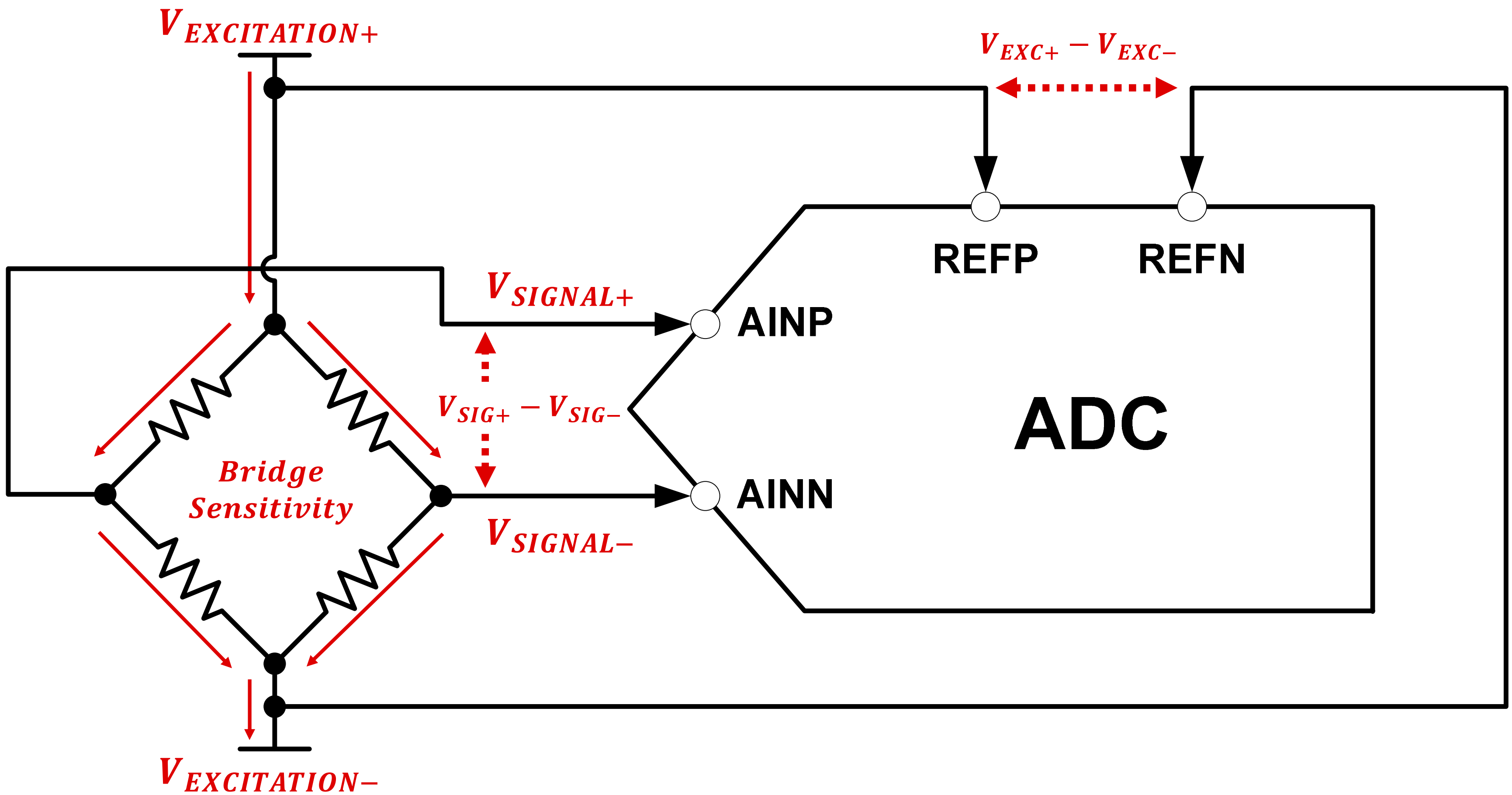
Defining system noise performance for low-speed delta-sigma ADCs

TI Precision Labs – ADCs

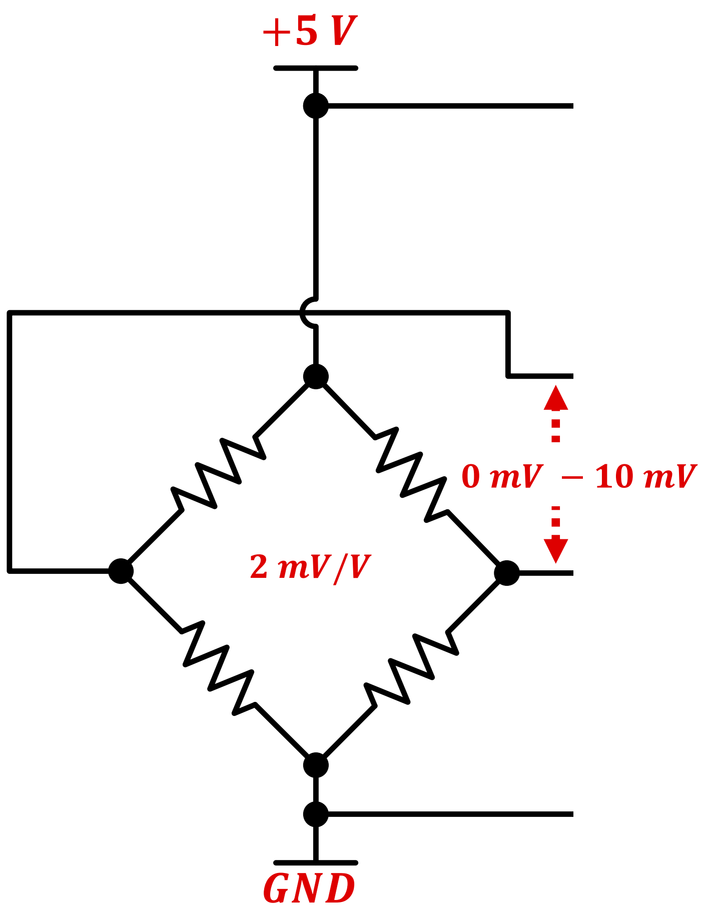
Created by Chris Hall & Bryan Lizon

Presented by Alex Smith

Measuring a resistive bridge



Application requirements



Type	Parameter	Value
System specifications	Bridge sensitivity	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV
	Output data rate	50 SPS
Weight requirements	Weight range	2 kg
	Weight resolution	50 mg

Converting to (relative) noise parameters

$$Noise - Free\ Counts\ (NFC)$$

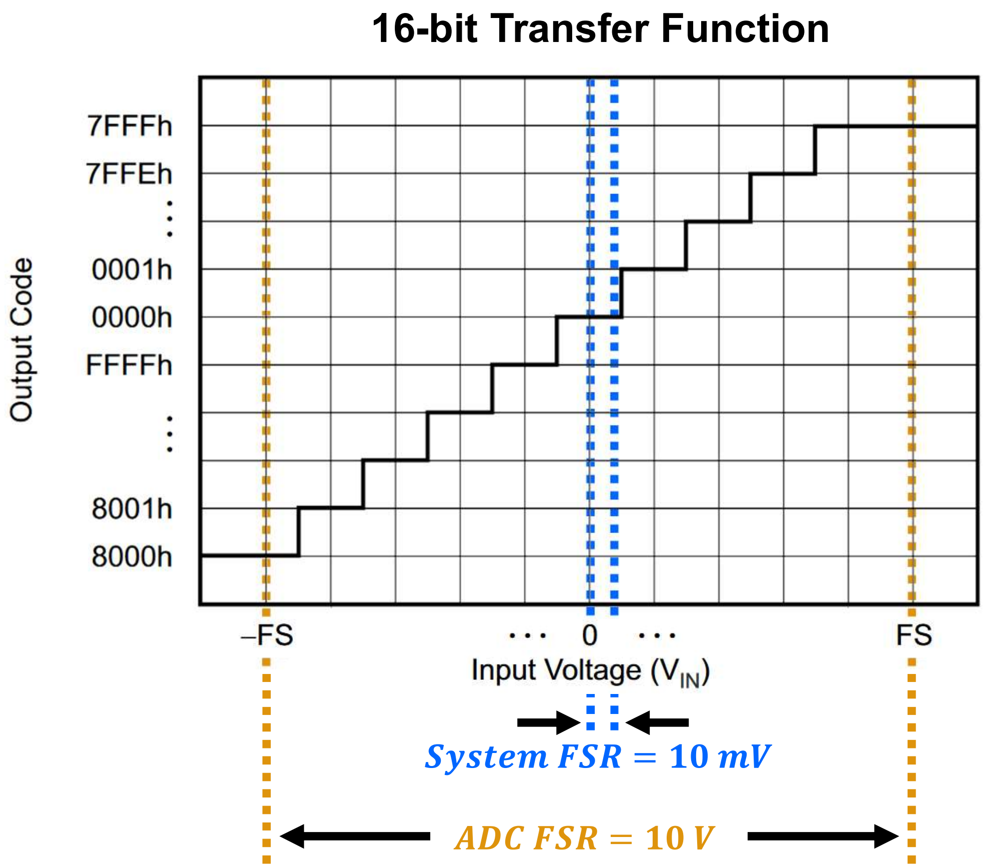
$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{2kg}{50mg} = 40{,}000\ counts$$

$$Noise - Free\ Bits$$

$$= \log_2(NFC) = \log_2\,(40{,}000) = 15.3\ NFB$$

Type	Parameter	Value
System specifications	**Bridge sensitivity**	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} – V_{EXCITATION-}$)	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV
	Output data rate	50 SPS
Weight requirements	**Weight range**	2 kg
	Weight resolution	50 mg

Can you use a 16-bit ADC?



