Reducing reference noise in precision ADC systems

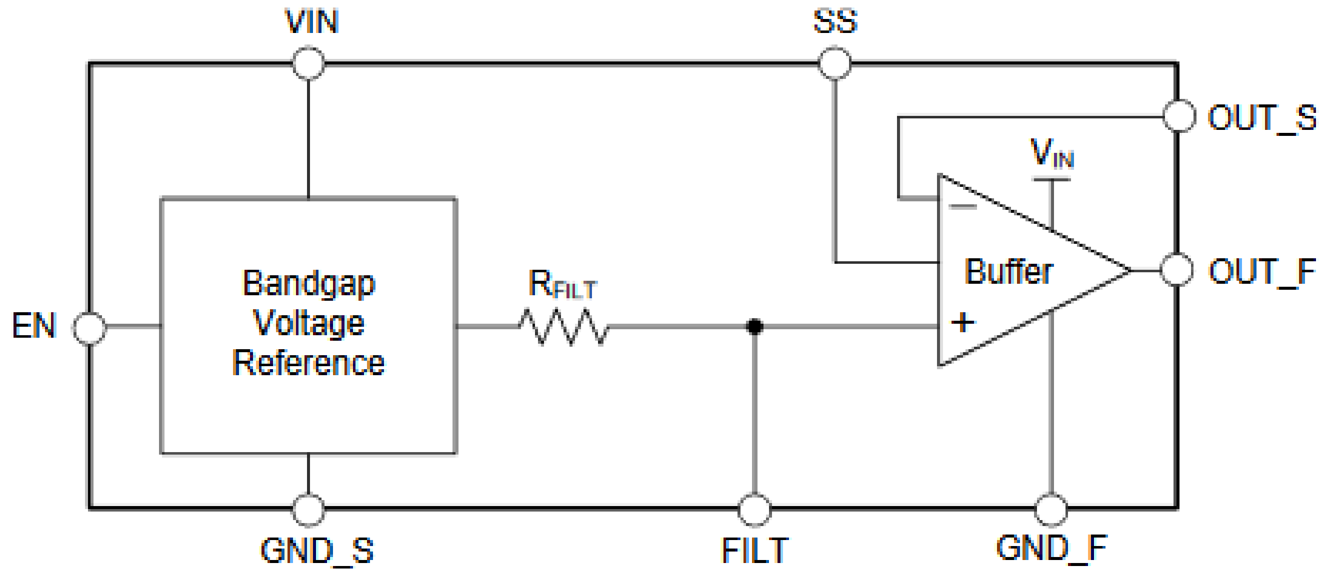
TI Precision Labs – ADCs

Created by Chris Hall & Bryan Lizon

Presented by Alex Smith

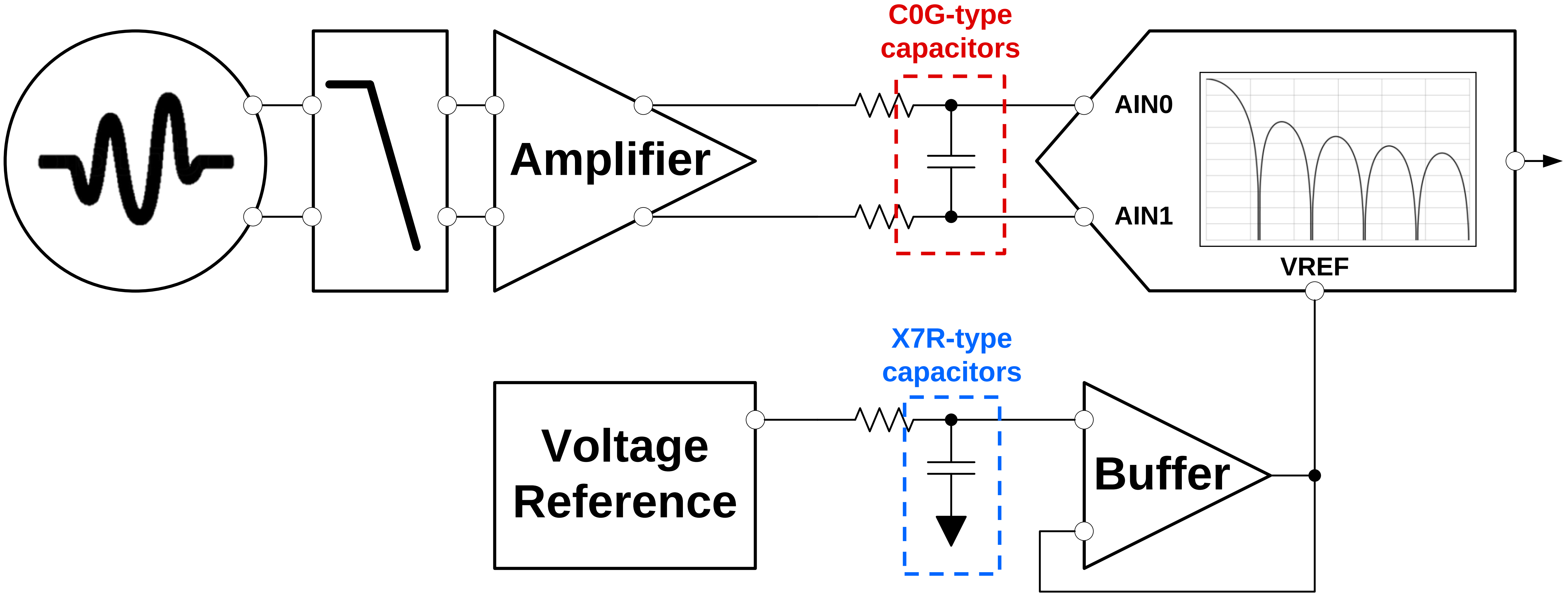
Minimizing reference noise – lower-noise VREF

