Introduction to reference noise in ADC systems

TI Precision Labs – ADCs

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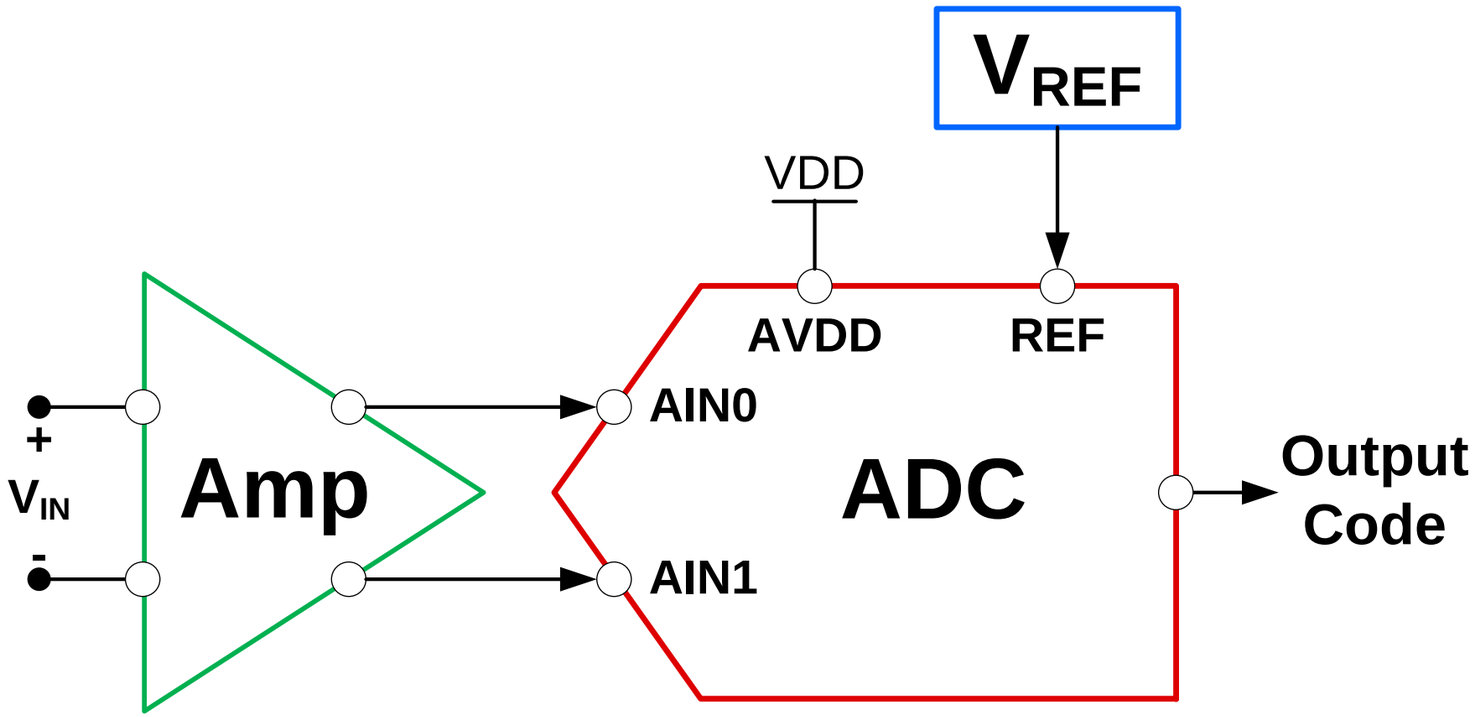
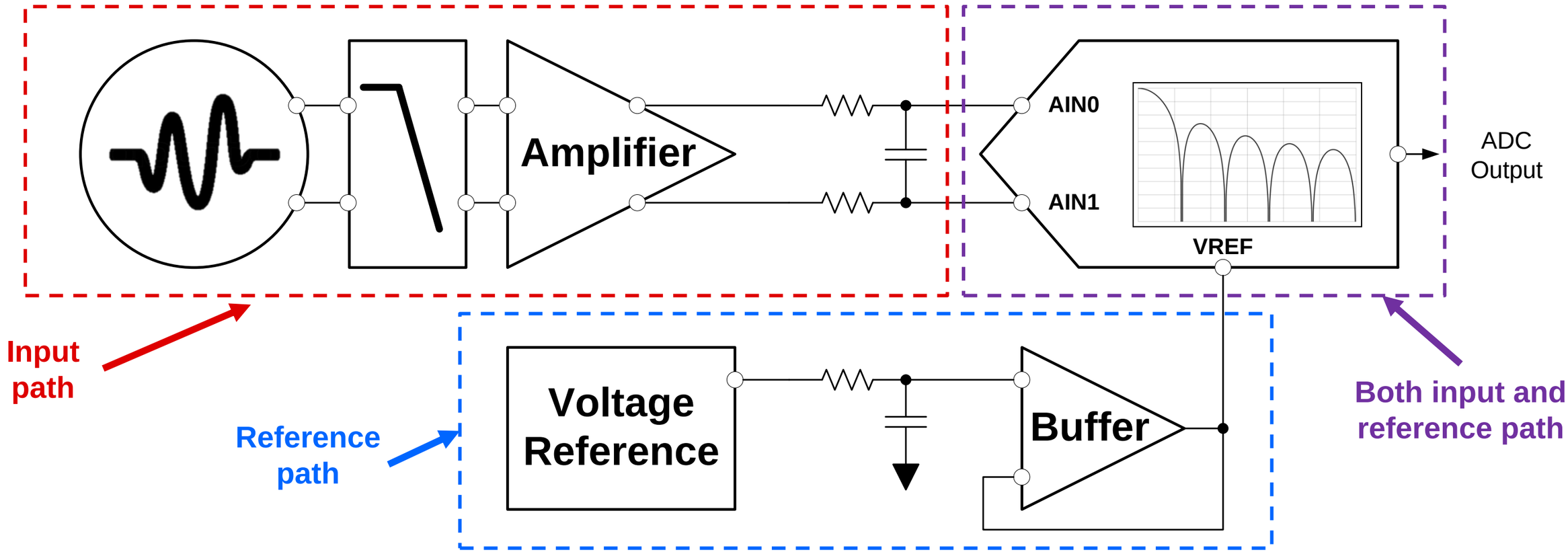
Presented by Alex Smith