Noise – Free Bits (NFB)

$$= \log_2(NFC) = \log_2(40{,}000) = 15.3\ NFB$$

Resolution Loss

$$= \log_2(\%\ utilization) = -\log_2\left(\frac{System\ FSR}{ADC\ FSR}\right)$$

$$= \log_2\left(\frac{5\ V * 2\ \frac{mV}{V}}{2 * 5V}\right) = -9.96\ bits$$

System Resolution

$$= ADC\ Resolution - Resolution\ Loss$$
$$= 16 - 9.96$$
$$= 6.04\ NFB$$

Using a relative parameter (noise-free resolution)

$$Noise - Free\ Bits\ (NFB)$$

$$= \log_2(NFC) = \log_2(40{,}000) = 15.3\ NFB$$

$$Resolution\ Loss\ @\ G = 128$$

$$= \log_2(\%\ utilization)$$

$$= -\log_2\left(\frac{System\ FSR}{ADC\ FSR}\right)$$

$$= \log_2\left(\frac{5\ V * 2\ \frac{mV}{V}}{2 * 5V/_{128}}\right) = -2.97\ bits$$

$$18.7 - 2.97 = 15.73\ bits$$

Table 1: ADS1261 effective (noise-free) resolution (Sinc 4, V_{REF} = 5 V)

DATA RATE	GAIN							
	1	2	4	8	16	32	64	128
2.5 SPS	24 (24)	24 (24)	24 (24)	24 (24)	24 (23.9)	24 (23.3)	24 (22.4)	23.5 (21.5)
5 SPS	24 (24)	24 (23.9)	24 (24)	24 (23.8)	24 (23.3)	24 (22.6)	24 (21.8)	22.9 (20.8)
10 SPS	24 (23.8)	24 (23.2)	24 (23.1)	24 (23.1)	24 (22.6)	24 (22.1)	23.4 (21.1)	22.4 (20.1)
16.6 SPS	24 (23.2)	24 (23)	24 (22.9)	24 (22.6)	24 (22.3)	23.9 (21.6)	23.1 (20.6)	22.1 (19.6)
20 SPS	24 (23.1)	24 (22.7)	24 (22.7)	24 (22.5)	24 (22.1)	23.8 (21.5)	22.9 (20.5)	22 (19.4)
50 SPS	24 (22.2)	24 (22)	24 (21.8)	24 (21.7)	23.9 (21.2)	23.1 (20.6)	22.2 (19.6)	21.3 (18.7)
60 SPS	24 (22.3)	24 (21.9)	24 (21.8)	24 (21.5)	23.8 (21.1)	23 (20.3)	22.1 (19.5)	21.1 (18.6)

Table 2: ADS1261 resolution loss (V_{IN} = 10 mV, V_{REF} = 5 V)

Parameter	Gain							
	1	2	4	8	16	32	64	128
Datasheet Resolution (bits)	22.2	22.0	21.8	21.7	21.2	20.6	19.6	18.7
% Utilization	0.1%	0.2%	0.4%	0.8%	1.6%	3.2%	6.4%	12.8%
Resolution Loss (bits)	-9.97	-8.97	-7.97	-6.97	-5.97	-4.97	-3.97	-2.97
System Resolution (bits)	12.23	13.03	13.83	14.73	15.23	15.63	15.63	15.73

These rows must be calculated by you

Changing system specifications

Type	Parameter	Original Value	New Value
System specifications	**Bridge sensitivity**	2 mV/V	**20 mV/V**
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V	**2.5 V**
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV	**50 mV**
	Output data rate	50 SPS	**100 SPS**
Weight requirements	**Weight range**	2 kg	2 kg
	Weight resolution	50 mg	50 mg

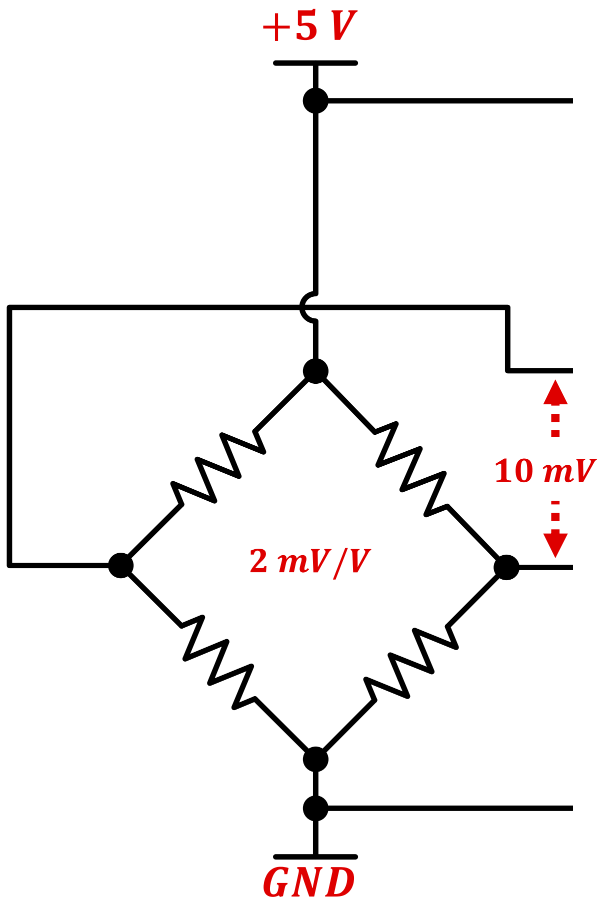
$$Noise - Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{2kg}{50mg} = 40{,}000\ counts$$

$$Noise - Free\ Bits$$

$$= \log_2(NFC) = \log_2(40{,}000) = 15.3\ NFB$$

Converting to (absolute) noise parameters



Type	Parameter	Value
System specifications	Bridge sensitivity	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV
	Output data rate	50 SPS
Weight requirements	Weight range	2 kg
	Weight resolution	50 mg

$$Noise-Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{2kg}{50mg} = 40{,}000\ counts$$

$$Peak-to-Peak\ Noise_{RTI}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{40{,}000} = 250\ nV_{PP}$$

ADS1261 input-referred noise tables

$$Noise - Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{2kg}{50mg}$$

$$= 40{,}000\ counts$$

$$Peak\ - to\ - Peak\ Noise_{RTI}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{40{,}000} = 250\ nV_{PP}$$

Table 1: ADS1261 input-referred noise, μV_{RMS} (μV_{PP}), Sinc 4, V_{REF} = 2.5 V

DATA RATE	GAIN							
	1	2	4	8	16	32	64	128
2.5 SPS	0.1 (0.26)	0.059 (0.17)	0.032 (0.085)	0.016 (0.059)	0.010 (0.035)	0.008 (0.027)	0.006 (0.025)	0.006 (0.024)
5 SPS	0.13 (0.51)	0.077 (0.28)	0.034 (0.12)	0.021 (0.075)	0.013 (0.053)	0.010 (0.044)	0.008 (0.038)	0.009 (0.038)
10 SPS	0.17 (0.68)	0.099 (0.45)	0.049 (0.24)	0.024 (0.12)	0.018 (0.085)	0.013 (0.063)	0.012 (0.061)	0.012 (0.062)
16.6 SPS	0.21 (1.1)	0.12 (0.53)	0.06 (0.29)	0.035 (0.18)	0.022 (0.11)	0.017 (0.084)	0.016 (0.085)	0.016 (0.086)
20 SPS	0.23 (1.1)	0.13 (0.66)	0.066 (0.33)	0.037 (0.19)	0.024 (0.12)	0.018 (0.095)	0.017 (0.095)	0.017 (0.099)
50 SPS	0.34 (2)	0.19 (1.1)	0.098 (0.61)	0.056 (0.32)	0.036 (0.23)	0.03 (0.17)	0.028 (0.17)	0.028 (0.17)
60 SPS	0.37 (2)	0.2 (1.1)	0.11 (0.6)	0.059 (0.36)	0.041 (0.25)	0.033 (0.21)	0.03 (0.18)	0.03 (0.17)

Type	Parameter	Original Value
System specifications	Bridge sensitivity	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV
	Output data rate	50 SPS
Weight requirements	Weight range	2 kg
	Weight resolution	50 mg

No additional calculations required!

Changing weight requirements

$$Noise-Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{5kg}{50mg}$$

$$= 100,000\ counts$$

$$Peak-to-Peak\ Noise_{RTI}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{40,000} = 250\ nV_{PP}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{100,000} = 100\ nV_{PP}$$

Table 1: ADS1261 input-referred noise, μV_{RMS} (μV_{PP}), Sinc 4, V_{REF} = 2.5 V

DATA RATE	GAIN							
	1	2	4	8	16	32	64	128
2.5 SPS	0.1 (0.26)	0.059 (0.17)	0.032 (0.085)	0.016 (0.059)	0.010 (0.035)	0.008 (0.027)	0.006 (0.025)	0.006 (0.024)
5 SPS	0.13 (0.51)	0.077 (0.28)	0.034 (0.12)	0.021 (0.075)	0.013 (0.053)	0.010 (0.044)	0.008 (0.038)	0.009 (0.038)
10 SPS	0.17 (0.68)	0.099 (0.45)	0.049 (0.24)	0.024 (0.12)	0.018 (0.085)	0.013 (0.063)	0.012 (0.061)	0.012 (0.062)
16.6 SPS	0.21 (1.1)	0.12 (0.53)	0.06 (0.29)	0.035 (0.18)	0.022 (0.11)	0.017 (0.084)	0.016 (0.085)	0.016 (0.086)
20 SPS	0.23 (1.1)	0.13 (0.66)	0.066 (0.33)	0.037 (0.19)	0.024 (0.12)	0.018 (0.095)	0.017 (0.095)	0.017 (0.099)
~~50 SPS~~	~~0.34 (2)~~	~~0.19 (1.1)~~	~~0.098 (0.61)~~	~~0.056 (0.32)~~	~~0.036 (0.23)~~	~~0.03 (0.17)~~	~~0.028 (0.17)~~	~~0.028 (0.17)~~
~~60 SPS~~	~~0.37 (2)~~	~~0.2 (1.1)~~	~~0.11 (0.6)~~	~~0.059 (0.36)~~	~~0.041 (0.25)~~	~~0.033 (0.21)~~	~~0.03 (0.18)~~	~~0.03 (0.17)~~

