Agenda

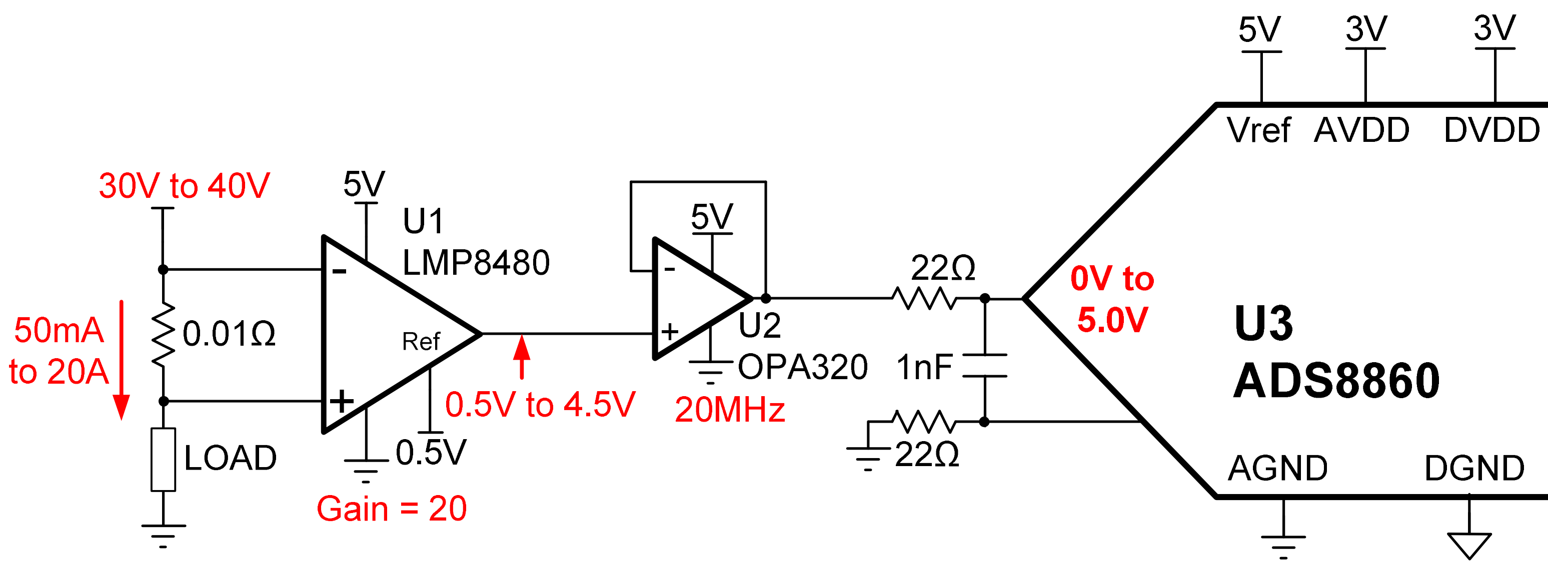
1. **ADC Input types**
   a) Single ended, pseudo-differential, fully-differential, and true-differential
   b) Switched capacitor vs. buffered
2. **Linear operation of amplifier and ADC**
   a) Rail-to-Rail amplifiers and crossover distortion
   b) Inverting configuration
3. **Common Front Ends**
   a) Instrumentation amplifier: Selecting gain and common mode range
   b) Fully Differential Amplifiers: Single Ended to Differential
4. **Error Sources:**
   a) **Statistics: Worst Case vs. Typical**
   b) **Offset and Gain Error**
   c) **Calibration**
   d) **Drift and Non-linearity**
   e) **Noise**
5. **AC Specifications and the FFT**
6. **Aliasing**

Find the worst case offset

Device	PARAMETER		MIN	TYP	MAX	UNITS
LMP8481	V_{OS}	Offset Error	-265	±80	+265	µV
OPA320	V_{OS}	Offset Error	-150	±40	+150	µV
ADS8860	E_O	Offset Error	-4	±1	+4	mV

Worst case offset at ADS Input
$V_{osT} = Gain \cdot V_{U1} + V_{U2} + V_{U3}$
$V_{osT} = 20 \cdot (265\mu V) + (150\mu V) + (4mV)$
$V_{osT} = 9.27mV$