REF6025



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	$\mu V_{PP}/V$

Minimizing reference noise – analog filter BW



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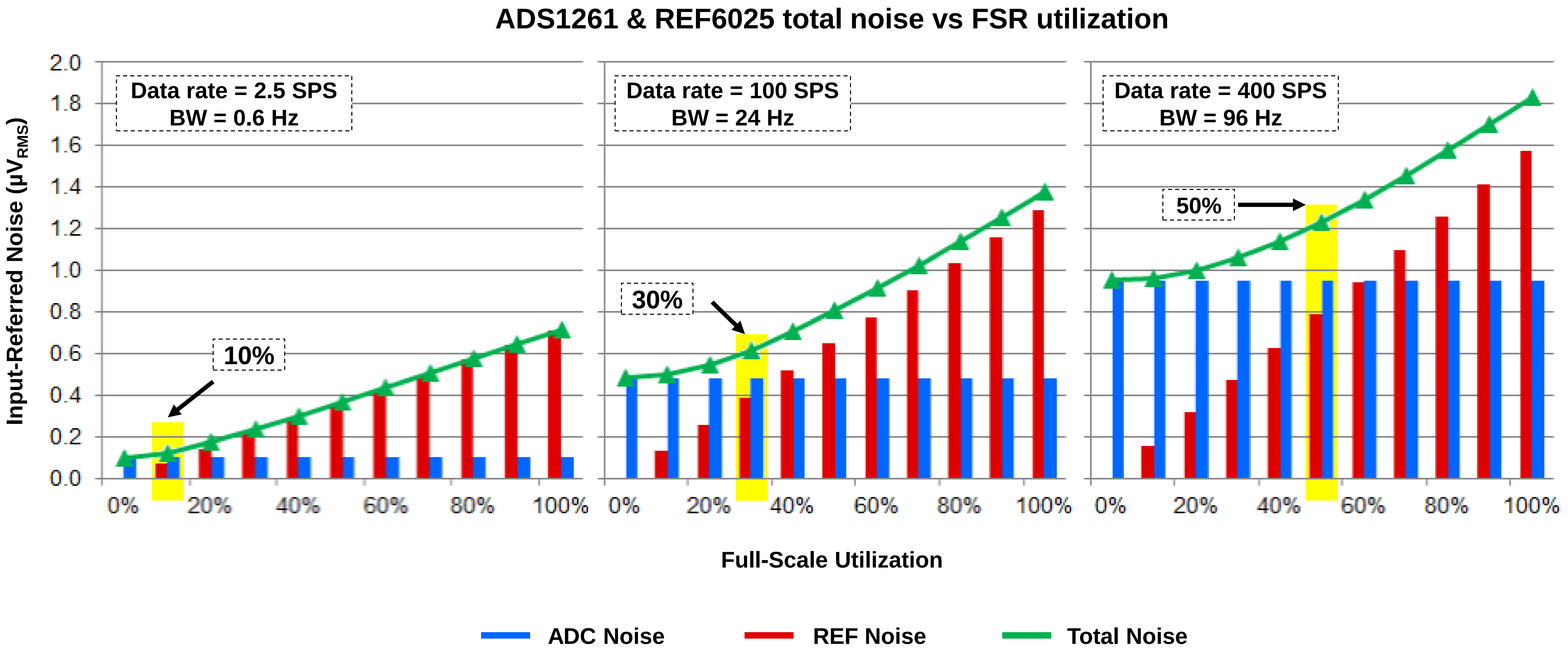
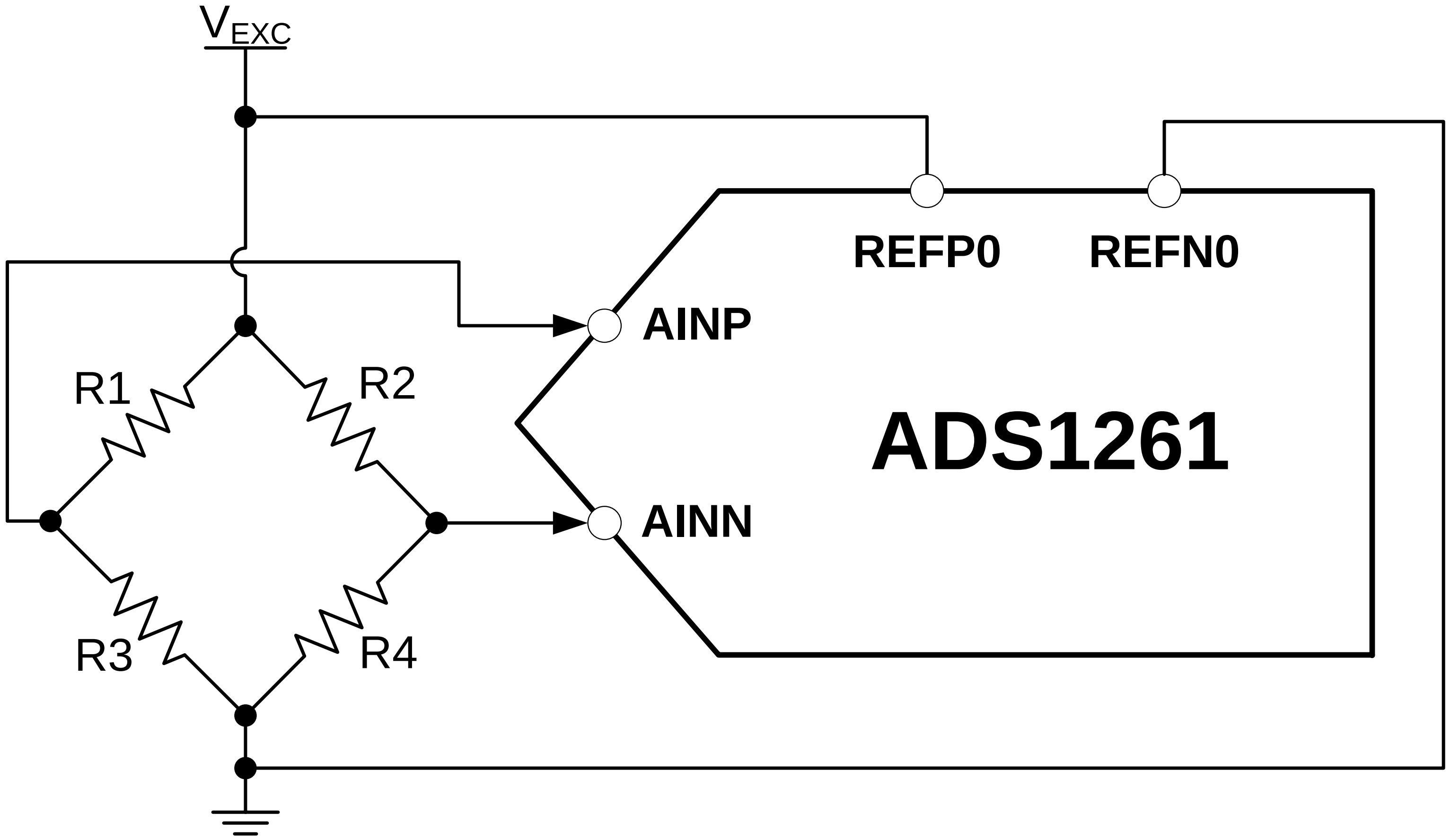