Total system noise



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

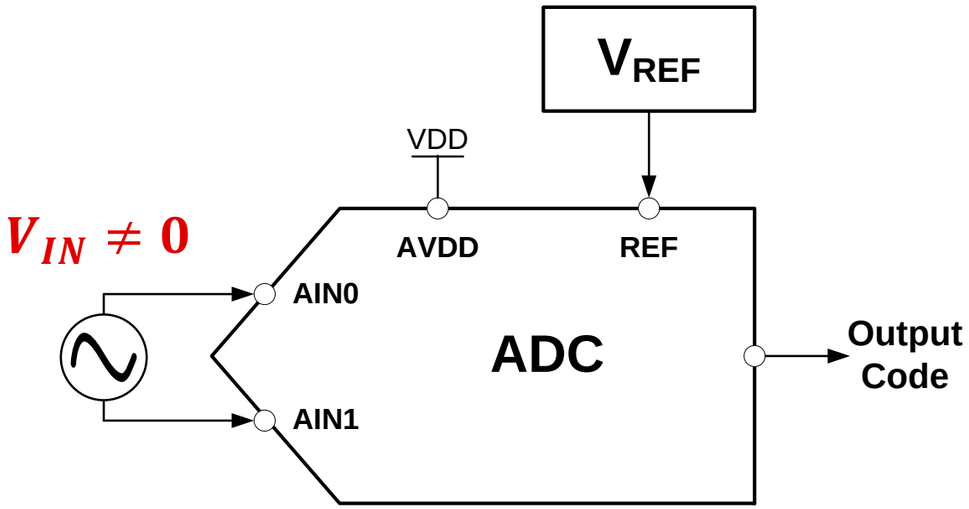
How VREF noise enters the signal chain



$$Output\ Code = V_{IN\ (RMS)} * \left(\frac{2^N}{V_{REF} + V_{N,REF\ (RMS)}} \right)$$

Does datasheet ADC noise include VREF noise?

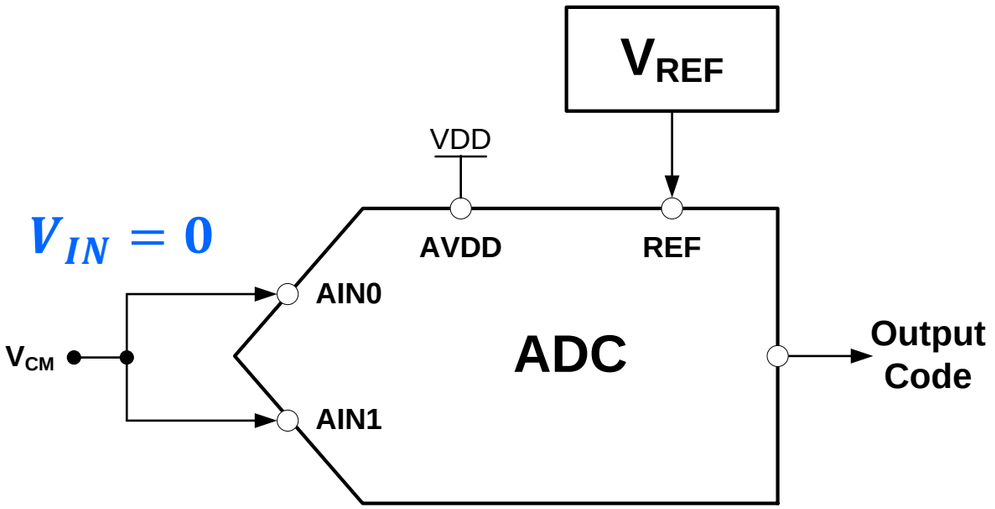
Input-sinewave test (SNR, SINAD, etc.)