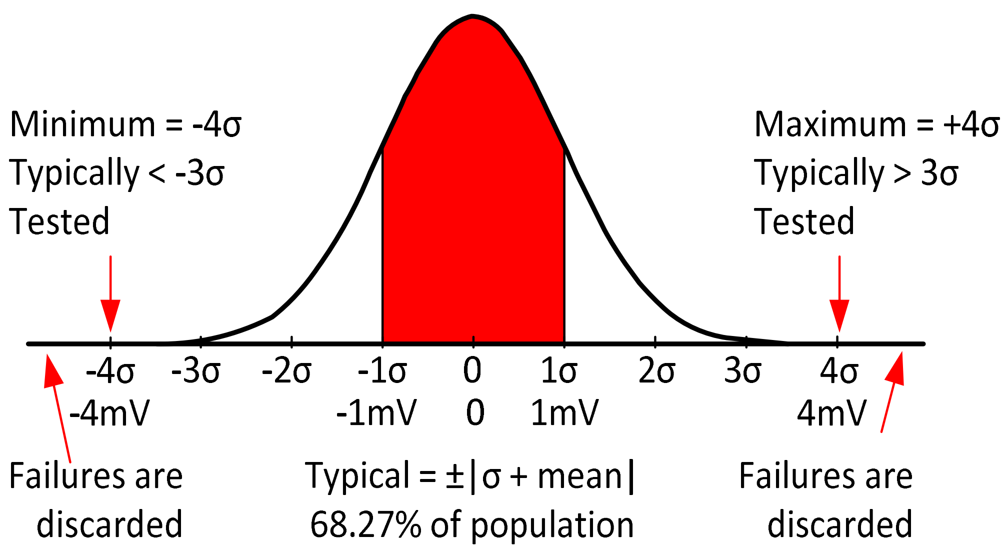
This result may be statistically unrealistic



Statistics Behind Typical and Maximum

PARAMETER ADS8860		MIN	TYP	MAX	UNITS
E_O	Offset Error	-4	±1	+4	mV
E_G	Gain Error	-0.01	±0.005	+0.01	%FSR

Gaussian Distribution



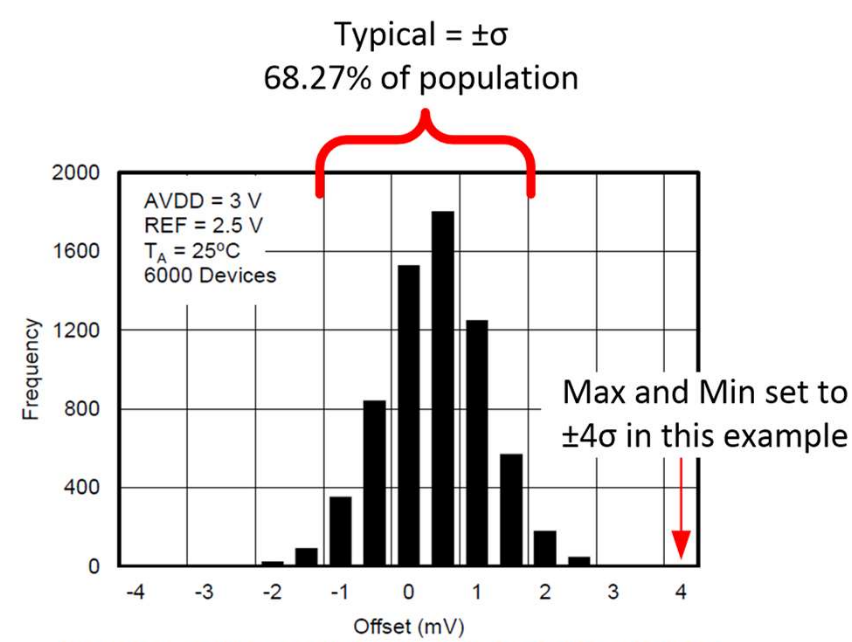
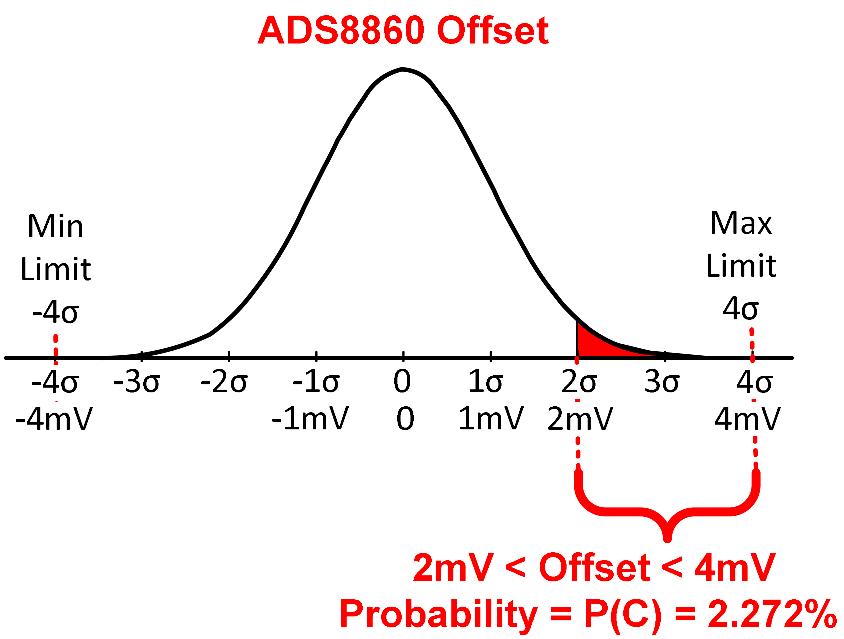


