How reference noise affects signal chain performance

TI Precision Labs – ADCs

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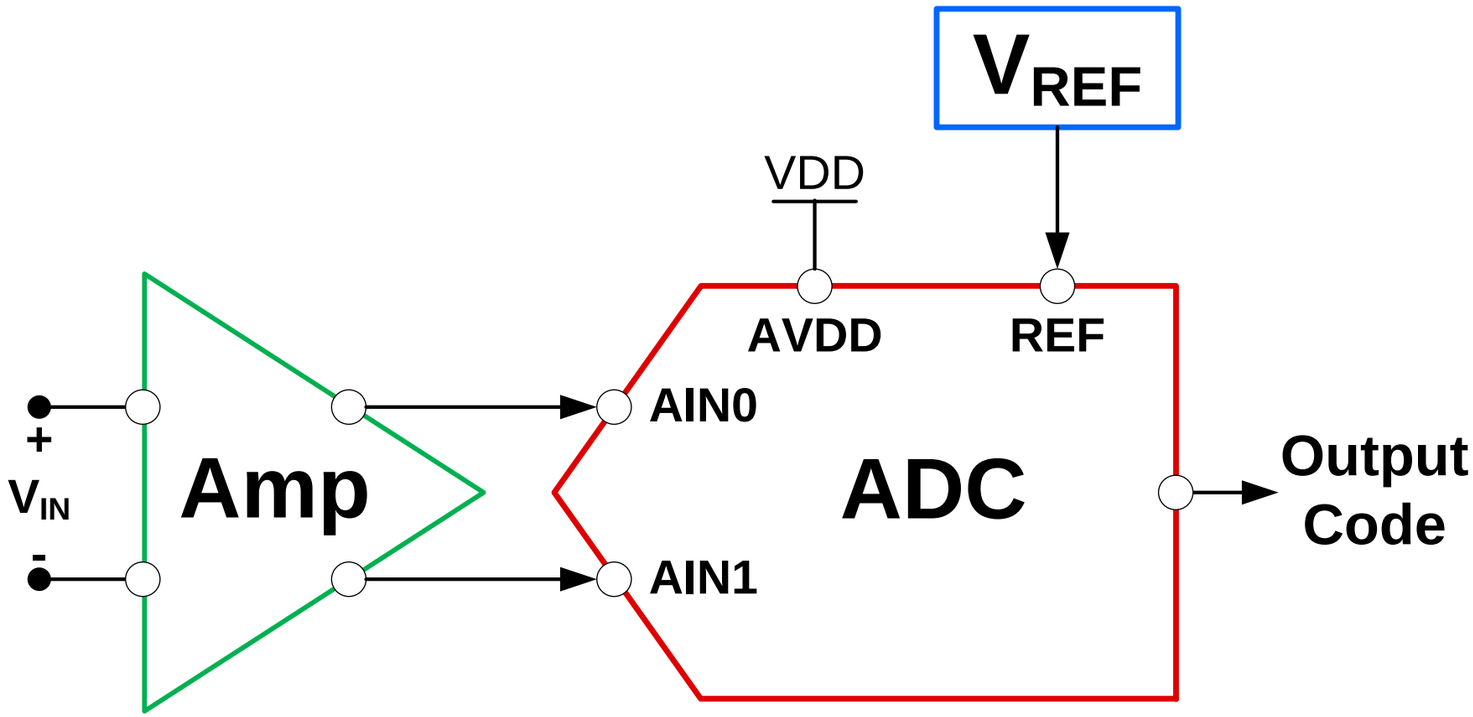
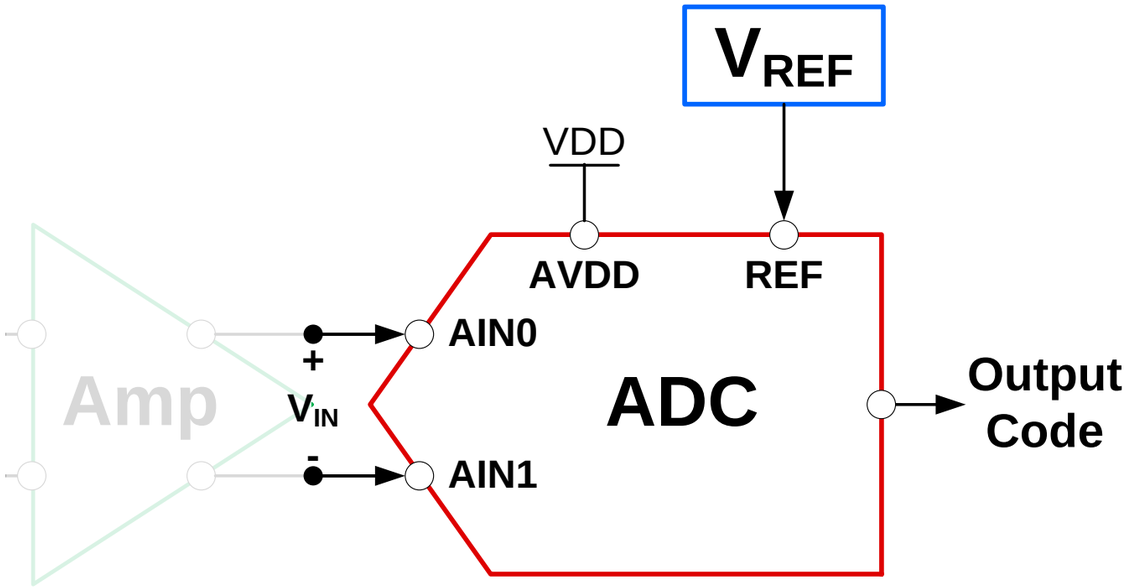
Presented by Alex Smith