Reference configuration – ratiometric



$$Output\ Code = V_{IN} * \left(\frac{2^N}{V_{EXC}}\right)$$

$$V_{IN} = V_{AINP} - V_{AINN} = V_{EXC} * \left(\frac{R3}{R1 + R3} - \frac{R4}{R2 + R4}\right)$$

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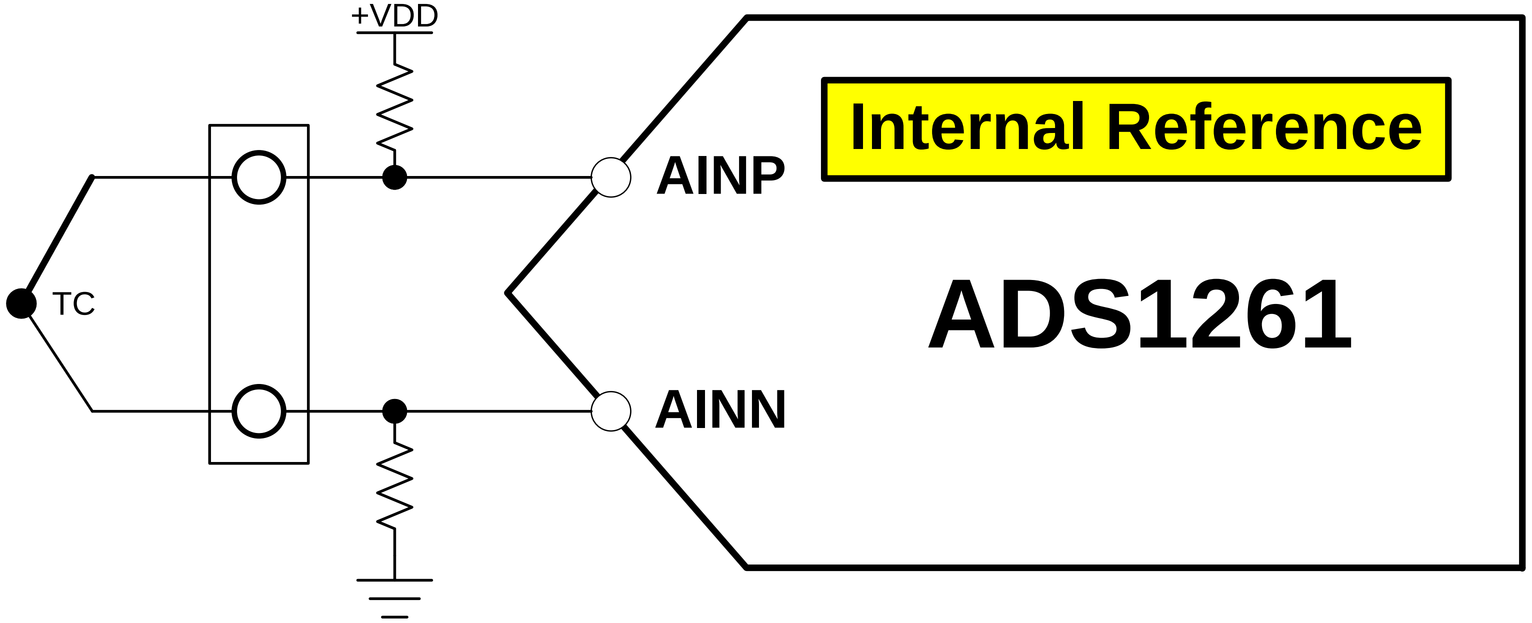