Figure 41. TYPICAL DISTRIBUTION OF OFFSET ERROR

Probability that we are near worst case

PARAMETER ADS8860		MIN	TYP	MAX	UNITS
E_O	Offset Error	-4	±1	+4	mV
E_G	Gain Error	-0.01	±0.005	+0.01	%FSR



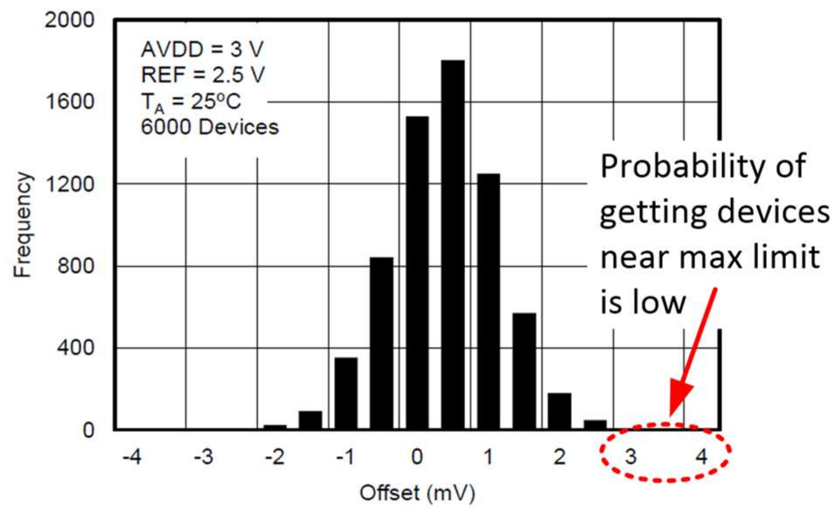
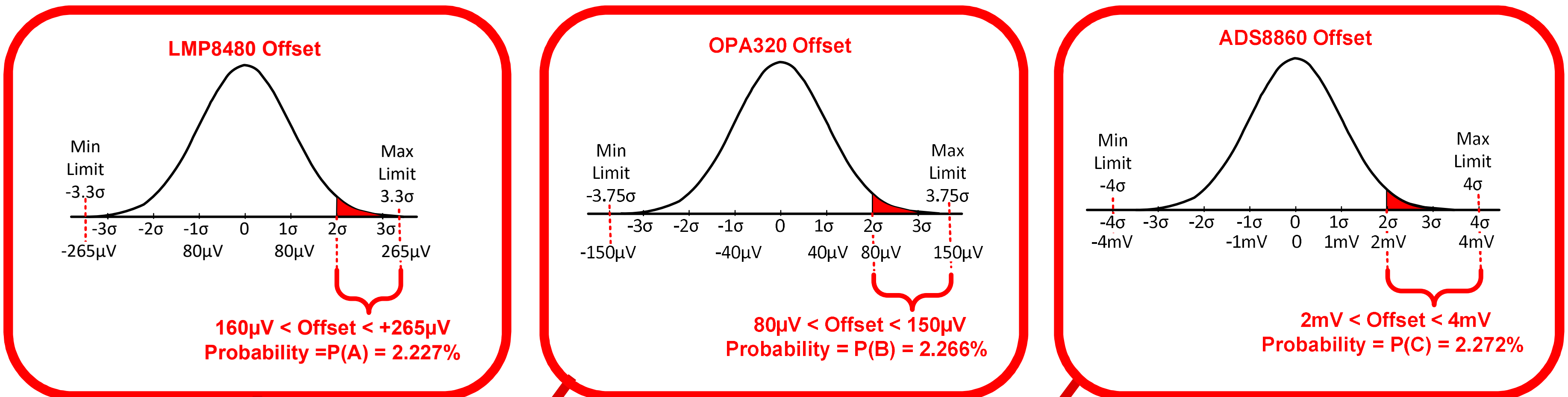
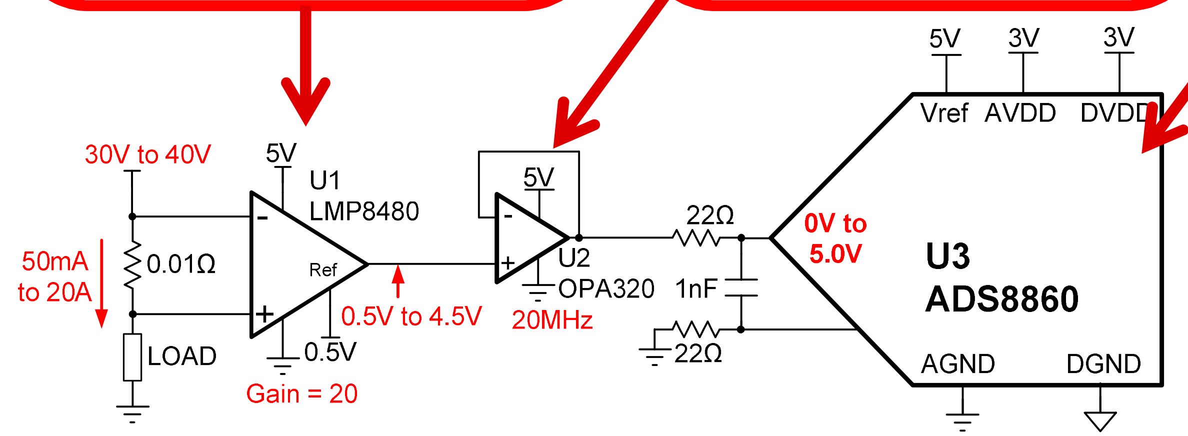