Type	Parameter	Original Value	New Value
System specifications	Bridge sensitivity	2 mV/V	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV	10 mV
	Output data rate	50 SPS	50 SPS ✗
Weight requirements	Weight range	2 kg	**5 kg**
	Weight resolution	50 mg	50 mg

Comparing different ADCs

$$Noise - Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{5kg}{\mathbf{500mg}}$$

$$= \mathbf{10,000\ counts}$$

$$Peak\ - to\ - Peak\ Noise_{RTI}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{10{,}000} = 1{,}000\ nV_{PP}$$

Table 1: ADS1261 input-referred noise, μV_{RMS} (μV_{PP}), Sinc 4, V_{REF} = 2.5 V

DATA RATE	GAIN							
	1	2	4	8	16	32	64	128
2.5 SPS	0.1 (0.26)	0.059 (0.17)	0.032 (0.085)	0.016 (0.059)	0.010 (0.035)	0.008 (0.027)	0.006 (0.025)	0.006 (0.024)
5 SPS	0.13 (0.51)	0.077 (0.28)	0.034 (0.12)	0.021 (0.075)	0.013 (0.053)	0.010 (0.044)	0.008 (0.038)	0.009 (0.038)
10 SPS	0.17 (0.68)	0.099 (0.45)	0.049 (0.24)	0.024 (0.12)	0.018 (0.085)	0.013 (0.063)	0.012 (0.061)	0.012 (0.062)
16.6 SPS	0.21 (1.1)	0.12 (0.53)	0.06 (0.29)	0.035 (0.18)	0.022 (0.11)	0.017 (0.084)	0.016 (0.085)	0.016 (0.086)
20 SPS	0.23 (1.1)	0.13 (0.66)	0.066 (0.33)	0.037 (0.19)	0.024 (0.12)	0.018 (0.095)	0.017 (0.095)	0.017 (0.099)
50 SPS	0.34 (2)	0.19 (1.1)	0.098 (0.61)	0.056 (0.32)	0.036 (0.23)	0.03 (0.17)	0.028 (0.17)	0.028 (0.17)
60 SPS	0.37 (2)	0.2 (1.1)	0.11 (0.6)	0.059 (0.36)	0.041 (0.25)	0.033 (0.21)	0.03 (0.18)	0.03 (0.17)

- **Lowest noise**
- **Highest power**
- **5 x 5 mm QFN**

Table 2: ADS124S08 input-referred noise, μV_{RMS} (μV_{PP}), V_{REF} = 2.5 V

DATA RATE (SPS)	GAIN							
	1	2	4	8	16	32	64	128
2.5	0.32 (1.8)	0.16 (0.89)	0.085 (0.45)	0.049 (0.26)	0.036 (0.20)	0.025 (0.13)	0.020 (0.14)	0.019 (0.11)
5	0.40 (2.4)	0.21 (1.0)	0.11 (0.60)	0.066 (0.37)	0.040 (0.30)	0.033 (0.20)	0.029 (0.16)	0.027 (0.20)
10	0.53 (3.0)	0.29 (1.6)	0.16 (0.89)	0.088 (0.52)	0.061 (0.39)	0.046 (0.25)	0.040 (0.23)	0.036 (0.24)
16.6	0.76 (4.2)	0.36 (2.2)	0.20 (1.2)	0.11 (0.67)	0.077 (0.47)	0.060 (0.35)	0.052 (0.32)	0.046 (0.30)
20	0.81 (4.8)	0.41 (2.4)	0.22 (1.4)	0.12 (0.71)	0.082 (0.48)	0.064 (0.44)	0.056 (0.37)	0.048 (0.30)
50	1.3 (7.2)	0.62 (3.7)	0.33 (1.9)	0.18 (1.2)	0.13 (0.76)	0.11 (0.69)	0.091 (0.53)	0.080 (0.53)

- **Low noise**
- **Low power**
- **5 x 5 mm QFN**

Table 3: ADS1220 input-referred noise, μV_{RMS} (μV_{PP}), V_{REF} = 2.048 V

DATA RATE (SPS)	GAIN (PGA Enabled)							
	1	2	4	8	16	32	64	128
20	3.71 (13.67)	1.54 (5.37)	1.15 (4.15)	0.80 (3.36)	0.35 (1.16)	0.23 (0.73)	0.10 (0.35)	0.09 (0.41)
45	7.36 (29.54)	2.93 (13.06)	1.71 (9.28)	0.88 (4.06)	0.50 (2.26)	0.29 (1.49)	0.19 (0.82)	0.12 (0.51)
90	10.55 (47.36)	4.50 (20.75)	2.43 (11.35)	1.51 (6.65)	0.65 (3.62)	0.42 (2.14)	0.27 (1.22)	0.18 (0.85)
175	11.90 (63.72)	6.45 (34.06)	3.26 (17.76)	1.82 (11.20)	1.01 (5.13)	0.57 (3.09)	0.34 (2.14)	0.26 (1.60)
330	19.19 (106.93)	9.38 (50.78)	4.25 (26.25)	2.68 (14.13)	1.45 (7.52)	0.79 (4.66)	0.50 (2.69)	0.34 (1.99)
600	24.78 (151.61)	13.35 (72.27)	6.68 (39.43)	3.66 (19.26)	2.10 (12.77)	1.14 (6.87)	0.70 (4.76)	0.55 (3.34)
1000	37.53 (227.29)	18.87 (122.68)	9.53 (58.53)	5.37 (31.52)	2.95 (18.08)	1.65 (10.71)	1.03 (6.52)	0.70 (4.01)

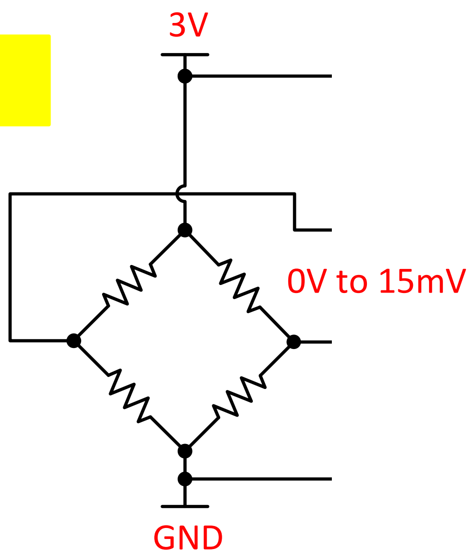
- **Medium noise**
- **Lowest power**
- **3.5 x 3.5 mm QFN**

Thanks for your time! Please try the quiz.

Quiz: System noise for low-speed delta-sigma ADCs

1. The table below is representative of a device that is quantization noise dominated. What noise free counts (NFC) is required?
   a. $1 \cdot 10^3$
   b. $3 \cdot 10^3$
   c. $15 \cdot 10^3$
   d. $100 \cdot 10^3$

$$NFC = \frac{10kg}{100mg} = 100 \cdot 10^3$$

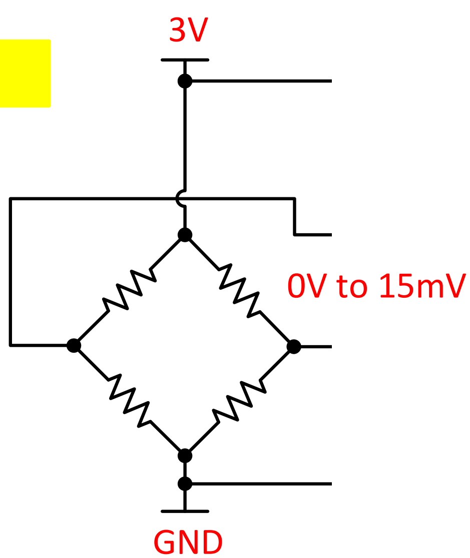


Type	Parameter	Value
System specifications	**Bridge sensitivity**	50 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	3 V
	Maximum output voltage (Sensitivity * V_{EXC})	150 mV
Weight requirements	**Weight range**	10 kg
	Weight resolution	100 mg

Quiz: System noise for low-speed delta-sigma ADCs

2. The table below is representative of a device that is quantization noise dominated. What is the maximum peak-to-peak input referred noise to achieve this resolution?
   a. 0.15µVpp
   b. 1.0µVpp
   c. 1.5µVpp
   d. 2.0µVpp

$$E_{nPP} = \frac{V_{OUT}}{NFC} = \frac{15mV}{100 \cdot 10^3} = 1.5\mu Vpp$$



Type	Parameter	Value
System specifications	Bridge sensitivity	50 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	3 V
	Maximum output voltage (Sensitivity * V_{EXC})	150 mV
Weight requirements	Weight range	10 kg
	Weight resolution	100 mg

Quiz: System noise for low-speed delta-sigma ADCs

3. The table below is an excerpt from the ADS1220 data sheet showing noise performance. Assuming your system has a maximum noise requirement of 1.5µVpp, what is the maximum data rate you could use?
   a. 20sps
   b. 45sps
   c. 90sps
   d. 175sps
   e. 330sps

Table 1. Noise in μV_{RMS} (μV_{PP}) at AVDD = 3.3 V, AVSS = 0 V, Normal Mode, and Internal Reference = 2.048 V