Total system noise



$$Total\ noise = \sqrt{V_{N,\,ADC\ (RTI)}^{2} + V_{N,\,AMP\ (RTI)}^{2} + V_{N,\,REF\ (RTI)}^{2}}$$

Calculating system (ADC + VREF) noise

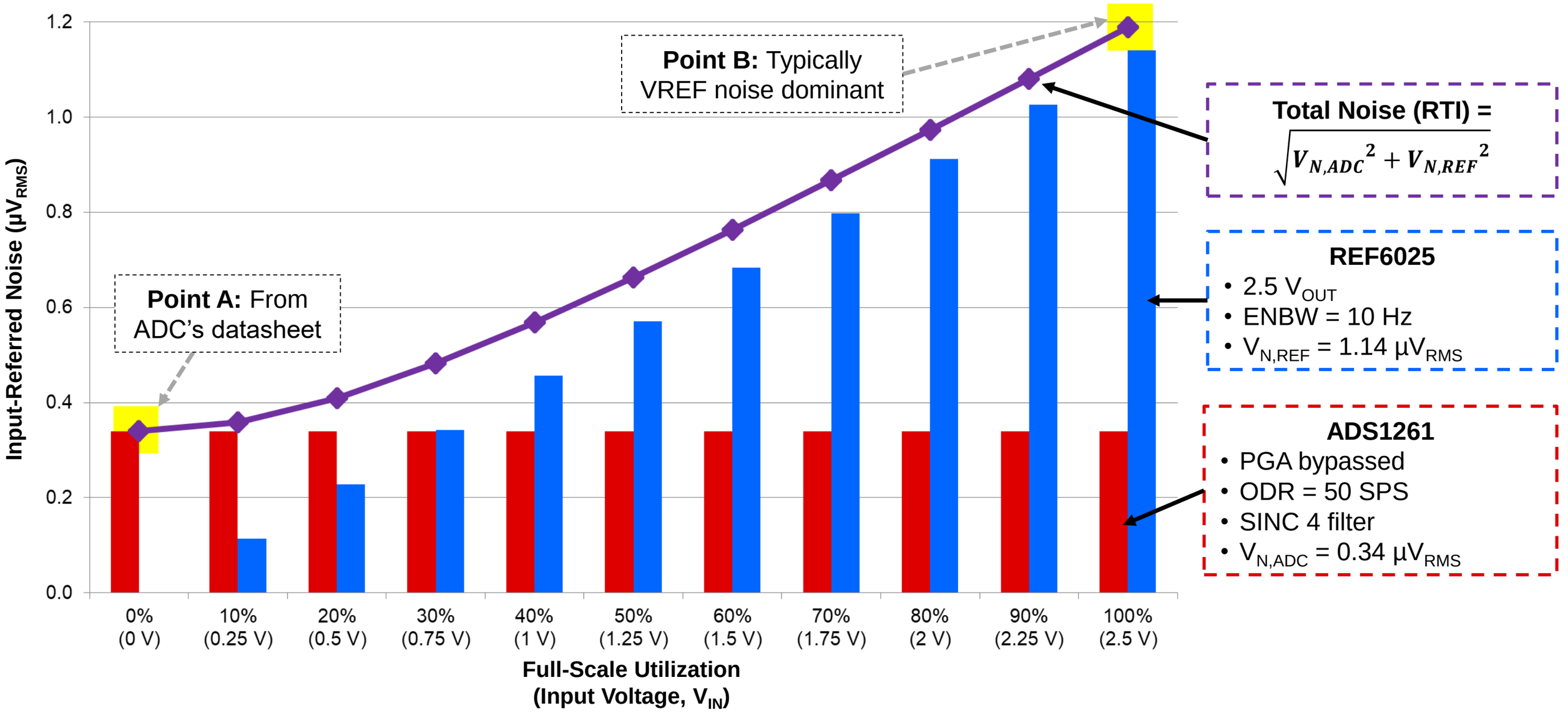


$$V_{N,\,REF\,(RTI)} = \frac{V_{IN\,(RMS)}}{V_{REF}} \cdot V_{N,REF\,(RMS)}$$

$$V_{N,\,ADC\,(RTI)} = ADC\ noise\ from\ datasheet$$

$$Total\ noise = \sqrt{V_{N,\,ADC\,(RTI)}^{2} + V_{N,\,REF\,(RTI)}^{2}}$$

Plotting system noise across V_{IN} (gain = 1)