$$Output\ Code = V_{IN\ (RMS)} * \left(\frac{2^N}{V_{REF} + V_{N,REF\ (RMS)}}\right) \neq 0$$

Includes reference & ADC noise

Input-short noise test (effective resolution, NFB)



$$Output\ Code = V_{IN\ (RMS)} \overset{0}{} * \left(\frac{2^N}{V_{REF} + V_{N,REF\ (RMS)}}\right) \cong 0$$

ADC noise only

Deriving how VREF noise impacts the system

	Comment	Equation
Step 1	Output code equation	$V_{IN\ (RMS)} * \left(\frac{2^N}{V_{REF} + V_{N,REF\ (RMS)}}\right)$
Step 2	Multiply by $\frac{V_{REF}}{V_{REF}}$	$\frac{V_{IN\ (RMS)}}{V_{REF}} * \left(\frac{2^N}{1 + \frac{V_{N,REF\ (RMS)}}{V_{REF}}}\right)$
Step 3	Simplify using binomial approximation**	$\frac{V_{IN\ (RMS)} * 2^N}{V_{REF}} * \left(1 - \frac{V_{N,REF\ (RMS)}}{V_{REF}}\right)$
Step 4	Distribute	$\frac{V_{IN\ (RMS)} * 2^N}{V_{REF}} - \frac{V_{IN\ (RMS)} * 2^N * V_{N,REF\ (RMS)}}{V_{REF}^2}$

Signal (in codes)

$V_{REF\ (noise)}$ (in codes)

Step 5: $V_{REF\ (noise)}$ in Volts (RTI)

$$= \frac{V_{IN\ (RMS)} * 2^N * V_{N,REF\ (RMS)}}{V_{REF}^2} * \frac{V_{REF}}{2^N}$$

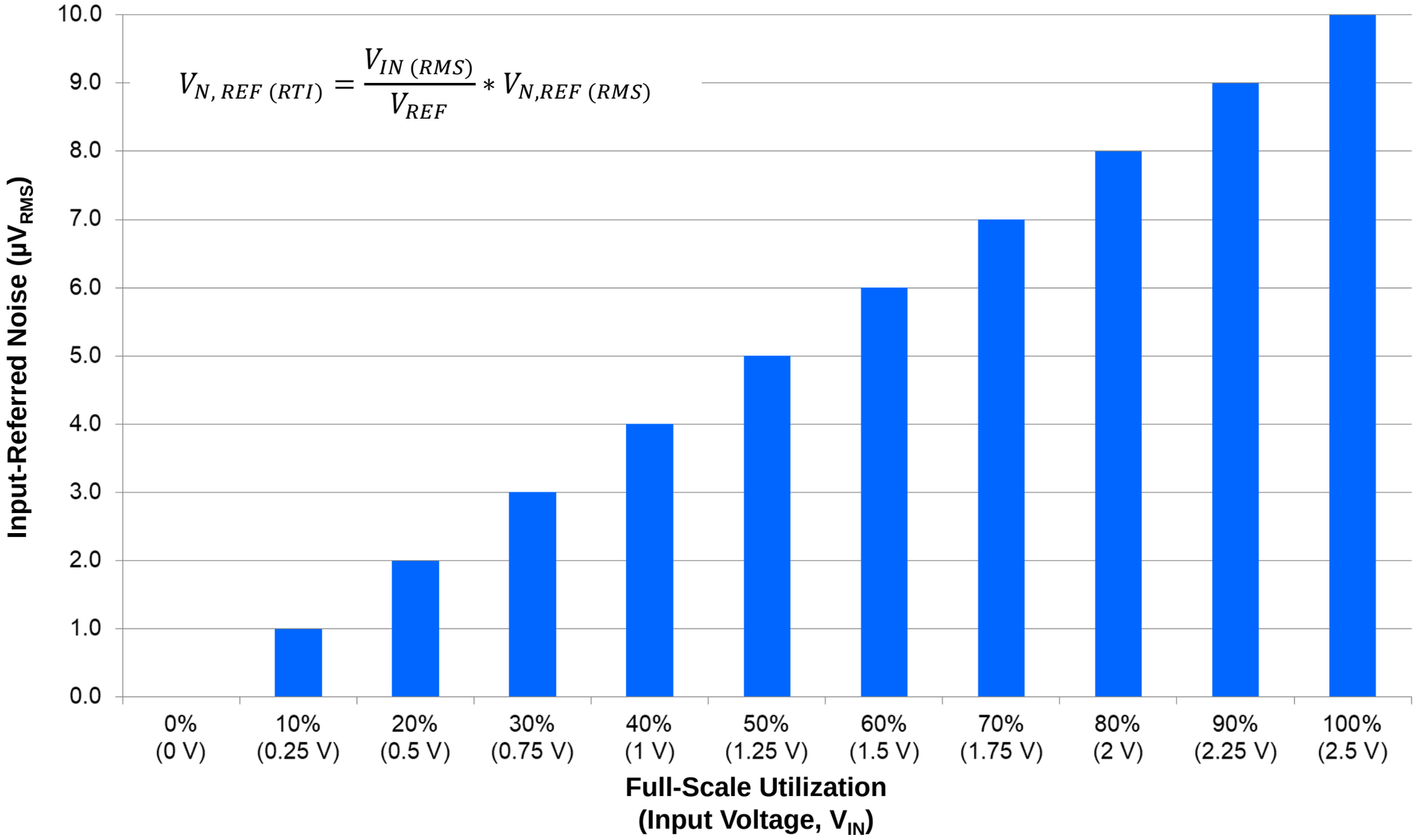
$$= \frac{V_{IN\ (RMS)}}{V_{REF}} * V_{N,REF\ (RMS)}$$