Figure 41. TYPICAL DISTRIBUTION OF OFFSET ERROR

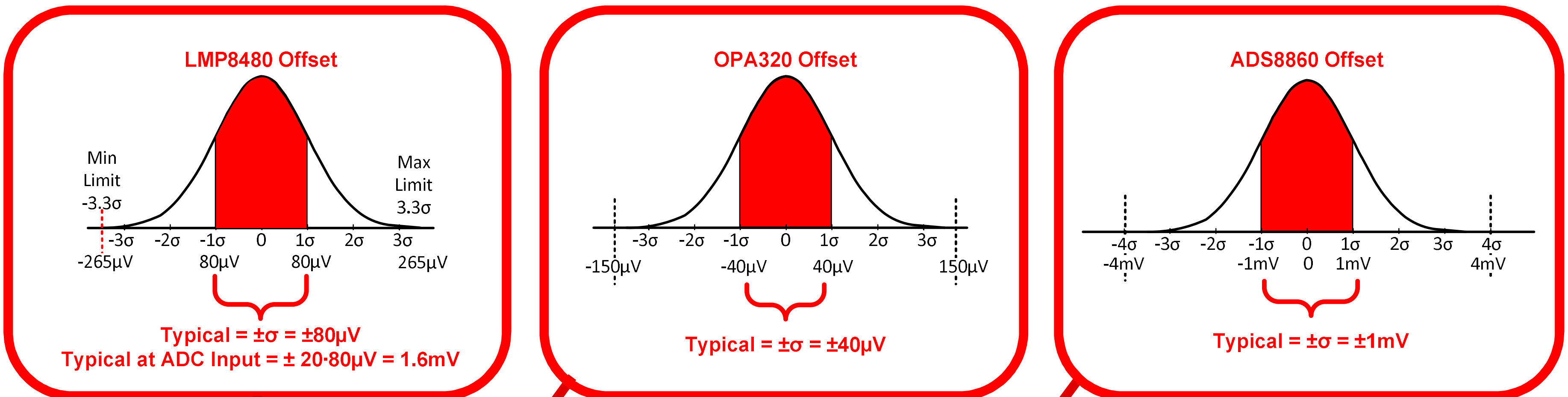
Compounding probabilities "near" worst case