System effective resolution (dynamic range)

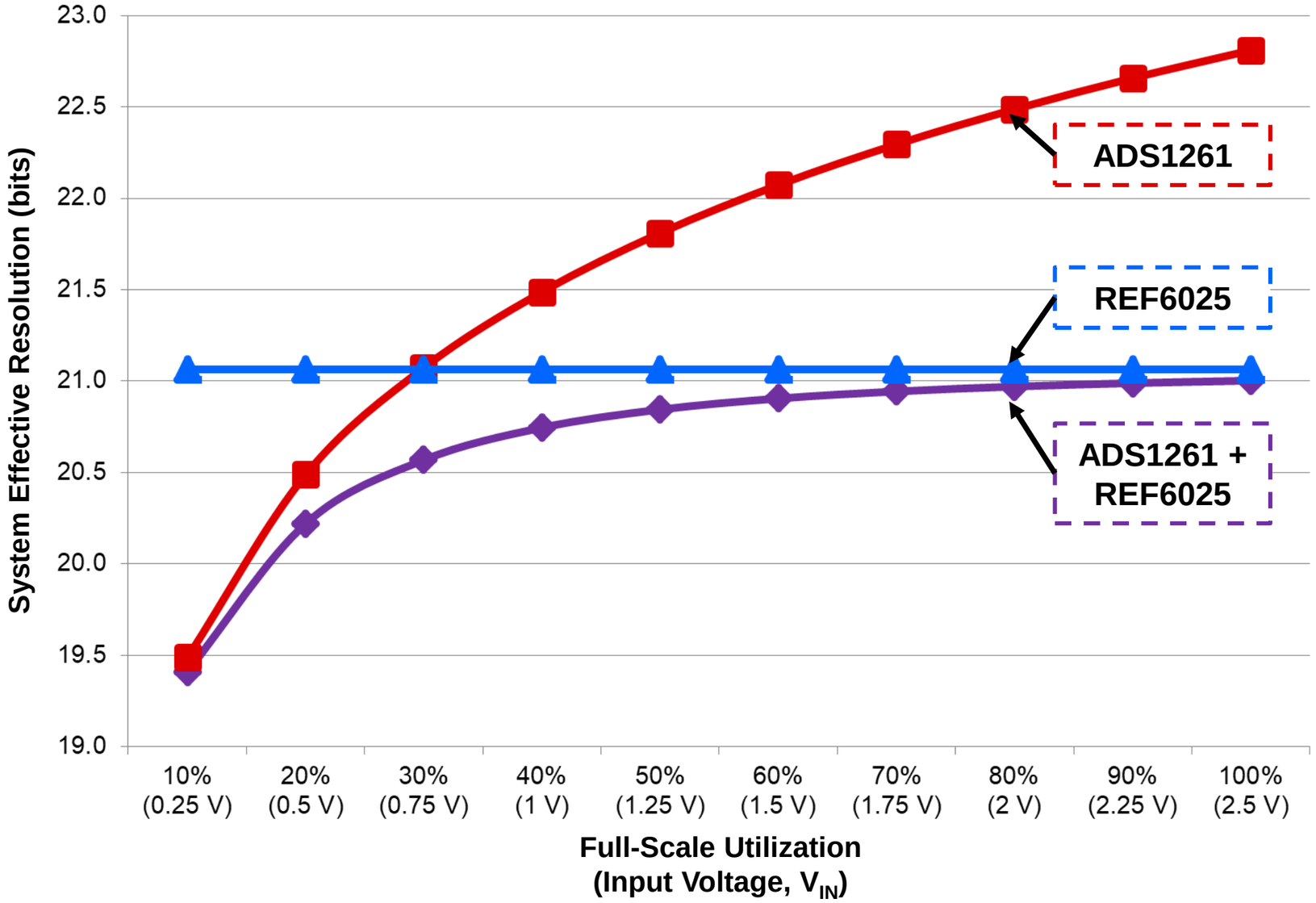
$$\text{Effective resolution} = \log_2\left(\frac{V_{IN}}{V_{N,RTI}}\right)$$