**https://en.wikipedia.org/wiki/Binomial_approximation

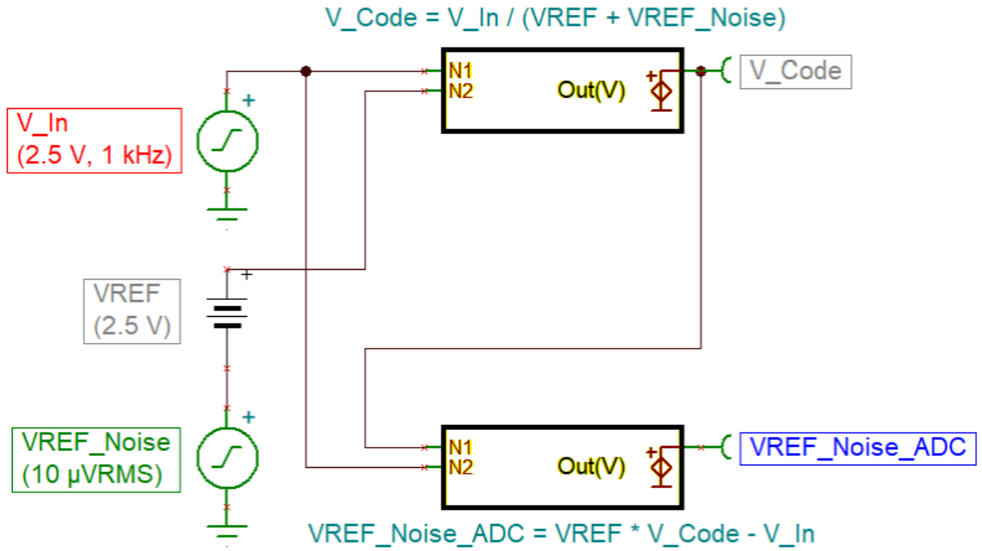
Plotting VREF noise for DC signals

System Parameters

- V_{REF} = 2.5 V
- $V_{N,REF\ (RMS)}$ = 10 μV_{RMS}
- $V_{IN\ (RMS)}$ = DC input swept from 0 V to +FS



