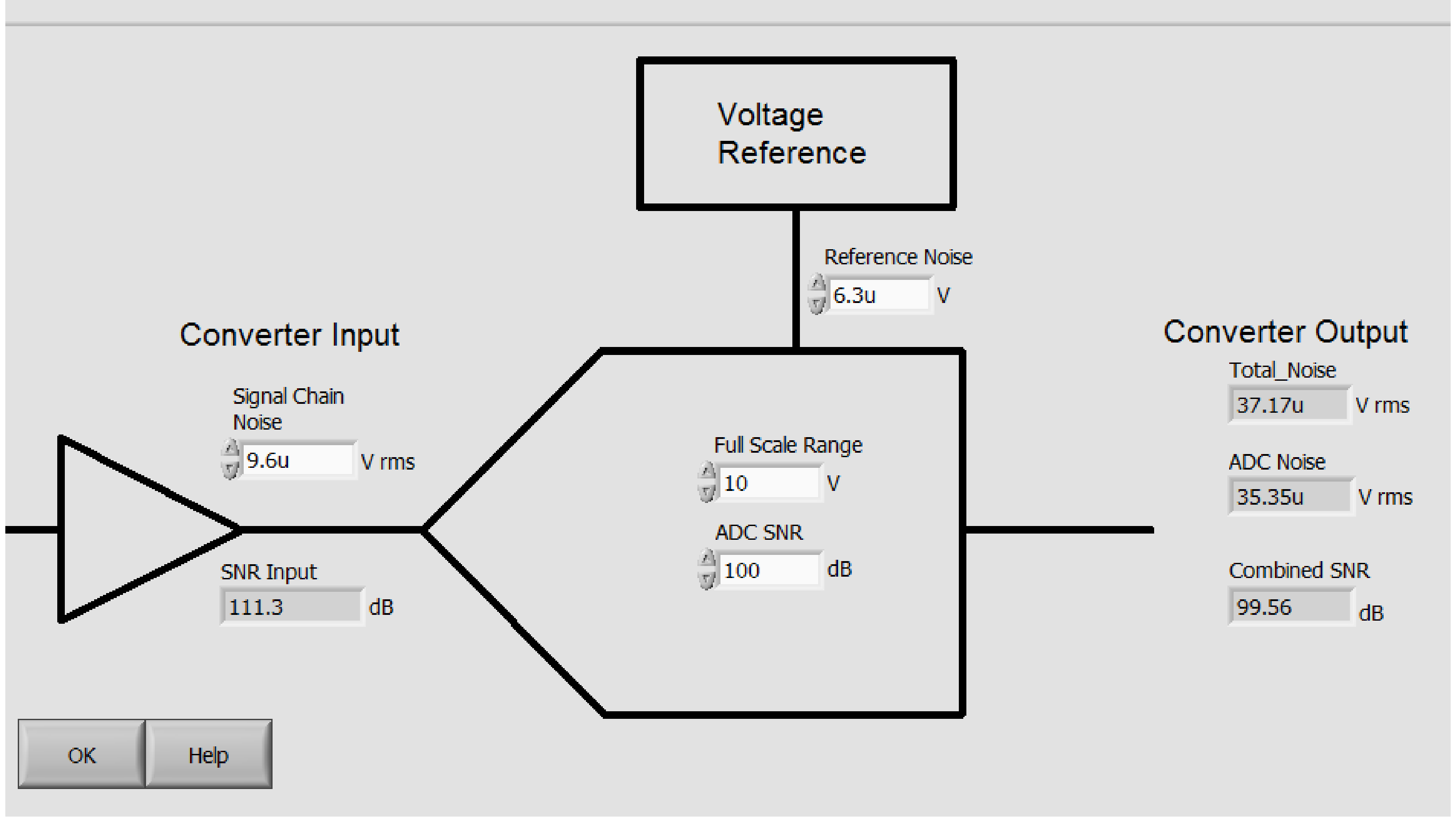
Click on this embedded file

REF6050 Noise.TSC

Integrated noise converges to 6.3uV rms.

Quiz: Calculating the total noise for ADC systems

3. For the circuit below.
   c) Calculate the total ADC Noise in microvolts RMS. **From calculator 35.35uV rms**
   d) Find the total RMS system noise. **From calculator 37.17uV rms**



Analog Engineer's Calculator: http://www.ti.com/tool/analog-engineer-calc

$$V_{ADC} = \frac{V_{FSR\_rms}}{10^{\frac{SNR}{20}}} = \frac{10V \cdot 0.5 \cdot 0.707}{10^{\frac{100}{20}}}$$
$$= 35.35\mu V\ rms$$

$$V_{total} = \sqrt{(9.6\mu V)^2 + (6.3\mu V)^2 + (35.3\mu V)^2}$$
$$= 37.2\mu V$$