ADC

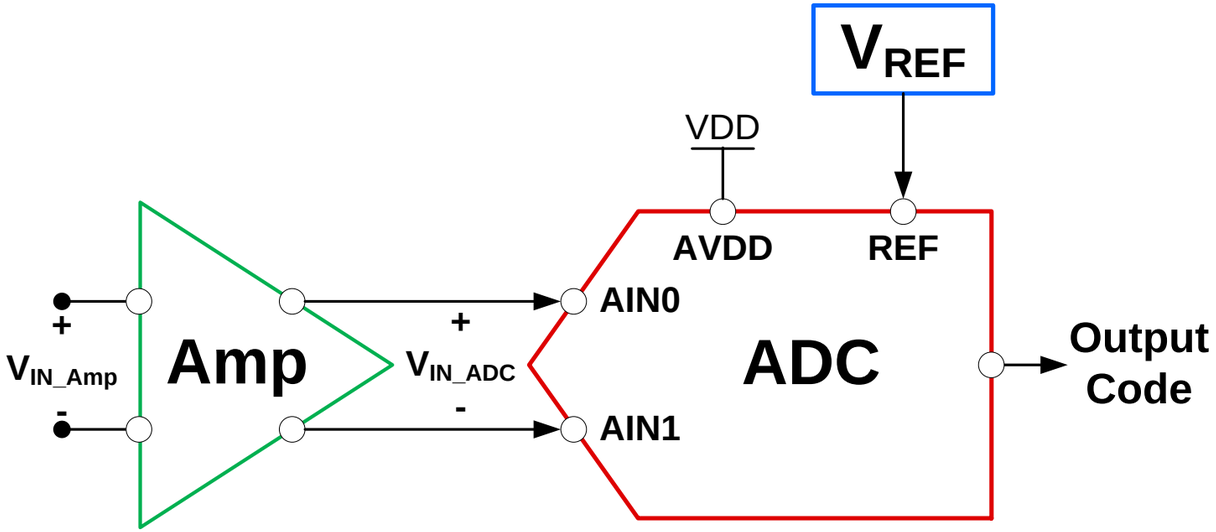
- **Noise =** constant w.r.t. V_{IN}
- **Effective resolution** = changes w.r.t. V_{IN}

VREF

- **Noise =** scales linearly w.r.t V_{IN}
- **Effective resolution** = constant w.r.t V_{IN}



Calculating system (amp + ADC + VREF) noise



$$V_{N,\,AMP\,(RTI)} = from\ datasheet$$

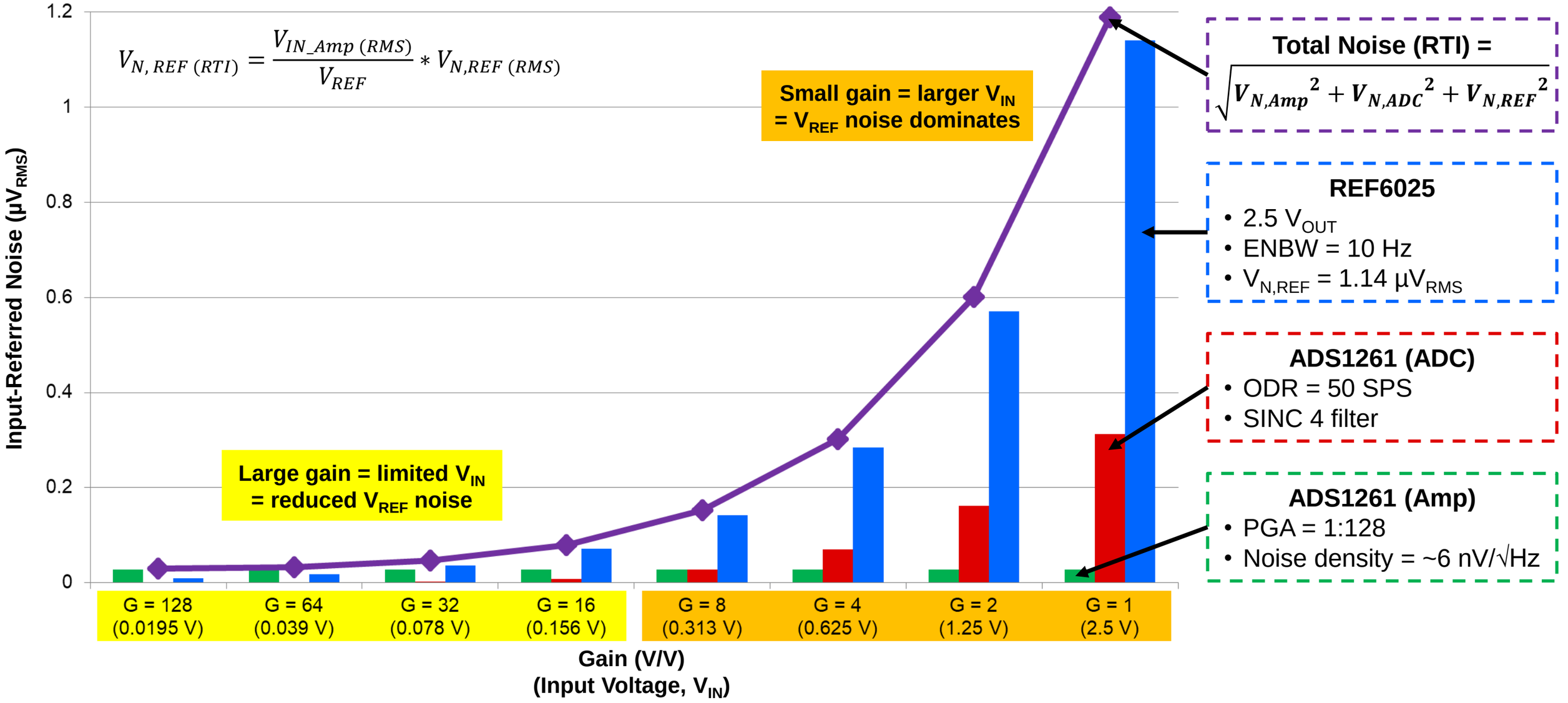
$$V_{N,\,ADC\,(RTI)} = \frac{V_{N,\,ADC\,(datasheet)}}{Gain}$$