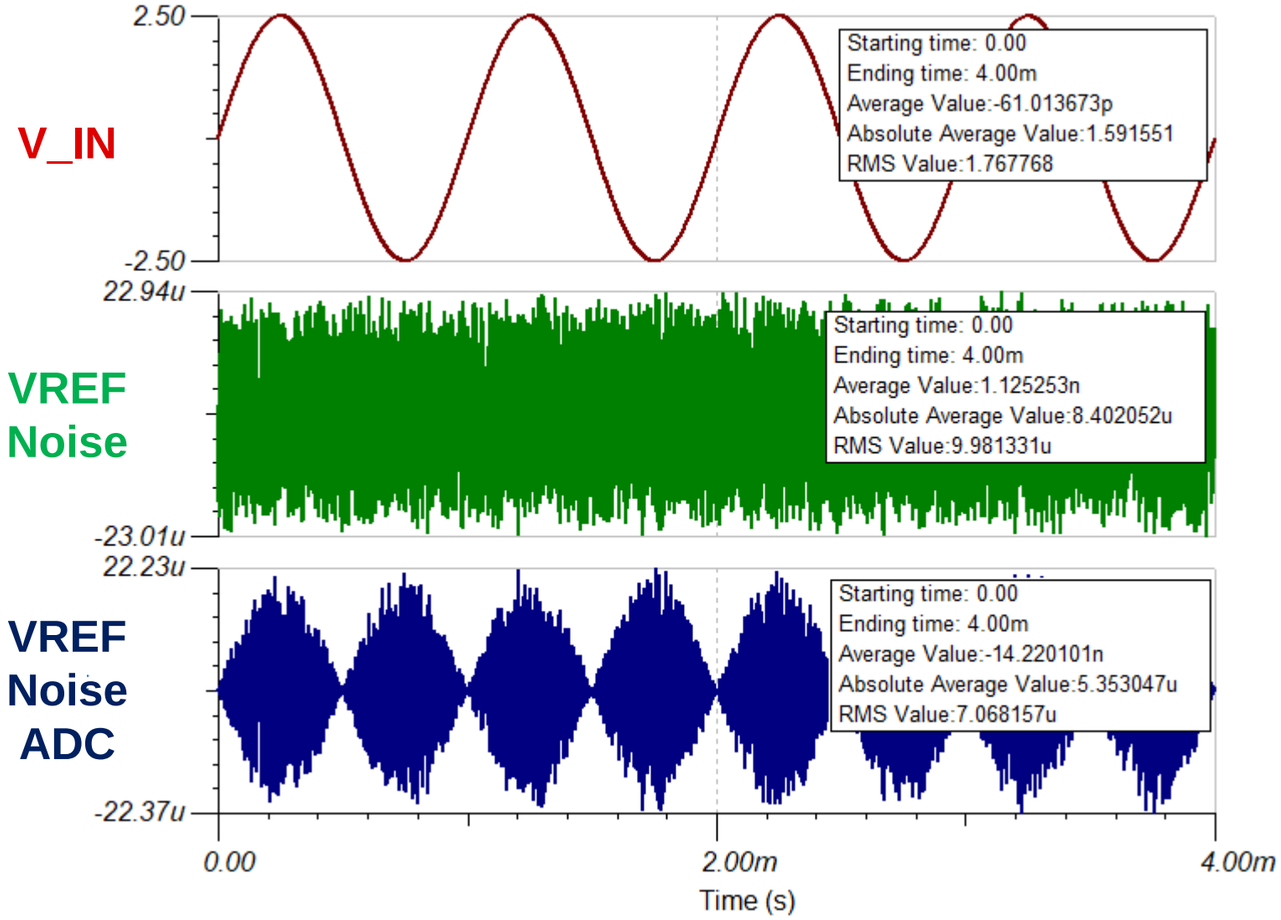
Simulating VREF noise for AC signals



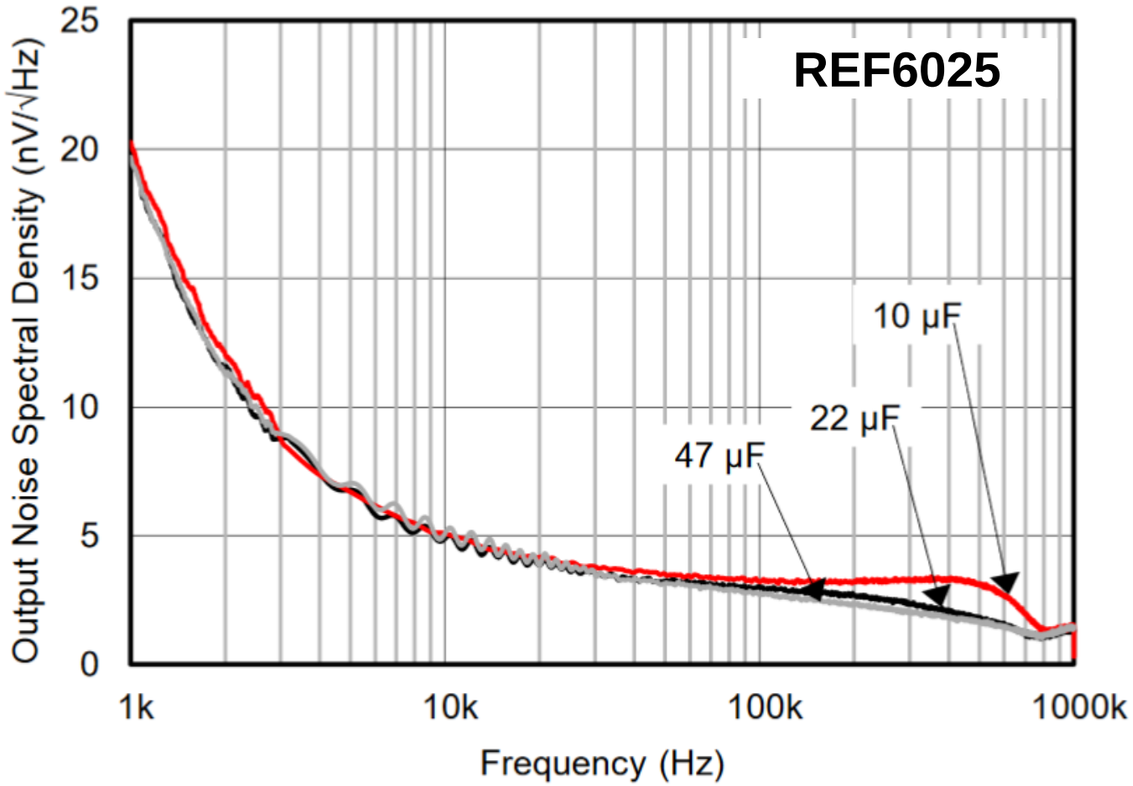
$$V_{N,REF\ (RTI)} = \frac{V_{IN(RMS)}}{V_{REF}} * V_{N,REF(RMS)}$$