DATA RATE (SPS)	GAIN (PGA Enabled)							
	1	2	4	8	16	32	64	128
20	3.71 (13.67)	1.54 (5.37)	1.15 (4.15)	0.80 (3.36)	0.35 (1.16)	0.23 (0.73)	0.10 (0.35)	0.09 (0.41)
45	7.36 (29.54)	2.93 (13.06)	1.71 (9.28)	0.88 (4.06)	0.50 (2.26)	0.29 (1.49)	0.19 (0.82)	0.12 (0.51)
90	10.55 (47.36)	4.50 (20.75)	2.43 (11.35)	1.51 (6.65)	0.65 (3.62)	0.42 (2.14)	0.27 (1.22)	0.18 (0.85)
175	11.90 (63.72)	6.45 (34.06)	3.26 (17.76)	1.82 (11.20)	1.01 (5.13)	0.57 (3.09)	0.34 (2.14)	0.26 (1.60)
330	19.19 (106.93)	9.38 (50.78)	4.25 (26.25)	2.68 (14.13)	1.45 (7.52)	0.79 (4.66)	0.50 (2.69)	0.34 (1.99)
600	24.78 (151.61)	13.35 (72.27)	6.68 (39.43)	3.66 (19.26)	2.10 (12.77)	1.14 (6.87)	0.70 (4.76)	0.55 (3.34)
1000	37.53 (227.29)	18.87 (122.68)	9.53 (58.53)	5.37 (31.52)	2.95 (18.08)	1.65 (10.71)	1.03 (6.52)	0.70 (4.01)

Quiz: System noise for low-speed delta-sigma ADCs

4. The following system requires 17.6 noise free bits of resolution. Is there an ADC setting that will meet the noise requirement?
   a. Yes, Data Rate = 20, Gain = 128 works
   b. Yes, Data Rate = 20, Gain = 1 works
   c. No. The ADC noise is too high.

$$NFC = \frac{10kg}{50mg} = 200 \cdot 10^3$$

$$E_{nPP} = \frac{5mV}{200 \cdot 10^3} = 0.025\mu Vpp$$

E_{npp} > lowest ADC noise setting

Parameter	spec
Bridge sensitivity	1 mV/V
Excitation/reference voltage	5 V
Max output voltage	5 mV
Weight range	10 kg
Weight resolution	50 mg

Table 2. ENOB from RMS Noise (Noise-Fre
at AVDD = 3.3 V, AVSS = 0 V, Normal Mode,

DATA RATE (SPS)	GAIN (PGA Enabled)							
	1	2	4	8	16	32	64	128
20	20.08 (18.19)	20.34 (18.54)	19.76 (17.91)	19.28 (17.22)	19.48 (17.75)	19.10 (17.42)	19.33 (17.49)	18.49 (16.26)
45	19.09 (17.08)	19.42 (17.26)	19.19 (16.75)	19.15 (16.94)	18.95 (16.79)	18.74 (16.39)	18.38 (16.25)	18.00 (15.49)
90	18.57 (16.40)	18.80 (16.59)	18.68 (16.46)	18.37 (16.23)	18.60 (16.11)	18.20 (15.87)	17.87 (15.67)	17.44 (15.20)

Table 1. Noise in μV_{RMS} (μV_{PP})
at AVDD = 3.3 V, AVSS = 0 V, Normal Mode, and Internal Reference = 2.048 V

DATA RATE (SPS)	GAIN (PGA Enabled)							
	1	2	4	8	16	32	64	128
20	3.71 (13.67)	1.54 (5.37)	1.15 (4.15)	0.80 (3.36)	0.35 (1.16)	0.23 (0.73)	0.10 (0.35)	0.09 (0.41)
45	7.36 (29.54)	2.93 (13.06)	1.71 (9.28)	0.88 (4.06)	0.50 (2.26)	0.29 (1.49)	0.19 (0.82)	0.12 (0.51)
90	10.55 (47.36)	4.50 (20.75)	2.43 (11.35)	1.51 (6.65)	0.65 (3.62)	0.42 (2.14)	0.27 (1.22)	0.18 (0.85)

Thanks for your time!

Defining system noise performance for low-speed delta-sigma ADCs
TI Precision Labs – ADCs

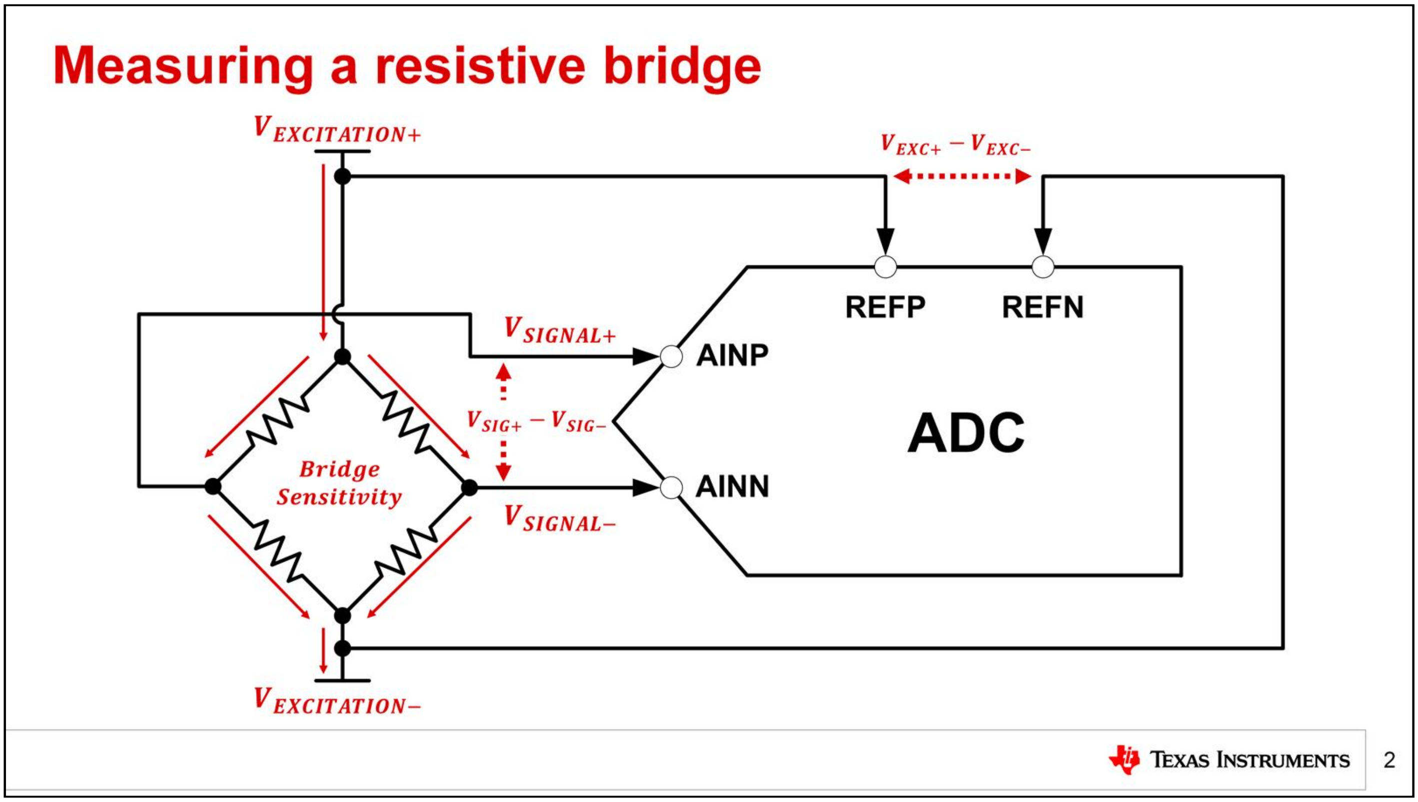
Created by Chris Hall & Bryan Lizon

Presented by Alex Smith

TEXAS INSTRUMENTS 1

Hello, and welcome to the TI Precision Lab module discussing how to use your system noise requirements to choose an ADC. In previous Precision Lab modules, we covered the types of ADC noise, how ADC noise is measured and specified, and the differences between relative and absolute noise parameters. This module will apply that information to an application example using a common sensor type and several low speed delta-sigma ADCs. We will walk through this example using relative and absolute noise parameters to understand the benefits and challenges of each. While this process is more specific to low speed delta-sigma ADCs, some of the general principles such as resolution loss and determining system specifications can be applied to wide bandwidth delta-sigma and SAR ADCs as well.

Ultimately, this module will help you answer the question, “What noise performance does my system really need?” This will help you to easily and confidently choose an ADC for your next application using your system requirements.



For this module, we will use a 4-wire resistive bridge often found in load cells and weigh scales as the application example. This sensor works by applying some voltage to the excitation lines such that current passes through the bridge circuit as shown. An applied force or weight changes the bridge resistance. The excitation current and varying bridge resistance establish a differential output voltage on the signal lines that is proportional to the applied force. Typically this is a very low-level, slow-moving voltage, which is an ideal use case for a low-speed delta-sigma ADC with an integrated amplifier.

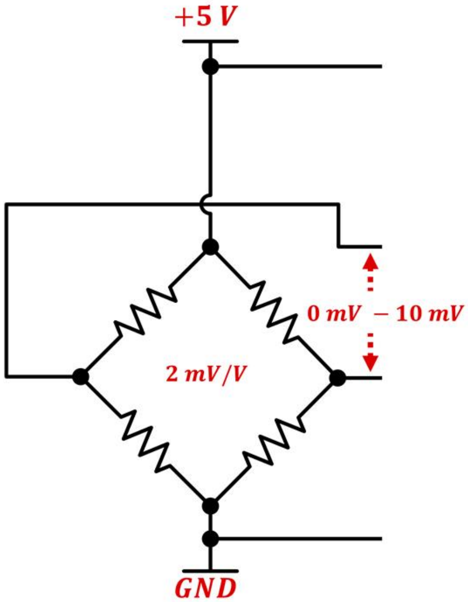
The bridge has a sensitivity that indicates its dynamic range, and is generally expressed in millivolts per volt. This specification means that for every volt of excitation, the maximum bridge output increases by the sensitivity. As the value of the sensitivity increases, the maximum dynamic range increases as well, typically at the expense of a higher-cost sensor.