Deriving an equation for $V_{N,\,REF\,(RTI)}$

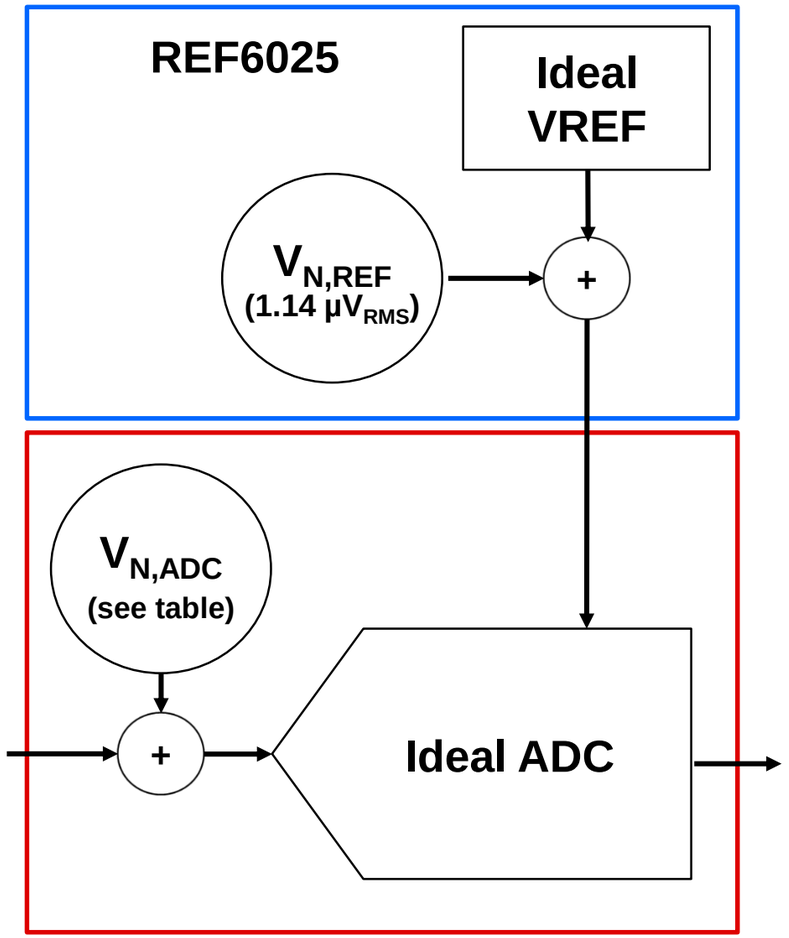
	Comment	Equation
Step #1	VREF noise equation	$\frac{V_{IN\_ADC\,(RMS)}}{V_{REF}} * V_{N,REF\,(RMS)}$
Step #2	Refer to input = divide by gain	$\frac{V_{IN\_ADC\,(RMS)}}{V_{REF} * Gain} * V_{N,REF\,(RMS)}$
Step #3	Substitute V_{IN_ADC} for V_{IN_AMP}*Gain	$\frac{V_{IN\_Amp\,(RMS)} * Gain}{V_{REF} * Gain} * V_{N,REF\,(RMS)}$
Step #4	Final equation	$\frac{V_{IN\_Amp\,(RMS)}}{V_{REF}} * V_{N,REF\,(RMS)}$

$$Total\ noise = \sqrt{V_{N,\,ADC\,(RTI)}^{\,2} + V_{N,\,AMP\,(RTI)}^{\,2} + V_{N,\,REF\,(RTI)}^{\,2}}$$