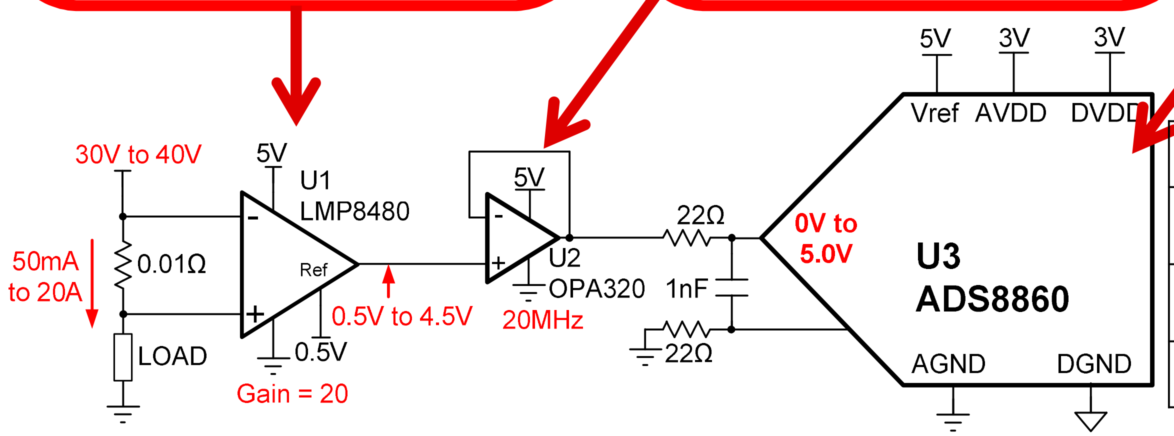




The probability that all three offsets are near worst case
$P = P(A) \cdot P(B) \cdot P(C)$
$P = (0.02227)(0.02266)(0.02272)$
$\%P = 100 \cdot P = 0.0011\%$

A more practical approach: use the typical limit



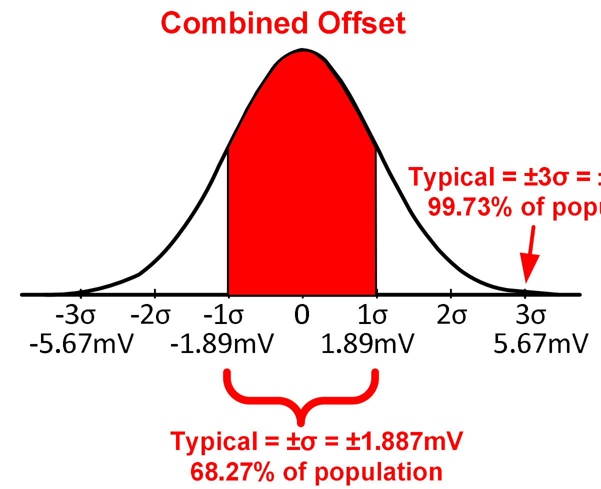


Typical offset at ADC Input
$V_{osT} = \sqrt{(20 \cdot V_{osINA})^2 + (V_{osOPA})^2 + (V_{osADS})^2}$
$V_{osT} = \sqrt{(20 \cdot 80\mu V)^2 + (40\mu V)^2 + (1mV)^2}$
$V_{osT} = 1.887mV$

A more practical approach: use typical

Number of Standard deviations	Probability Inside limit	Probability Outside limit
±1·σ	68.27%	31.73%
±2·σ	95.45%	4.55%
±3·σ	99.73%	0.27%
±4·σ	99.9937%	0.0063%
±5·σ	99.99994%	$5.73 \cdot 10^{-5}$ %
±6·σ	≈100%	$1.97 \cdot 10^{-7}$ %