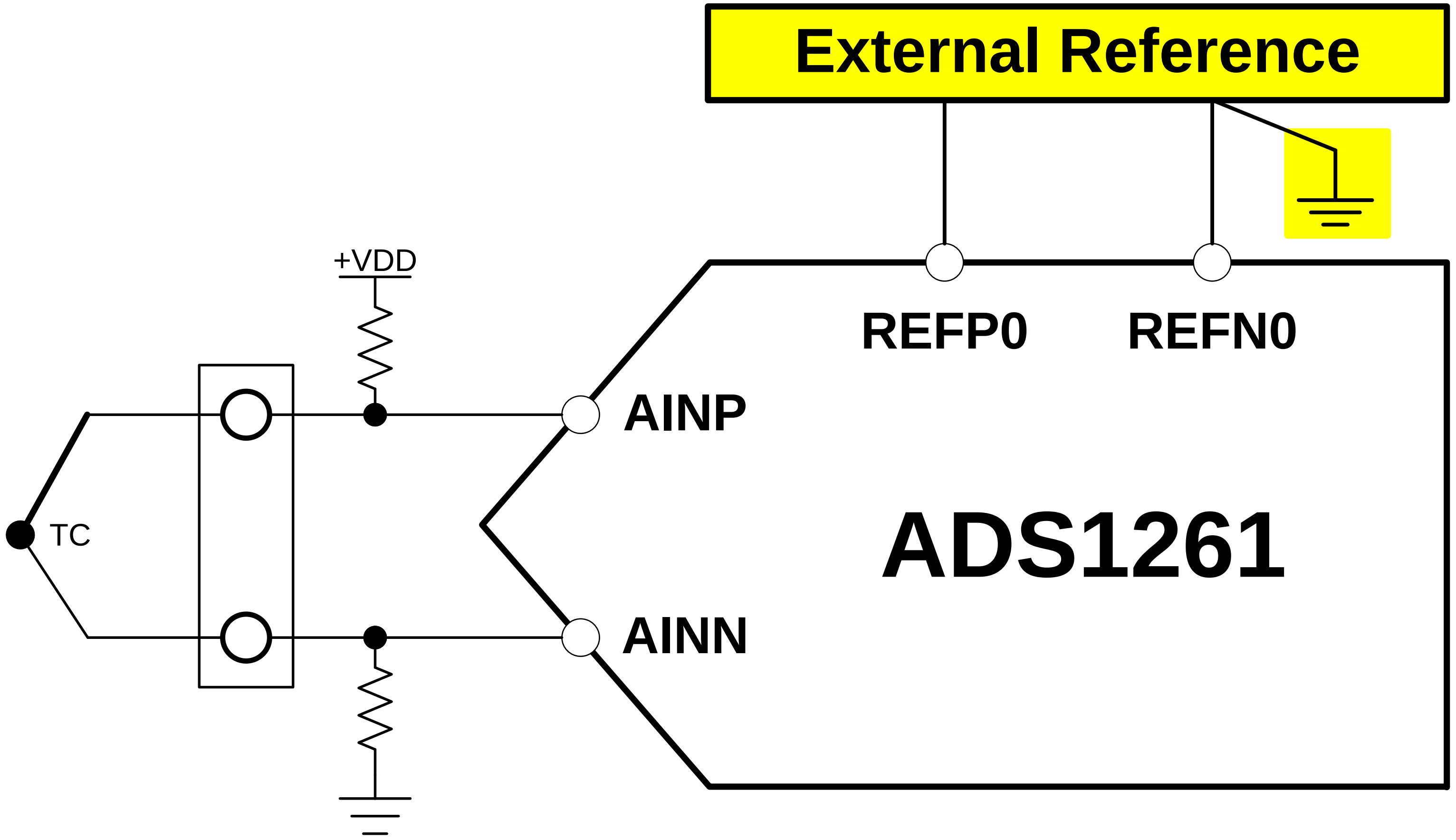
Advantages
• Lowest reference noise & drift • Minimal PCB area required • Low cost
Disadvantages
• Only possible for certain applications (where sensor excitation is necessary)