Plotting system noise across gain (V_{IN} = 100% FS)



Lower- vs higher-resolution ADCs: references



Parameter	Conditions	Units	ADC Resolution (bits)							
			8	10	12	14	16	20	24	32
ADC noise	G=1, 50 SPS, V_{REF} = 2.5 V	μV_{RMS}	19,531	4,883	1,221	305	76	11.2	0.53	0.18
LSB size	FSR = 2*V_{REF}	μV	19,531	4,883	1,221	305	76	4.76	0.29	0.001
VREF noise	BW = 10 Hz	μV_{RMS}	1.14							
Total noise	V_{IN} = 100% FS	μV_{RMS}	19,531	4,883	1,221	305	76	11.3	1.3	1.2
Increase in noise	n/a	%	0%	0%	0%	0%	0.01%	0.9%	148%	589%

For **lower-resolution ADCs**, reference noise has **virtually no impact** on total noise

For **higher-resolution ADCs**, reference noise has **a large impact** on total noise

Key takeaways

Input closer to full-scale = system is in low gain with high utilization, ensure that ADC + VREF noise are comparable

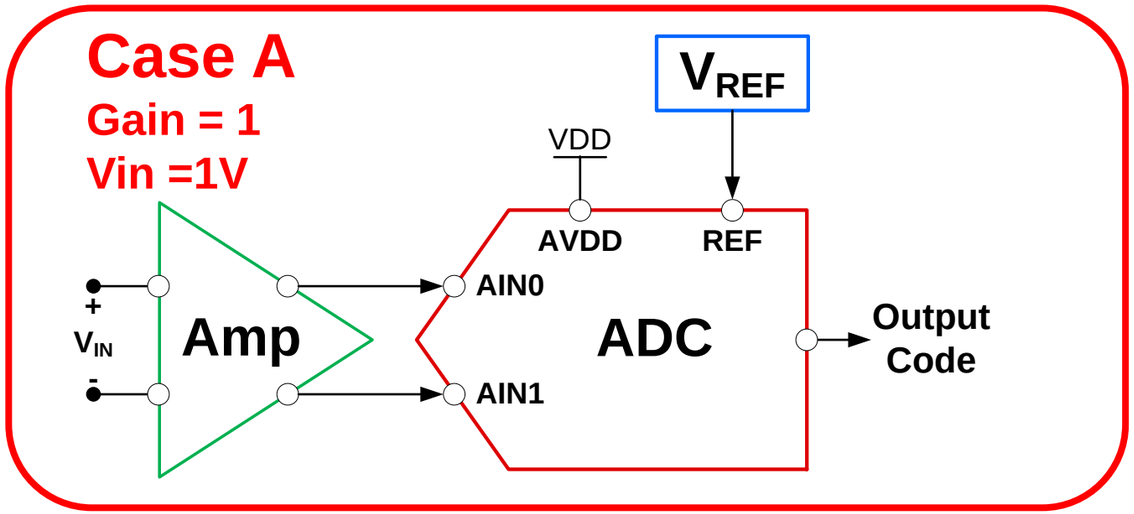
Small input signals = large gain reduces ADC noise and allowable full scale input, which indirectly limits VREF noise

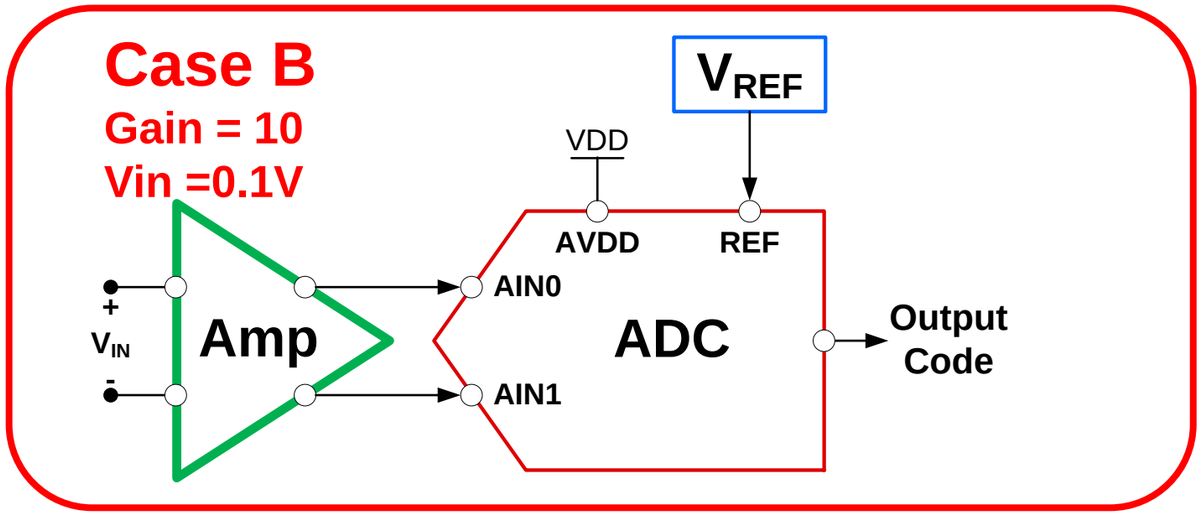
Lower- vs higher-resolution ADCs = amp and VREF noise effects have a greater impact on higher-resolution ADCs, while quantization noise dominates in lower-resolution ADCs

Thanks for your time!
Please try the quiz.