Set end system specifications based on risk tolerance

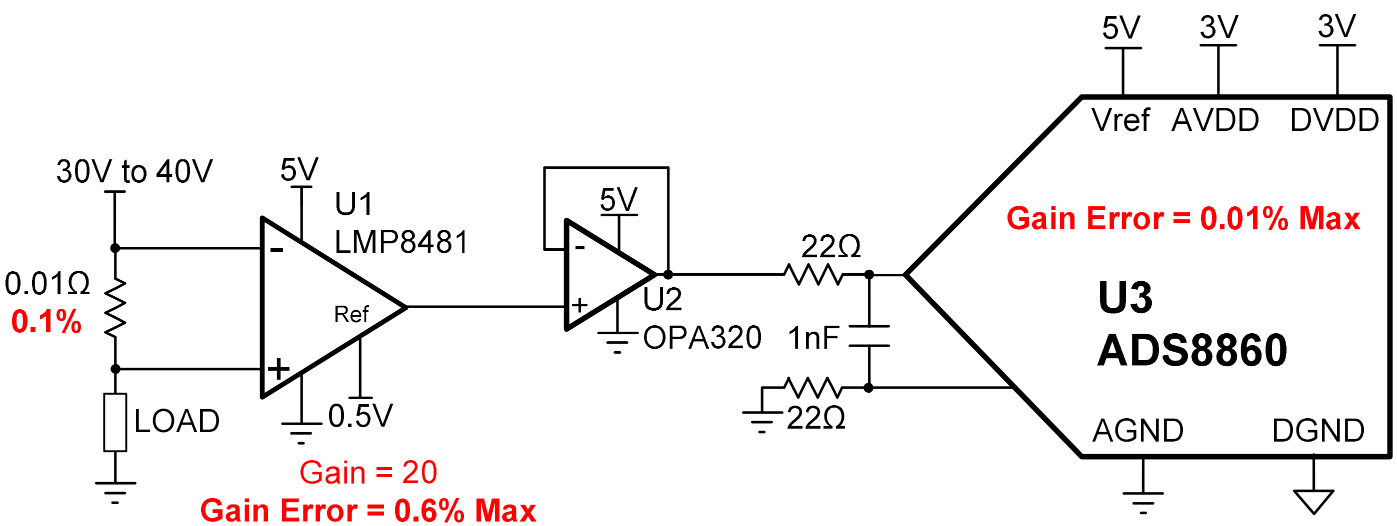


Typical offset at ADC Input
$V_{osT} = \sqrt{(20 \cdot V_{osINA})^2 + (V_{osOPA})^2 + (V_{osADS})^2}$
$V_{osT} = \sqrt{(20 \cdot 80\mu V)^2 + (40\mu V)^2 + (1mV)^2}$
$V_{osT} = 1.887mV$

Gain Error Calculation

Device	PARAMETER		MIN	TYP	MAX	UNITS
R1	E_R	Tolerance	-0.1		+0.1	%
LMP8481	E_G	Gain Error	-0.6		+0.6	%
ADS8860	E_G	Gain Error	-0.01	±0.005	+0.01	%

Absolute Worse Case Gain Error
$V_{osT} = E_{R1} + E_{GU1} + E_{GU3}$
$V_{osT} = 0.1\% + 0.6\% + 0.01\% = .71\%$
Statistical Worse Case Gain Error
$V_{osT} = \sqrt{(E_{R1})^2 + (E_{GU1})^2 + (E_{GU3})^2}$
$V_{osT} = \sqrt{(0.1\%)^2 + (0.6\%)^2 + (0.01\%)^2} = 0.608\%$