You can also see that the bridge output and the ADC's reference voltage are directly proportional to the excitation voltage. This latter configuration is referred to as a ratiometric reference, and will be covered in greater detail in a subsequent Precision Labs module on reference noise. For now, it is sufficient to understand that the ADC reference voltage is directly derived from the bridge excitation voltage in this application.

Finally, it should be noted that the differential output voltage, V_{signal}, can be positive or negative. In physical terms, this corresponds to compression versus tension in a load cell. However, since there is no such thing as negative weight, we will assume that the bridge output voltage will always be positive for the purposes of this example. In either case, the analysis remains the same, though some of the parameter values would be different.

Let's now apply typical values to our system to continue this analysis

Application requirements



Type	Parameter	Value
System specifications	Bridge sensitivity	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV
	Output data rate	50 SPS
Weight requirements	Weight range	2 kg
	Weight resolution	50 mg

Common application requirements for a resistive bridge measurement are shown in the table, though the same analysis could be applied to any variation of these specs or even other sensor types. System specifications include the bridge sensitivity, the excitation voltage and the desired output data rate for the ADC. The important weight requirements are range and resolution.

As shown, the bridge has a 2 mV/V sensitivity and the excitation voltage is 5 V. We choose this excitation voltage because many ADCs used for bridge measurements support both an analog supply and reference voltage of 5 V. And since the reference voltage is derived from the excitation voltage, choosing 5 V enables the maximum possible bridge dynamic range while ensuring we are still within the ADC's operating conditions. The bridge output voltage is the product of the sensitivity – 2 mV/V – and the excitation voltage – 5V – yielding a 10 mV maximum output. As you can see, such a small output voltage requires very low noise to support wide dynamic range applications, which is why we will use a precision delta-sigma ADC.

The bridge output voltage also corresponds to the bridge's weight range. This specification is defined by the load cell manufacturer, so we have chosen a common value of 2 kg for this example. Weight range is effectively the full-scale range of the load cell, describing the maximum weight that can applied to the device. Like an ADC, if you were only using a portion of the load cell's weight range – for example, you only needed to measure up to 1 kg instead of 2 kg – you could not expect to achieve the maximum output voltage, thereby reducing the system's dynamic range. However, our analysis assumes we need to measure the bridge's entire weight range.

Finally, the weight resolution is 50 mg. This means that within our 2 kg weight range, we want to be able to resolve a change in weight as small as 50 mg. You can now convert the application requirements into common noise parameters to help you choose your ADC.

Converting to (relative) noise parameters

$$Noise - Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{2kg}{50mg} = 40{,}000\ counts$$

$$Noise - Free\ Bits$$

$$= \log_2(NFC) = \log_2(40{,}000) = 15.3\ NFB$$

Type	Parameter	Value
System specifications	Bridge sensitivity	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV
	Output data rate	50 SPS
Weight requirements	Weight range	2 kg
	Weight resolution	50 mg

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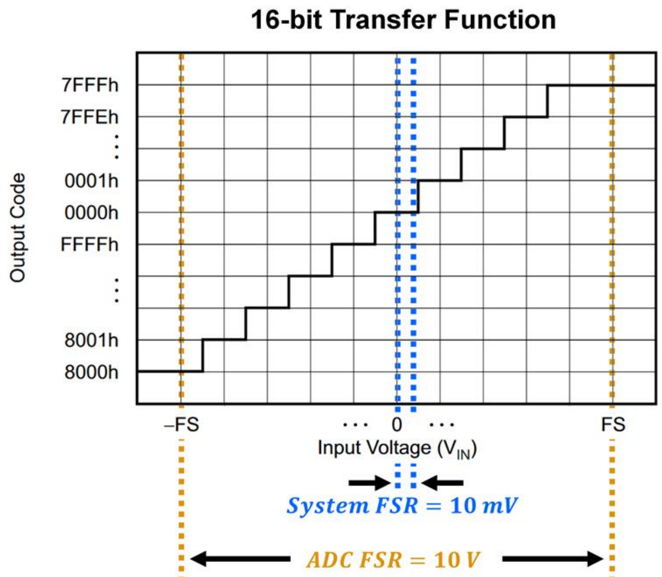
If you have watched the Precision Lab module on noise measurement methods and parameters, you might recall that we recommended using input-referred noise to define system noise parameters and choose an ADC. While that is still true, many engineers speak in terms of relative parameters, especially for weigh scales. In fact, the two relative parameters shown here – noise-free counts and noise-free resolution – are commonly-used metrics to describe weigh scale dynamic range performance. Specifically, noise-free parameters are used instead of RMS values since manufacturers want the weight reading to settle quickly and remain unchanged once a weight is applied. Therefore, let's first analyze this system using the more common method of relative noise parameters and compare this to the same analysis using absolute noise parameters. This will make it more clear how even the choice of noise parameter, irrespective of your application requirements, can complicate noise analysis and why absolute parameters are the preferred method.

Per the equations shown here, noise-free counts is calculated by dividing the maximum input signal by the weight resolution. With a 2 kg weight range and 50 mg weight resolution, the system requires 40,000 noise free counts. This value is equivalent to 15.3 bits of noise-free resolution. You can compare this value to the expected resolution given in most low-speed delta-sigma ADC datasheets to understand if the ADC can meet your target noise performance. And with a required noise-free resolution of 15.3 bits, you might quickly conclude that you only need a 16-bit ADC. But is this conclusion correct?

Can you use a 16-bit ADC?



$Noise - Free\ Bits\ (NFB)$

$$= \log_2(NFC) = \log_2\ (40{,}000) = 15.3\ NFB$$

$Resolution\ Loss$

$$= \log_2(\%\ utilization) = -\log_2\left(\frac{System\ FSR}{ADC\ FSR}\right)$$

$$= \log_2\left(\frac{5\ V * 2\ \frac{mV}{V}}{2 * 5V}\right) = -\ 9.96\ bits$$

$System\ Resolution$

$$= ADC\ Resolution\ - Resolution\ Loss$$
$$= 16 -\ 9.96$$
$$= 6.04\ NFB$$

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We introduced this topic in the previous Precision Labs module on noise measurement methods and parameters, where we discussed if a 16-bit ADC was sufficient to provide 16-bit resolution. One important factor is how much of the ADC's full-scale range you use. In order to get all available codes, you need to use the ADC's entire full-scale range, represented on this 16-bit ADC transfer function by the orange lines. Since this ADC's full scale range extends from negative VREF to positive VREF assuming no gain, and the reference voltage for this example is 5 V, the ADC full-scale range is 10 V.

However, if you don't use this entire range, you can only expect a fraction of the ADC's ideal performance. That fraction is referred to as the percent utilization, defined here as the ratio of the system's full-scale range to the ADC's full-scale range. In this example, the maximum input signal is only 10 millivolts, so we are only using 0.1% of the ADC's full-scale range. Using the resolution loss equation shown here and assuming the input-referred noise is absolute, you'll find that you lose almost 10 bits of resolution by only utilizing 0.1% of the available full-scale range. That leaves you with only 6 bits of noise-free resolution using a 16-bit ADC, far below the target of 15.3. In fact, even a 24-bit ADC would not be sufficient to meet the system requirements, which clearly proves that you cannot use a 16-bit ADC to measure these signals as-is.

Instead, you need to increase the percentage utilization by either changing the system specs or amplifying the input signal. Assuming that you have little control over the system requirements, you must gain up the input, which changes both the noise performance of the signal chain and the full-scale range of the ADC. Fortunately, you can continue this analysis without needing a detailed understanding of how amplifier noise affects system performance. Instead, you can apply the information learned in the previous Precision Labs modules to the datasheet noise tables of an ADC with an integrated amplifier to determine if it meets the system requirements. But, if you do want to learn more about how amplifier noise affects ADC performance, you can view the Precision Labs modules on this topic.

Using a relative parameter (noise-free resolution)

$$Noise - Free\ Bits\ (NFB)$$

$$= \log_2(NFC) = \log_2(40{,}000) = 15.3\ NFB$$

$$Resolution\ Loss\ @\ G = 128$$

$$= \log_2(\%\ utilization)$$

$$= -\log_2\left(\frac{System\ FSR}{ADC\ FSR}\right)$$

$$= \log_2\left(\frac{5\,V * 2\,\frac{mV}{V}}{2 * 5V/_{128}}\right) = -2.97\ bits$$

$$18.7 - 2.97 = 15.73\ bits$$

Table 1: ADS1261 effective (noise-free) resolution (Sinc 4, V_{REF} = 5 V)

DATA RATE	GAIN							
	1	2	4	8	16	32	64	128
2.5 SPS	24 (24)	24 (24)	24 (24)	24 (24)	24 (23.9)	24 (23.3)	24 (22.4)	23.5 (21.5)
5 SPS	24 (24)	24 (23.9)	24 (24)	24 (23.8)	24 (23.3)	24 (22.6)	24 (21.8)	22.9 (20.8)
10 SPS	24 (23.8)	24 (23.2)	24 (23.1)	24 (23.1)	24 (22.6)	24 (22.1)	23.4 (21.1)	22.4 (20.1)
16.6 SPS	24 (23.2)	24 (23)	24 (22.9)	24 (22.6)	24 (22.3)	23.9 (21.6)	23.1 (20.6)	22.1 (19.6)
20 SPS	24 (23.1)	24 (22.7)	24 (22.7)	24 (22.5)	24 (22.1)	23.8 (21.5)	22.9 (20.5)	22 (19.4)
50 SPS	24 (22.2)	24 (22)	24 (21.8)	24 (21.7)	23.9 (21.2)	23.1 (20.6)	22.2 (19.6)	21.3 (18.7)
60 SPS	24 (22.3)	24 (21.9)	24 (21.8)	24 (21.5)	23.8 (21.1)	23 (20.3)	22.1 (19.5)	21.1 (18.6)

Table 2: ADS1261 resolution loss (V_{IN} = 10 mV, V_{REF} = 5 V)

Parameter	Gain							
	1	2	4	8	16	32	64	128
Datasheet Resolution (bits)	22.2	22.0	21.8	21.7	21.2	20.6	19.6	18.7
% Utilization	0.1%	0.2%	0.4%	0.8%	1.6%	3.2%	6.4%	12.8%
Resolution Loss (bits)	-9.97	-8.97	-7.97	-6.97	-5.97	-4.97	-3.97	-2.97
System Resolution (bits)	12.23	13.03	13.83	14.73	15.23	15.63	15.63	15.73

These rows must be calculated by you

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To begin, recall that the system noise-free resolution target is 15.3 bits. Now we need to compare this value to the performance of an ADC.