Reference configuration – internal



Advantages
• Reduces PCB area + power consumption & cost • Suitable for many applications
Disadvantages
• Higher (relative) noise • Higher (relative) drift

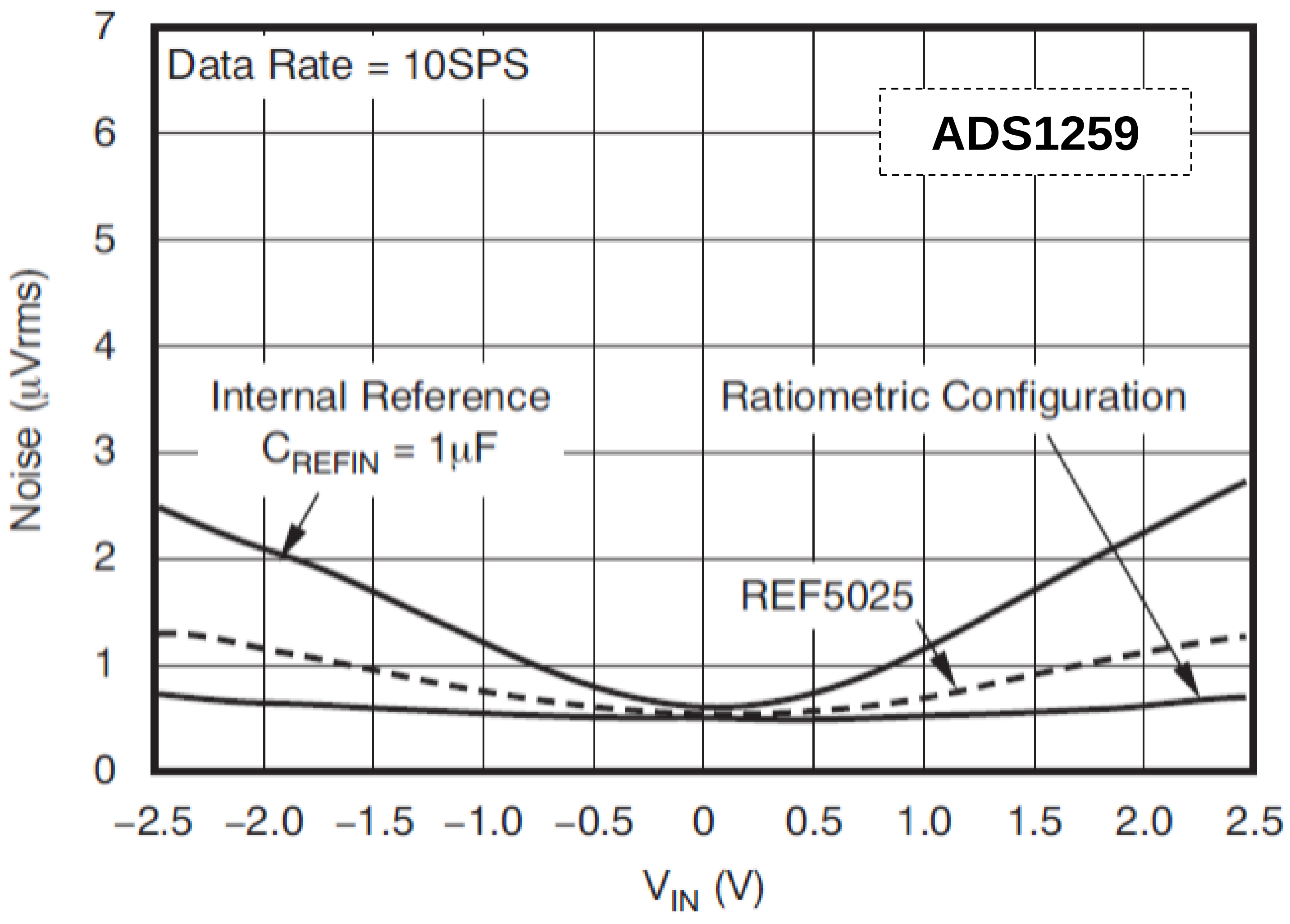
Reference configuration – external



Advantages
• Lower reference noise • Lower reference drift

Disadvantages
• Generally higher power • Added cost & board space • REF & ADC noise are uncorrelated

Total noise for different configurations



Configuration	Noise, RTI (μV_{RMS})	Noise increase
ADC noise only	0.5	-
ADC + internal VREF	2.5	5x
ADC + REF5025	1.25	2.5x
ADC + ratiometric	0.7	1.4x

Thanks for your time!
Please try the quiz.

Quiz: Reducing reference noise in ADC systems

1. (T/F) A ratiometric system has a noise advantage over an absolute voltage reference system?
   a. True
   b. False
2. (T/F) A thermocouple is an example of a sensor that would work well as a ratiometric system?
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4. Why would you use an external reference over an integrated reference?
   a. Often, external voltage references have better drift and noise specifications than integrated references