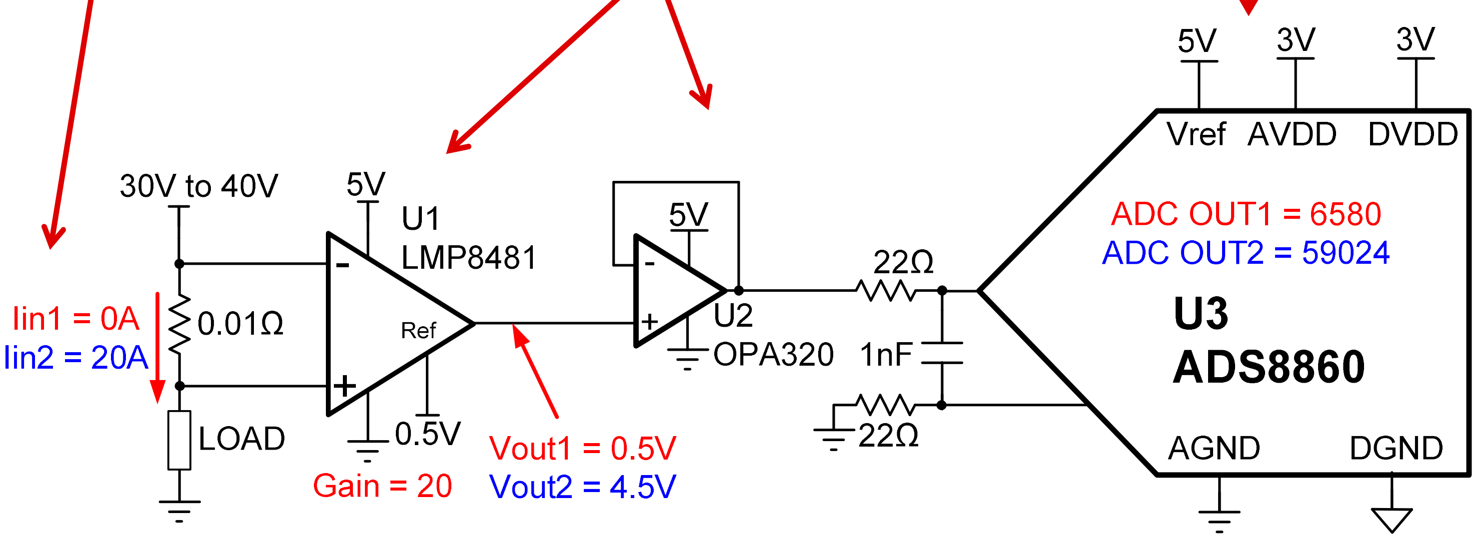


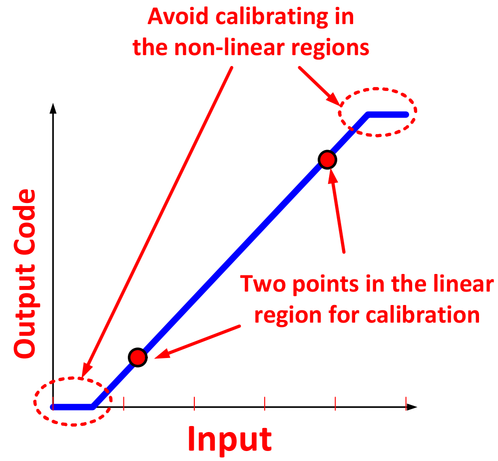
Offset and Gain Calibration: two test signals

Two Precision inputs applied

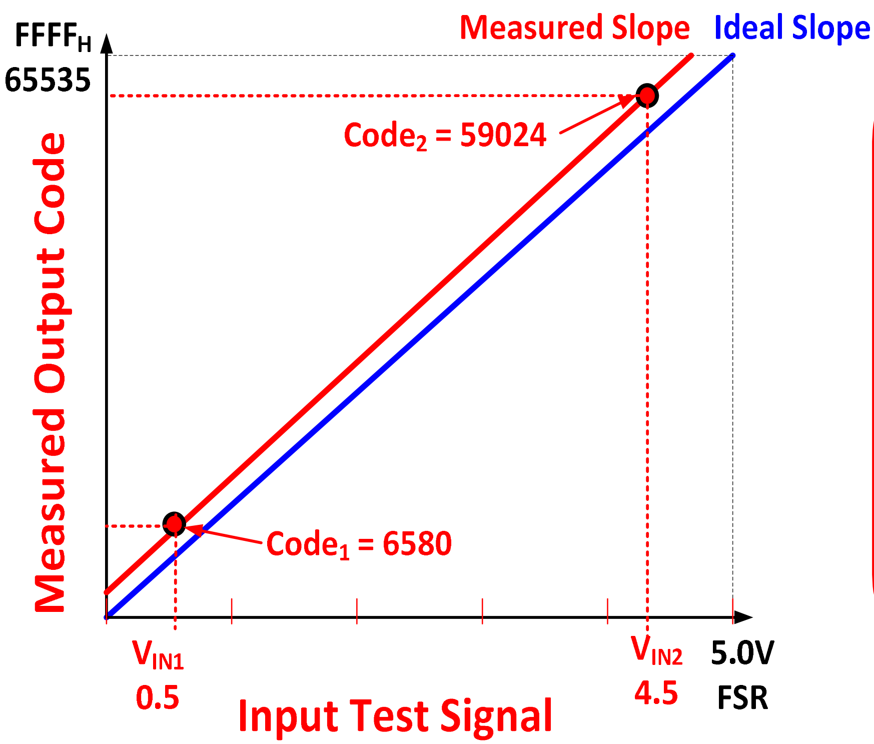
Make sure amplifiers are in linear range