$$= \frac{2.5\ V}{2.5\ V * \sqrt{2}} * 10\ \mu V_{RMS}$$

$$= 7.08\ \mu V_{RMS}$$



Calculating reference noise (REF60xx)



PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
NOISE					
Total integrated noise	C_L = 22 µF		5		μV_{RMS}
	C_L = 47 µF		5		
Low frequency noise	0.1 Hz ≤ f ≤ 10 Hz		3		$\mu V_{PP}/V$

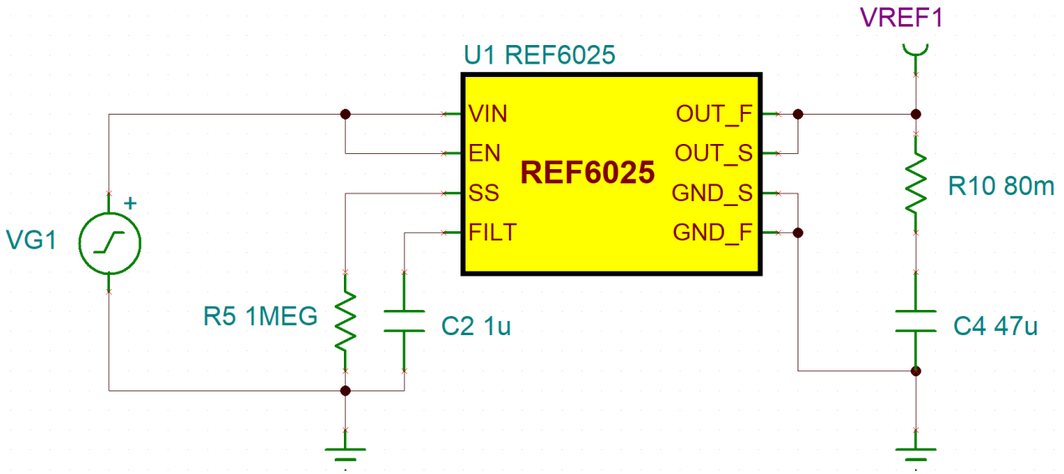
$$\mathbf{REF6025_{1/f\ noise}} = 3\,\frac{\mu V_{PP}}{V} * 2.5\ V = \mathbf{7.5\ \mu V_{PP}\ (\sim 1.14\ \mu V_{RMS})}$$

For REF6025 noise at other frequencies e.g. 100 Hz, use equations or simulation**