Shown here are the effective and noise-free resolution tables for the ADS1261, a 24-bit, high precision, low-speed delta-sigma ADC. This device includes gains from 1 V/V to 128 V/V and can sample up to 40 kSPS. However, since our target data rate is 50 SPS, we will keep things simple and only show data rates less than 100 SPS using the sinc 4 filter. At first, it appears that all of the highlighted noise-free resolution values meet the target since they're all well above 15.3 bits. However, recall from the previous Precision Labs module that effective and noise-free resolution are defined in the datasheet assuming 100% utilization. For the values in Table 1, this means a ±5 V input using a 5 V reference voltage and a gain of 1. Therefore, you also need to calculate the ADS1261's achievable noise-free resolution given the system specifications. This requires calculating the resolution loss for each gain setting separately, since each gain setting changes the ADC's full-scale range and subsequent percentage utilization. You then need to subtract this result from each corresponding noise-free resolution value in Table 1 to determine the expected performance for the conditions in this example.

Table 2 shows the results of these calculations, including the % utilization, corresponding resolution loss and resulting system resolution for each gain setting based on the ADS1261's stated noise-free resolution performance at 50 SPS. We've also highlighted the values in Table 2 that can meet the 15.3 bit target noise-free resolution, as well as the corresponding datasheet values in Table 1. Note that the last three rows in Table 2 need to be calculated by you – these are not included in the datasheet since they are specific to this application. This means that multiple calculations are required to correlate the datasheet resolution tables to the settings that meet your system noise requirements. This could be very problematic if your application requirements weren't so clearly defined. What if instead of operating at 50 samples per second, you wanted to know how fast you could sample and still get the requisite noise performance? It would be challenging to get that level of information from this analysis. Or what if your requirements changed after you had already completed your ADC noise calculations?

Let's make some changes to our initial application requirements to see how this impacts our analysis

Changing system specifications

Type	Parameter	Original Value	New Value
System specifications	Bridge sensitivity	2 mV/V	**20 mV/V**
	Excitation/reference voltage ($V_{EXCITATION+} – V_{EXCITATION-}$)	5 V	**2.5 V**
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV	**50 mV**
	Output data rate	50 SPS	**100 SPS**
Weight requirements	Weight range	2 kg	2 kg
	Weight resolution	50 mg	50 mg

$$Noise - Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{2kg}{50mg} = 40{,}000\ counts$$

$$Noise - Free\ Bits$$

$$= \log_2(NFC) = \log_2\ (40{,}000) = 15.3\ NFB$$

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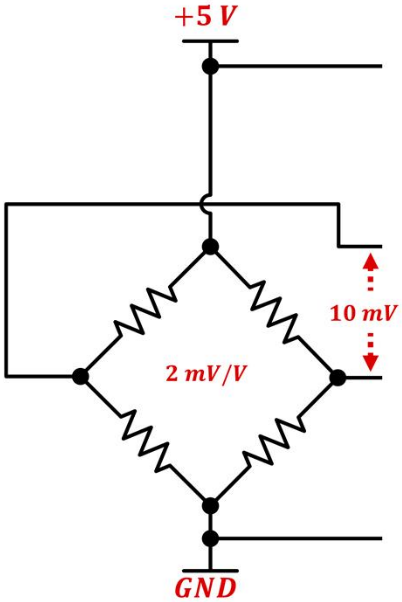
Shown here are the original requirements defined at the beginning of this presentation, highlighted in the yellow column. In purple, we've provided modified system specifications that represent several ways your requirements might change throughout the design process. For example, you might discover that the 2 mV/V sensor does not have enough dynamic range, requiring you to purchase a higher cost, more sensitive device at 20 mV/V. At the same time, you find out that your system does not have a 5 V power rail and it would be cost prohibitive to add one. As a result, you must use an excitation voltage of 2.5 V. Both of these changes results in a new maximum bridge output voltage of 50 mV. Finally, you confirm that the increased dynamic range relaxes your noise budget a bit, enabling you to sample at 100 SPS.

While these are significant system changes, they don't actually alter the target noise-free counts or noise-free bits. These relative parameters depend exclusively on the weight requirements, which we will modify and analyze in an example later in this presentation. And even though changing the system specifications didn't affect the target dynamic range, they do have an effect on your ADC noise analysis. In order to determine if your ADC can still provide the necessary noise performance at the new system parameters, you would first have to calculate the resolution loss for each gain setting at the new data rate and reference voltage. Moreover, you would have to recreate the datasheet noise table at a reference voltage of 2.5 V since the original table is characterized using VREF equal to 5 V. The new reference voltage reduces the ADC' s dynamic range performance by 1 bit compared to the datasheet. Finally, you would have subtract each resolution loss from your new, recreated noise table and compare to the target specification as we did on the last slide.

Admittedly, this is a lot of work, and is a direct result of noise-free resolution being a relative parameter. So let's now switch to using an absolute noise parameter, as previously suggested, and see how the analysis changes.

Converting to (absolute) noise parameters



Type	Parameter	Value
System specifications	Bridge sensitivity	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV
	Output data rate	50 SPS
Weight requirements	Weight range	2 kg
	Weight resolution	50 mg

$$Noise - Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{2kg}{50mg} = 40{,}000\ counts$$

$$Peak\ - to\ - Peak\ Noise_{RTI}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{40{,}000} = 250\ nV_{PP}$$

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For the absolute noise parameter analysis, we will use the original specifications as shown here. Note that we can still use noise-free counts to define the required dynamic range, which is 40,000 counts just as it was in the original example.

However, since we now want to define a system metric based on volts instead of bits, we need to divide the maximum output voltage by the dynamic range. This calculation tells us how finely we need to resolve the ADC’s input signal. In this case, the maximum output is still 10 mV as shown, and we want to be able to resolve this signal into 40,000 distinct parts. Taking the ratio of these values, the system noise target is 250 nV referred to the input, or RTI. We will assume this is a peak-to-peak value since we are using noise-free counts, but RMS values will work for this analysis in general as long as you are consistent.

This tells us we need an ADC that can detect and resolve a 250 nV peak to peak signal. We can now apply this noise analysis based on absolute parameters to an ADC.

ADS1261 input-referred noise tables

$$Noise - Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{2kg}{50mg}$$

$$= 40{,}000\ counts$$

$$Peak - to - Peak\ Noise_{RTI}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{40{,}000} = 250\ nV_{PP}$$

Table 1: ADS1261 input-referred noise, μV_{RMS} (μV_{PP}), Sinc 4, V_{REF} = 2.5 V

DATA RATE	GAIN							
	1	2	4	8	16	32	64	128
2.5 SPS	0.1 (0.26)	0.059 (0.17)	0.032 (0.085)	0.016 (0.059)	0.010 (0.035)	0.008 (0.027)	0.006 (0.025)	0.006 (0.024)
5 SPS	0.13 (0.51)	0.077 (0.28)	0.034 (0.12)	0.021 (0.075)	0.013 (0.053)	0.010 (0.044)	0.008 (0.038)	0.009 (0.038)
10 SPS	0.17 (0.68)	0.099 (0.45)	0.049 (0.24)	0.024 (0.12)	0.018 (0.085)	0.013 (0.063)	0.012 (0.061)	0.012 (0.062)
16.6 SPS	0.21 (1.1)	0.12 (0.53)	0.06 (0.29)	0.035 (0.18)	0.022 (0.11)	0.017 (0.084)	0.016 (0.085)	0.016 (0.086)
20 SPS	0.23 (1.1)	0.13 (0.66)	0.066 (0.33)	0.037 (0.19)	0.024 (0.12)	0.018 (0.095)	0.017 (0.095)	0.017 (0.099)
50 SPS	0.34 (2)	0.19 (1.1)	0.098 (0.61)	0.056 (0.32)	0.036 (0.23)	0.03 (0.17)	0.028 (0.17)	0.028 (0.17)
60 SPS	0.37 (2)	0.2 (1.1)	0.11 (0.6)	0.059 (0.36)	0.041 (0.25)	0.033 (0.21)	0.03 (0.18)	0.03 (0.17)

Type	Parameter	Original Value
System specifications	Bridge sensitivity	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV
	Output data rate	50 SPS
Weight requirements	Weight range	2 kg
	Weight resolution	50 mg

No additional calculations required!

Since we've already used the ADS1261 in this presentation, let's keep things consistent and choose this same ADC for input-referred noise analysis.

Shown here is the target input-referred noise as well as the ADS1261's input-referred noise table. Note that Table 1 looks similar to the effective and noise-free resolution table we've already seen, though these values are based on a reference voltage of 2.5 V, not 5 V. However, as was determined in the Precision Labs module on noise measurement methods and parameters, noise in higher-resolution ADCs does not exhibit a dependence on reference voltage, so the difference in reference voltages is not important for this example

One of the benefits of using input-referred noise is that you don't have to worry about calculating resolution loss. Since both the noise target and the noise table are input-referred, you can directly compare the calculated value against the ADC's datasheet performance to determine which combination of settings meets the target. To that end, all of the yellow highlighted values in Table 1 are combinations of gain and data rate settings that meet the 250 nanovolts peak to peak input-referred noise requirement. Note that this method provides *all* combinations that meet the target, while using noise-free resolution only provided those combinations that met the target at the desired data rate. If you wanted to know the noise-free resolution at a different data rate, or even how fast you could sample, you would have to calculate the resolution loss for these new values as well. This makes noise analysis with relative parameters less adaptable to system changes, and confirms that input-referred noise is a better choice for ADC noise analysis.