Average code read





Calibration Example

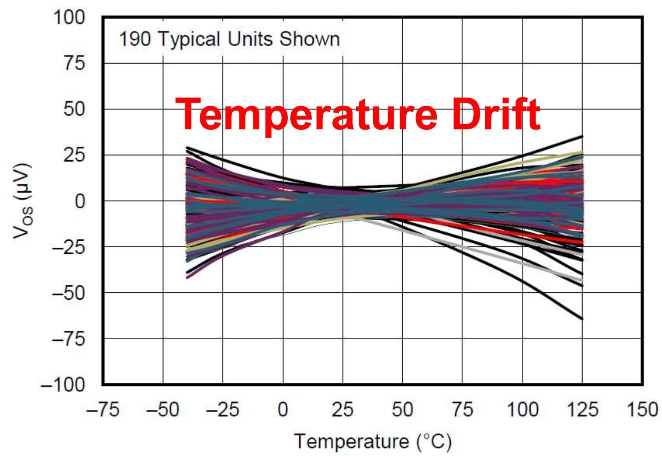


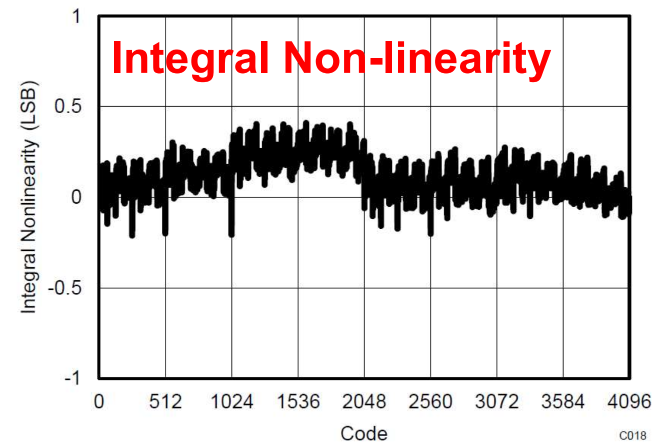
Example calculation for Offset and Gain Error:

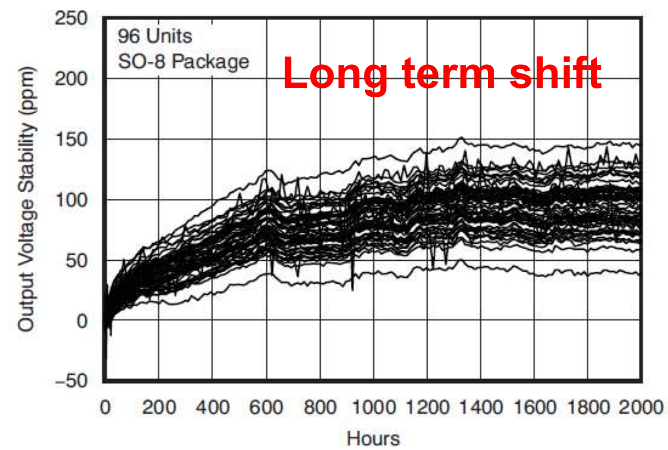
$V_{IN1} = 0.5V$	Apply 0A
$V_{IN2} = 4.5V$	Apply 20A
$m_m = \frac{Code_2 - Code_1}{V_{IN2} - V_{IN1}} = \frac{59024 - (6580)}{4.5 - 0.5} = 13111$	Compute Slope based on codes
$b_m = Code_1 - m_m \cdot V_{IN1} = 6580 - 13111 \cdot 0.5 = 24.5$	Offset
$V_{IN\_applied} = 2.0V$	Example Input
$Code = 26246$	Output code
$V_{IN\_uncal} = Code \cdot LSB = 26246 \cdot 76.029\mu V = 2.002V$	Uncalibrated 2mV error
$V_{IN} = \frac{Code - b_m}{m_m} = \frac{26246 - (24.5)}{13111} = 2.0000V$	Calibration eliminates error

Error Sources that are difficult to Calibrate

- Temperature Drift
- Non-linearity
- Long term shift (Aging)
- Hysteresis
- Noise







Thanks for your time!

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