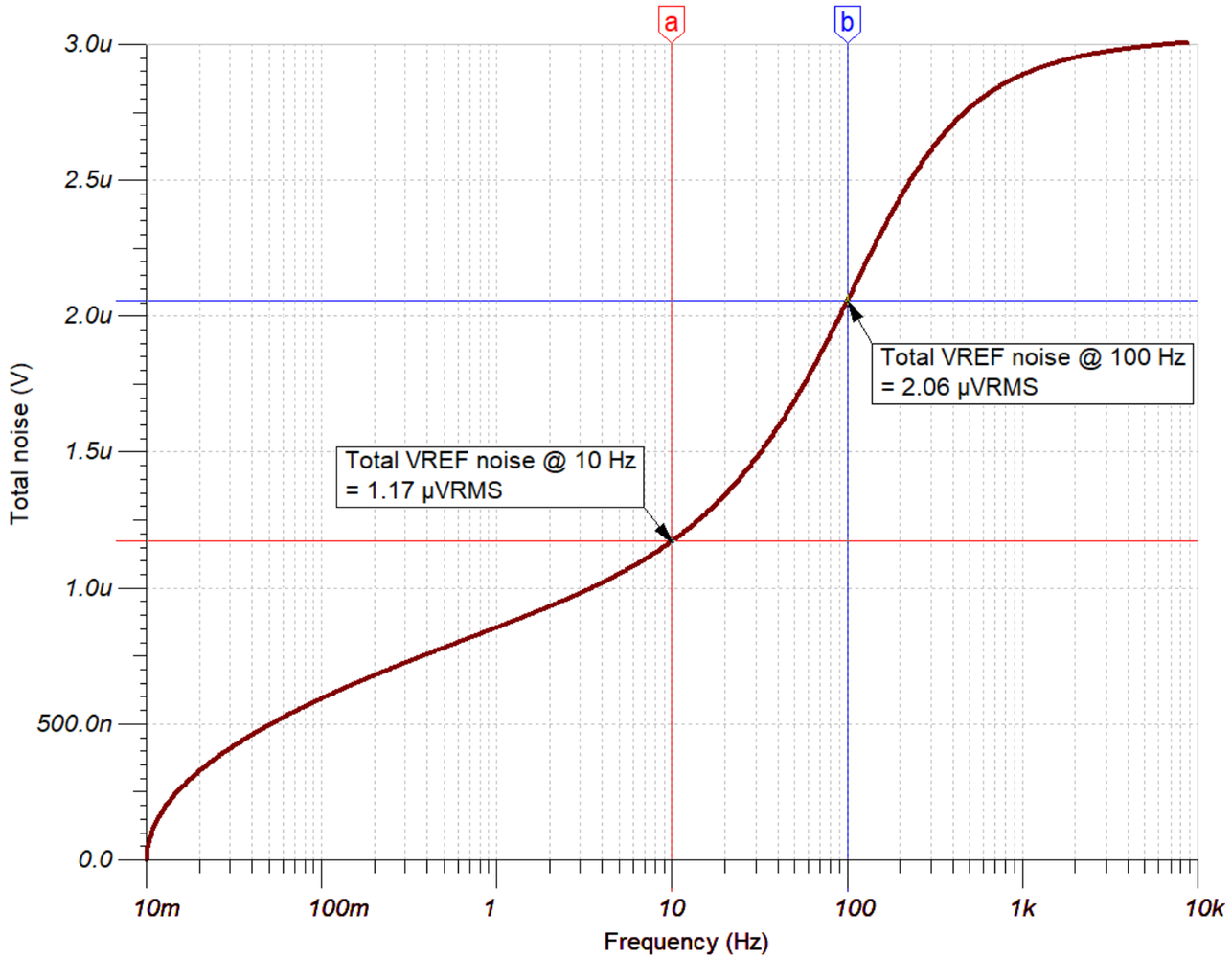
****View the Precision Labs modules on amplifier noise & effective noise bandwidth to learn how to calculate total noise**

Simulating reference noise (REF60xx)