So far we have limited the system changes to those that did not affect the target noise. How would altering the weight requirements change this analysis? Would using absolute parameters still be beneficial?

Changing weight requirements

Table 1: ADS1261 input-referred noise, μV_{RMS} (μV_{PP}), Sinc 4, V_{REF} = 2.5 V

DATA RATE	GAIN 1	2	4	8	16	32	64	128
2.5 SPS	0.1 (0.26)	0.059 (0.17)	0.032 (0.085)	0.016 (0.059)	0.010 (0.035)	0.008 (0.027)	0.006 (0.025)	0.006 (0.024)
5 SPS	0.13 (0.51)	0.077 (0.28)	0.034 (0.12)	0.021 (0.075)	0.013 (0.053)	0.010 (0.044)	0.008 (0.038)	0.009 (0.038)
10 SPS	0.17 (0.68)	0.099 (0.45)	0.049 (0.24)	0.024 (0.12)	0.018 (0.085)	0.013 (0.063)	0.012 (0.061)	0.012 (0.062)
16.6 SPS	0.21 (1.1)	0.12 (0.53)	0.06 (0.29)	0.035 (0.18)	0.022 (0.11)	0.017 (0.084)	0.016 (0.085)	0.016 (0.086)
20 SPS	0.23 (1.1)	0.13 (0.66)	0.066 (0.33)	0.037 (0.19)	0.024 (0.12)	0.018 (0.095)	0.017 (0.095)	0.017 (0.099)
~~50 SPS~~	~~0.34 (2)~~	~~0.19 (1.1)~~	~~0.098 (0.61)~~	~~0.056 (0.32)~~	~~0.036 (0.23)~~	~~0.03 (0.17)~~	~~0.028 (0.17)~~	~~0.028 (0.17)~~
~~60 SPS~~	~~0.37 (2)~~	~~0.2 (1.1)~~	~~0.11 (0.6)~~	~~0.059 (0.36)~~	~~0.041 (0.25)~~	~~0.033 (0.21)~~	~~0.03 (0.18)~~	~~0.03 (0.17)~~

$$Noise - Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{5kg}{50mg}$$

$$= 100,000\ counts$$

$$Peak - to - Peak\ Noise_{RTI}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{40,000} = 250\ nV_{PP}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{100,000} = 100\ nV_{PP}$$

Type	Parameter	Original Value	New Value
System specifications	Bridge sensitivity	2 mV/V	2 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	5 V	5 V
	Maximum output voltage (Sensitivity * V_{EXC})	10 mV	10 mV
	Output data rate	50 SPS	50 SPS ✗
Weight requirements	Weight range	2 kg	**5 kg**
	Weight resolution	50 mg	50 mg

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As in the previous example where we changed the systems specifications, the original system specifications and corresponding noise table are highlighted in yellow. For this new example, the blue column represents any modified values, which in this case is only the maximum applied weight that has been increased to 5 kg. Using the same equation for peak to peak noise, you can determine that your system noise requirement is now 100 nanovolts peak to peak.

This lower noise requirement corresponds to the data-rate and gain combinations highlighted in blue in Table 1. As a result of these more stringent weight requirements, you now have fewer options available despite using the same ADC. For example, now you couldn't sample at the desired output date rate of 50 samples per second. And you would need at least a gain of 4 V/V at any data rate to achieve the requisite noise performance. Most importantly however is that this information would not be easy to determine with relative parameters. Using relative parameters would require the multiple calculation steps described throughout this presentation.

How would this analysis change if instead of comparing different system specifications or weight requirements you wanted to compare different ADCs? Let's increase the target input-referred noise to find out.

Comparing different ADCs

$$Noise-Free\ Counts\ (NFC)$$

$$= \frac{Weight\ Range}{Weight\ Resolution} = \frac{5kg}{500mg}$$

$$= 10,000\ counts$$

$$Peak-to-Peak\ Noise_{RTI}$$

$$= \frac{V_{Out(Max)}}{NFC} = \frac{0.01\ V}{10,000} = 1,000\ nV_{PP}$$

Table 1: ADS1261 input-referred noise, μV_{RMS} (μV_{PP}), Sinc 4, V_{REF} = 2.5 V

DATA RATE	GAIN							
	1	2	4	8	16	32	64	128
2.5 SPS	0.1 (0.26)	0.059 (0.17)	0.032 (0.085)	0.016 (0.059)	0.010 (0.035)	0.008 (0.027)	0.006 (0.025)	0.006 (0.024)
5 SPS	0.13 (0.51)	0.077 (0.28)	0.034 (0.12)	0.021 (0.075)	0.013 (0.053)	0.010 (0.044)	0.008 (0.038)	0.009 (0.038)
10 SPS	0.17 (0.68)	0.099 (0.45)	0.049 (0.24)	0.024 (0.12)	0.018 (0.085)	0.013 (0.063)	0.012 (0.061)	0.012 (0.062)
16.6 SPS	0.21 (1.1)	0.12 (0.53)	0.06 (0.29)	0.035 (0.18)	0.022 (0.11)	0.017 (0.084)	0.016 (0.085)	0.016 (0.086)
20 SPS	0.23 (1.1)	0.13 (0.66)	0.066 (0.33)	0.037 (0.19)	0.024 (0.12)	0.018 (0.095)	0.017 (0.095)	0.017 (0.099)
50 SPS	0.34 (2)	0.19 (1.1)	0.098 (0.61)	0.056 (0.32)	0.036 (0.23)	0.03 (0.17)	0.028 (0.17)	0.028 (0.17)
60 SPS	0.37 (2)	0.2 (1.1)	0.11 (0.6)	0.059 (0.36)	0.041 (0.25)	0.033 (0.21)	0.03 (0.18)	0.03 (0.17)

- Lowest noise
- Highest power
- 5 x 5 mm QFN

Table 2: ADS124S08 input-referred noise, μV_{RMS} (μV_{PP}), V_{REF} = 2.5 V

DATA RATE (SPS)	GAIN							
	1	2	4	8	16	32	64	128
2.5	0.32 (1.8)	0.16 (0.89)	0.085 (0.45)	0.049 (0.26)	0.036 (0.20)	0.025 (0.13)	0.020 (0.14)	0.019 (0.11)
5	0.40 (2.4)	0.21 (1.0)	0.11 (0.60)	0.066 (0.37)	0.040 (0.30)	0.033 (0.20)	0.029 (0.16)	0.027 (0.20)
10	0.53 (3.0)	0.29 (1.6)	0.16 (0.89)	0.088 (0.52)	0.061 (0.39)	0.046 (0.25)	0.040 (0.23)	0.036 (0.24)
16.6	0.76 (4.2)	0.36 (2.2)	0.20 (1.2)	0.11 (0.67)	0.077 (0.47)	0.060 (0.35)	0.052 (0.32)	0.046 (0.30)
20	0.81 (4.8)	0.41 (2.4)	0.22 (1.4)	0.12 (0.71)	0.082 (0.48)	0.064 (0.44)	0.056 (0.37)	0.048 (0.30)
50	1.3 (7.2)	0.62 (3.7)	0.33 (1.9)	0.18 (1.2)	0.13 (0.76)	0.11 (0.69)	0.091 (0.53)	0.080 (0.53)

- Low noise
- Low power
- 5 x 5 mm QFN

Table 3: ADS1220 input-referred noise, μV_{RMS} (μV_{PP}), V_{REF} = 2.048 V

DATA RATE (SPS)	GAIN (PGA Enabled)							
	1	2	4	8	16	32	64	128
20	3.71 (13.67)	1.54 (5.37)	1.15 (4.15)	0.80 (3.36)	0.35 (1.16)	0.23 (0.73)	0.10 (0.35)	0.09 (0.41)
45	7.36 (29.54)	2.93 (13.06)	1.71 (9.28)	0.88 (4.06)	0.50 (2.26)	0.29 (1.49)	0.19 (0.82)	0.12 (0.51)
90	10.55 (47.36)	4.50 (20.75)	2.43 (11.35)	1.51 (6.65)	0.65 (3.62)	0.42 (2.14)	0.27 (1.22)	0.18 (0.85)
175	11.90 (63.72)	6.45 (34.06)	3.26 (17.76)	1.82 (11.20)	1.01 (5.13)	0.57 (3.09)	0.34 (2.14)	0.26 (1.60)
330	19.19 (106.93)	9.38 (50.78)	4.25 (26.25)	2.68 (14.13)	1.45 (7.52)	0.79 (4.66)	0.50 (2.69)	0.34 (1.99)
600	24.78 (151.61)	13.35 (72.27)	6.68 (39.43)	3.66 (19.26)	2.10 (12.77)	1.14 (6.87)	0.70 (4.76)	0.55 (3.34)
1000	37.53 (227.29)	18.87 (122.68)	9.53 (58.53)	5.37 (31.52)	2.95 (18.08)	1.65 (10.71)	1.03 (6.52)	0.70 (4.01)

- Medium noise
- Lowest power
- 3.5 x 3.5 mm QFN

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On this slide we've increased the weight resolution requirement to 500 mg, which reduces the required noise-free counts to 10,000. This yields a target peak to peak noise of 1,000 nanovolts as shown. On the right, we are comparing three different ADC's input-referred noise tables. Table 1 shows the ADS1261's noise that we looked at on the previous slide. All of the data rate and gain combinations highlighted in that table correspond to the new target. If you wanted the widest range of options or wanted to use a gain of 1 for example, the ADS1261 would be the device to choose.