Quiz: How reference noise affects signal chain

1. Referring to the figure below, assume both circuits are the same except for the gain and input signal. Which of the following are true? Select more than one answer if needed.
   a. The ADC noise is minimized in case A
   b. The ADC noise is minimized in case B
   c. The reference noise is minimized in case A
   d. The reference noise is minimized in case B





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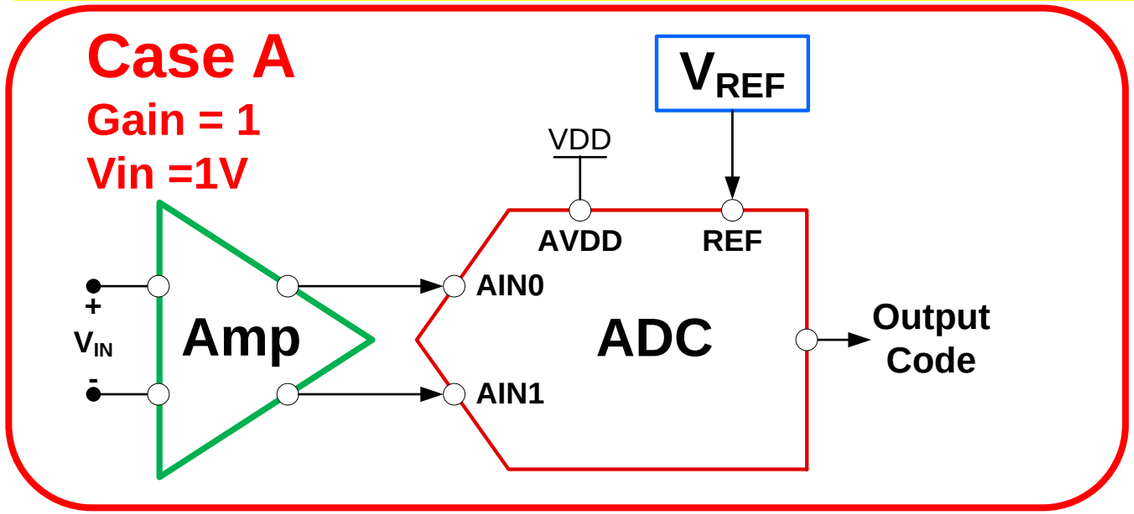
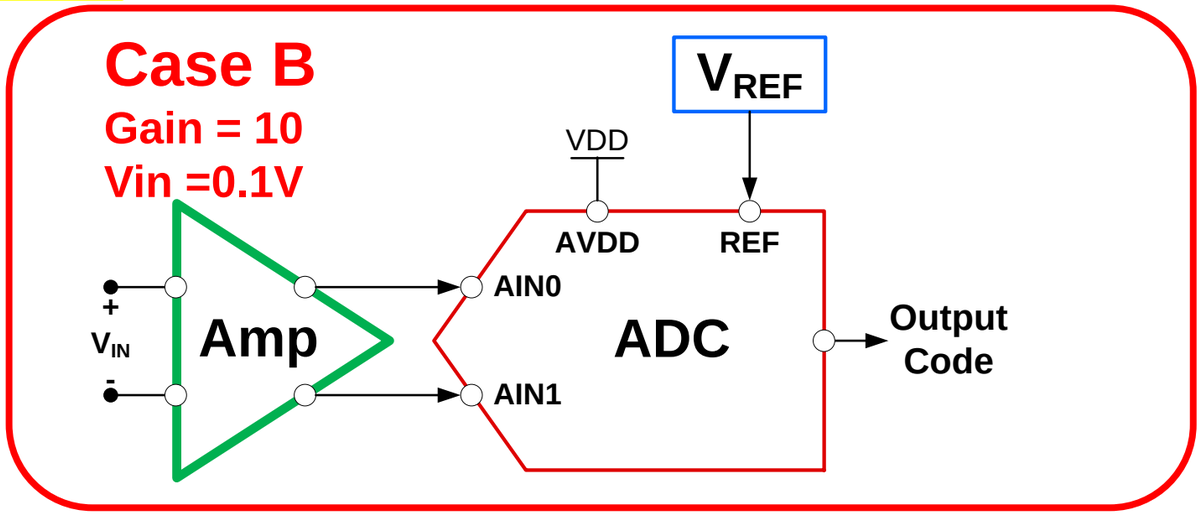
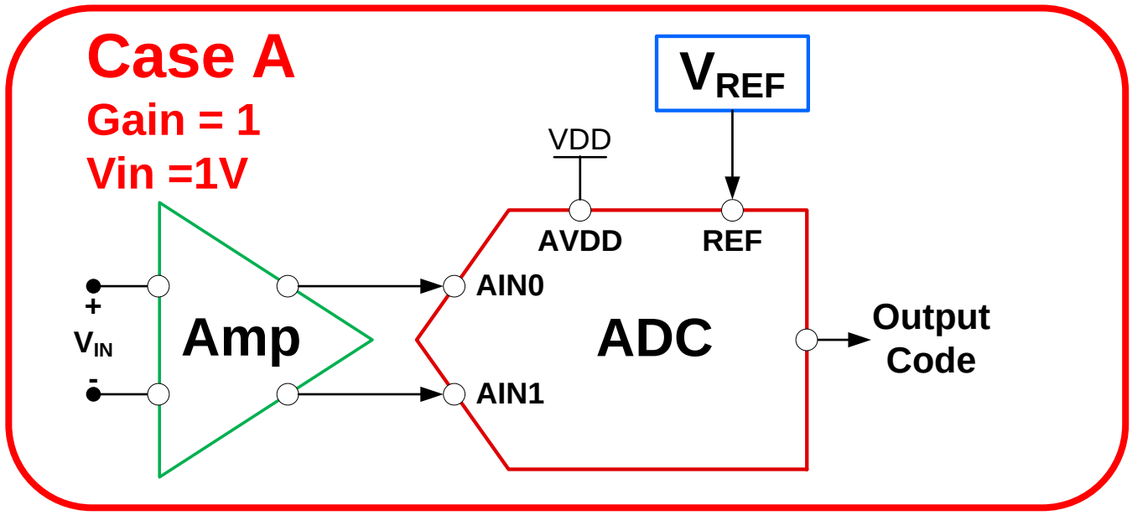
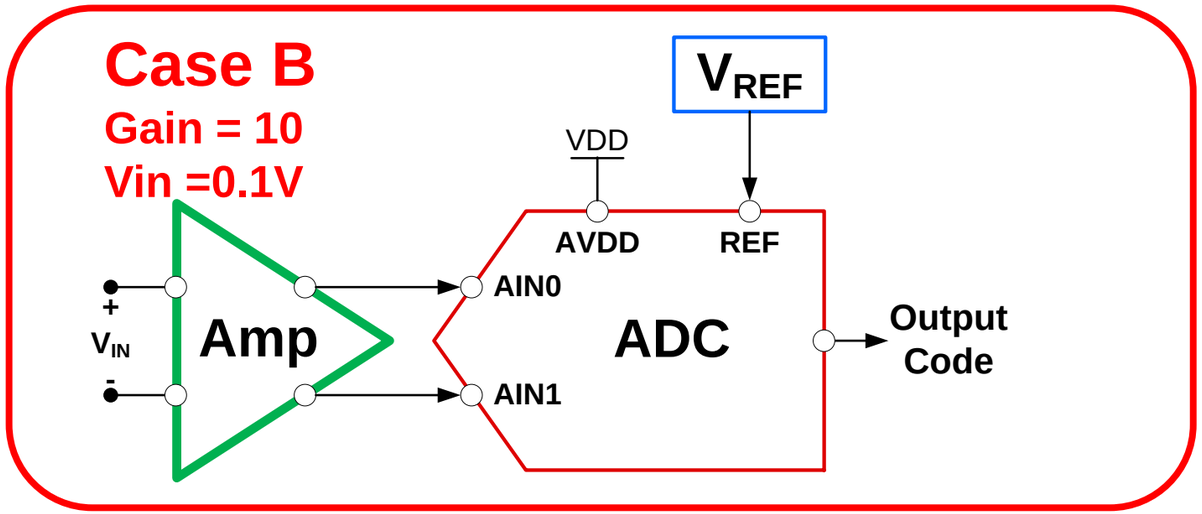




Quiz: How reference noise affects signal chain

2. Referring to the figure below, assume both circuits are the same except for the gain and input signal. Which of the following are true? Select more than one answer if needed.
   a. The amplifier noise referred to the input is the same in both cases
   b. The amplifier noise referred to the input is smaller for case B
   c. The amplifier noise referred to the output is larger for case A
   d. The amplifier noise referred to the output is larger for case B





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c. The amplifier noise referred to the output is larger for case A

d. The amplifier noise referred to the output is larger for case B