Simulated circuit

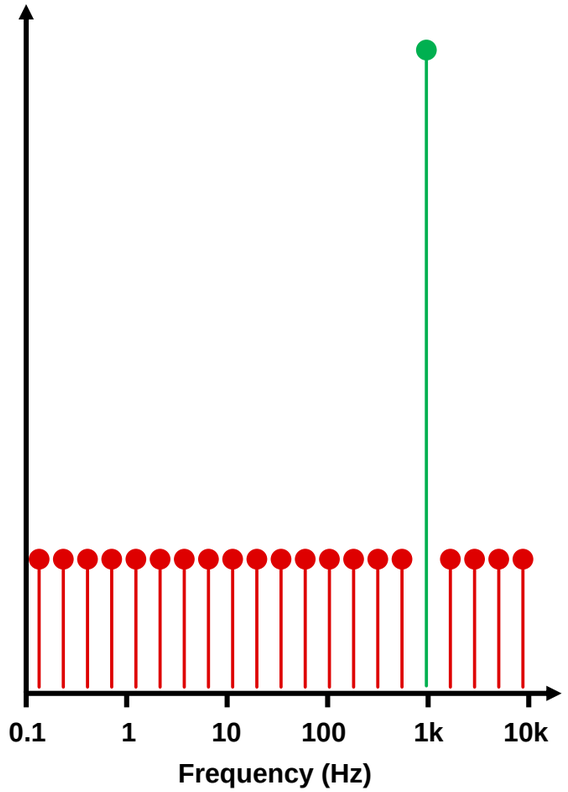


Total output noise @ 10 Hz & 100 Hz

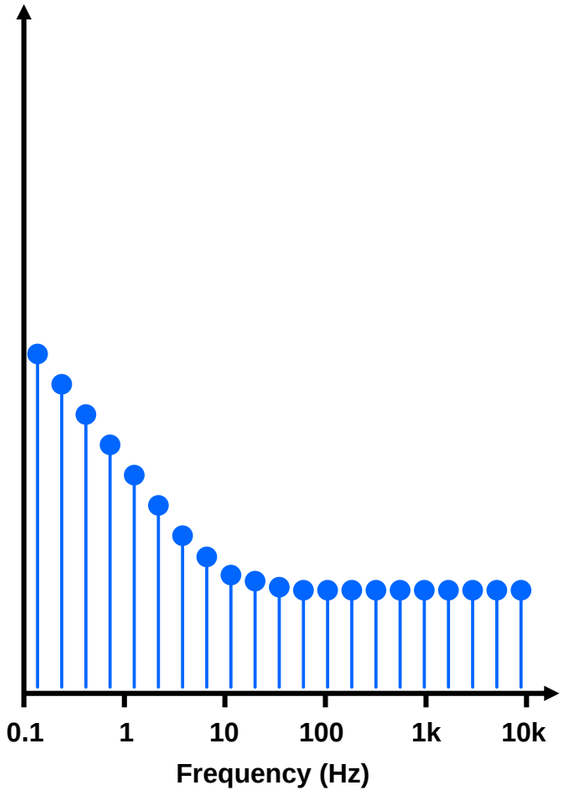


Effects of low-frequency (1/f) reference noise

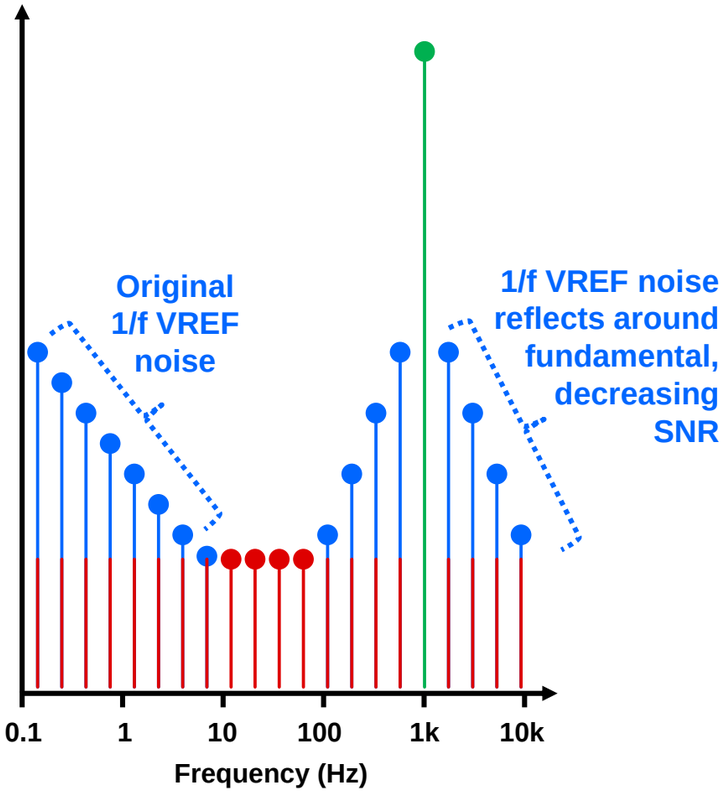
FFT of V_{IN} = 2.5 V_P, 1 kHz (BB noise only)



VREF noise vs frequency (BB & 1/f noise)



FFT of V_{IN} = 2.5 V_P, 1 kHz (BB & 1/f noise)



Low-frequency VREF noise often dominates the overall system noise performance

Thanks for your time!
Please try the quiz.

Quiz: Intro to reference noise in ADC systems

1. How will applying a DC input signal impact the system noise due to the voltage reference?
   a. The input signal has no impact on the reference noise
   b. The reference noise at the output will be directly proportional to the DC input signal
   c. Reference noise is only impacted by AC input signals
   d. The reference noise at the output will be inversely proportional to the DC input signal

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Quiz: Intro to reference noise in ADC systems

2. (T/F) When applying a sinusoidal input, the output reference noise will be proportional to the RMS of the sine wave?
   a. True
   b. False

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3. How does the 1/f noise in the voltage reference show up in the ADC output spectrum?
   a. It shows up in the same frequency range in the output spectrum as it does in the reference noise
   b. It shows up as skirts on any AC signal applied to the system
   c. Both A & B

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