Table 2 shows the input-referred noise values taken from the 24-bit ADS124S08's datasheet. This device is a slower speed, lower power ADC, so if your system was power sensitive you could operate the ADS124S08 at any of the highlighted combinations in Table 2 to meet the target noise performance. If size was a concern, Table 3 represents the input-referred noise for the ADS1220. This ADC has higher noise compared to the ADS124S08 and the ADS1261, but can still meet the target performance at the lower data rates and higher gain settings. Importantly, the ADS1220 is offered in a 3.5 x 3.5 millimeter QFN package, making it the smallest of the three ADCs shown here. It's also the lowest power. Ultimately, using input-referred noise enables you to compare devices easily to understand which ones can meet your target noise performance. These quick comparisons then allow you to consider other important systems specs, such as power, size or cost, to determine which ADC to choose. If you tried to complete this same analysis using noise-free or effective resolution, as we previously cautioned against, you would discover that the dependence on reference voltage makes this challenging. This is especially true when the ADCs are characterized at different reference voltages, as is the case here. This might cause some ADCs to seem better or worse than others, even though this is not a fair comparison. Fortunately, a high-resolution ADC's input-referred noise has virtually no dependence on reference voltage, so this does not affect your analysis. This also helps explain the true benefit of a high-resolution ADC

Even though our example system only needed 15.3 bits of resolution, it required a 24-bit ADC to meet the target. While you might conclude that you're paying for ADC performance you won't actually use, you're actually taking advantage of a noise floor as low as 24 nanovolts peak to peak in the case of the ADS1261. This is an incredibly small value, which no 16-bit ADC and few 24-bit ADCs can provide. Ultimately, you need high-resolution ADCs even if your target-noise performance is only 15.3 bits because the system actually requires low noise performance. That is why it makes sense to define system performance and choose ADCs using input-referred noise.

Thanks for your time! Please try the quiz.

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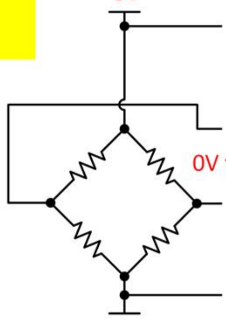
That concludes this video. Thank you for watching. Please try the quiz to check your understanding of this video's content.

Quiz: System noise for low-speed delta-sigma ADCs

1. The table below is representative of a device that is quantization noise dominated. What noise free counts (NFC) is required?
   a. $1 \cdot 10^3$
   b. $3 \cdot 10^3$
   c. $15 \cdot 10^3$
   d. $100 \cdot 10^3$

$$NFC = \frac{10kg}{100mg} = 100 \cdot 10^3$$



Type	Parameter	Value
System specifications	Bridge sensitivity	50 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} – V_{EXCITATION-}$)	3 V
	Maximum output voltage (Sensitivity * V_{EXC})	150 mV
Weight requirements	Weight range	10 kg
	Weight resolution	100 mg

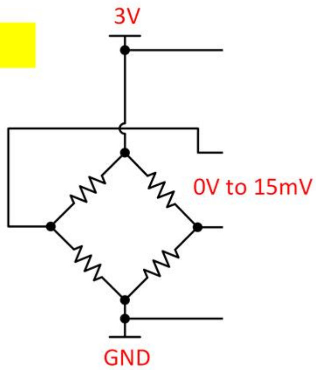
The table below is representative of a device that is quantization noise dominated. What noise free counts (NFC) is required?

The correct answer is “d”. This is calculated by taking the weight range and dividing by the weight resolution.

Quiz: System noise for low-speed delta-sigma ADCs

2. The table below is representative of a device that is quantization noise dominated. What is the maximum peak-to-peak input referred noise to achieve this resolution?
   a. 0.15μVpp
   b. 1.0μVpp
   c. 1.5μVpp
   d. 2.0μVpp

$$E_{nPP} = \frac{V_{OUT}}{NFC} = \frac{15mV}{100 \cdot 10^3} = 1.5\mu Vpp$$



Type	Parameter	Value
System specifications	Bridge sensitivity	50 mV/V
	Excitation/reference voltage ($V_{EXCITATION+} - V_{EXCITATION-}$)	3 V
	Maximum output voltage (Sensitivity * V_{EXC})	150 mV
Weight requirements	Weight range	10 kg
	Weight resolution	100 mg

The table below is representative of a device that is quantization noise dominated. What is the maximum peak-to-peak input referred noise to achieve this resolution?

The correct answer is “c”. This is calculated using the noise free count from the last slide. Dividing the maximum sensor output by the noise free count provides the maximum peak-to-peak ADC noise level that will achieve our system specification.

Quiz: System noise for low-speed delta-sigma ADCs

3. The table below is an excerpt from the ADS1220 data sheet showing noise performance. Assuming your system has a maximum noise requirement of 1.5µVpp, what is the maximum data rate you could use?
   a. 20sps
   b. 45sps
   c. 90sps
   d. 175sps
   e. 330sps

Table 1. Noise in μV_{RMS} (μV_{PP}) at AVDD = 3.3 V, AVSS = 0 V, Normal Mode, and Internal Reference = 2.048 V

DATA RATE (SPS)	GAIN (PGA Enabled)							
	1	2	4	8	16	32	64	128
20	3.71 (13.67)	1.54 (5.37)	1.15 (4.15)	0.80 (3.36)	0.35 (1.16)	0.23 (0.73)	0.10 (0.35)	0.09 (0.41)
45	7.36 (29.54)	2.93 (13.06)	1.71 (9.28)	0.88 (4.06)	0.50 (2.26)	0.29 (1.49)	0.19 (0.82)	0.12 (0.51)
90	10.55 (47.36)	4.50 (20.75)	2.43 (11.35)	1.51 (6.65)	0.65 (3.62)	0.42 (2.14)	0.27 (1.22)	0.18 (0.85)
175	11.90 (63.72)	6.45 (34.06)	3.26 (17.76)	1.82 (11.20)	1.01 (5.13)	0.57 (3.09)	0.34 (2.14)	0.26 (1.60)
330	19.19 (106.93)	9.38 (50.78)	4.25 (26.25)	2.68 (14.13)	1.45 (7.52)	0.79 (4.66)	0.50 (2.69)	0.34 (1.99)
600	24.78 (151.61)	13.35 (72.27)	6.68 (39.43)	3.66 (19.26)	2.10 (12.77)	1.14 (6.87)	0.70 (4.76)	0.55 (3.34)
1000	37.53 (227.29)	18.87 (122.68)	9.53 (58.53)	5.37 (31.52)	2.95 (18.08)	1.65 (10.71)	1.03 (6.52)	0.70 (4.01)

The table below is an excerpt from the ADS1220 data sheet showing noise performance. Assuming your system has a maximum noise requirement of 150nVpp, what is the maximum data rate you could use?

The correct answer is “c”. Inspecting the table, the range highlighted in yellow shows the different gain settings and sampling rates that will work for this application. Note that options not highlighted in yellow have more than 1.5Vpp noise. The highest sampling rate of 90 is circled in red.

Quiz: System noise for low-speed delta-sigma ADCs

4. The following system requires 17.6 noise free bits of resolution. Is there an ADC setting that will meet the noise requirement?
   a. Yes, Data Rate = 20, Gain = 128 works
   b. Yes, Data Rate = 20, Gain = 1 works
   c. No. The ADC noise is too high.

$$NFC = \frac{10kg}{50mg} = 200 \cdot 10^3$$

$$E_{nPP} = \frac{5mV}{200 \cdot 10^3} = 0.025\mu Vpp$$

E_{npp} > lowest ADC noise setting

Parameter	spec
Bridge sensitivity	1 mV/V
Excitation/reference voltage	5 V
Max output voltage	5 mV
Weight range	10 kg
Weight resolution	50 mg

Table 2. ENOB from RMS Noise (Noise-Fre
at AVDD = 3.3 V, AVSS = 0 V, Normal Mode,

DATA RATE (SPS)	GAIN (PGA Enabled)							
	1	2	4	8	16	32	64	128
20	20.08 (18.19)	20.34 (18.54)	19.76 (17.91)	19.28 (17.22)	19.48 (17.75)	19.10 (17.42)	19.33 (17.49)	18.49 (16.26)
45	19.09 (17.08)	19.42 (17.26)	19.19 (16.75)	19.15 (16.94)	18.95 (16.79)	18.74 (16.39)	18.38 (16.25)	18.00 (15.49)
90	18.57 (16.40)	18.80 (16.59)	18.68 (16.46)	18.37 (16.23)	18.60 (16.11)	18.20 (15.87)	17.87 (15.67)	17.44 (15.20)

Table 1. Noise in μV_{RMS} (μV_{PP})
at AVDD = 3.3 V, AVSS = 0 V, Normal Mode, and Internal Reference = 2.048 V

DATA RATE (SPS)	GAIN (PGA Enabled)							
	1	2	4	8	16	32	64	128
20	3.71 (13.67)	1.54 (5.37)	1.15 (4.15)	0.80 (3.36)	0.35 (1.16)	0.23 (0.73)	0.10 (0.35)	0.09 (0.41)
45	7.36 (29.54)	2.93 (13.06)	1.71 (9.28)	0.88 (4.06)	0.50 (2.26)	0.29 (1.49)	0.19 (0.82)	0.12 (0.51)
90	10.55 (47.36)	4.50 (20.75)	2.43 (11.35)	1.51 (6.65)	0.65 (3.62)	0.42 (2.14)	0.27 (1.22)	0.18 (0.85)

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The following system requires 17.6 noise free bits of resolution. Is there an ADC setting that will meet the noise requirement?

The correct answer is “c”. Inspecting table 2 you might think that the case where data rate is 20 and gain is 1 would work as the noise free bits are 18.19 and that is better than our requirement of 17.6. But you need to remember that the table is defined for a full scale input you can’t just consider the noise free bits. A much better approach to analyzing this circuit is to fine the input referred noise. The math shown in the red circle shows that the required peak-to-peak noise is 0.025uVpp. But the lowest noise on this ADC is 0.35uVpp which is much higher than our requirement. So, this ADC will not work as its noise is too high.

Thanks for your time!