   b. Some ADCs do not offer an internal integrated voltage reference
   c. When using the external reference, one reference may be used for an entire system consisting of multiple ADCs
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Thanks for your time!

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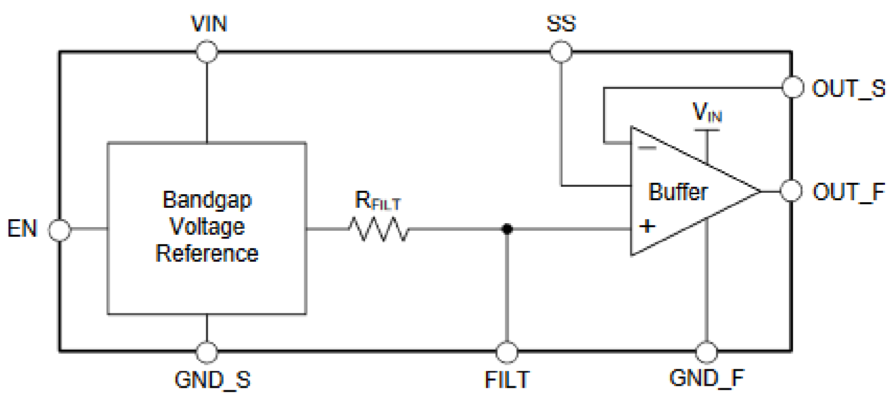
TEXAS INSTRUMENTS

Hello, and welcome to the TI Precision Lab module discussing reference noise reduction methods for high precision ADC systems. In the previous Precision Labs module on how reference noise affects ADC performance, we covered topics including how reference noise enters your signal chain and how it's characterized by an ADC, the reference's impact on system noise, and an analysis of how voltage references change your system's dynamic range.

This module will expand upon that knowledge by discussing methods to minimize reference noise as well as how reference noise affects lower and higher resolution ADCs differently.

Minimizing reference noise – lower-noise VREF

REF6025



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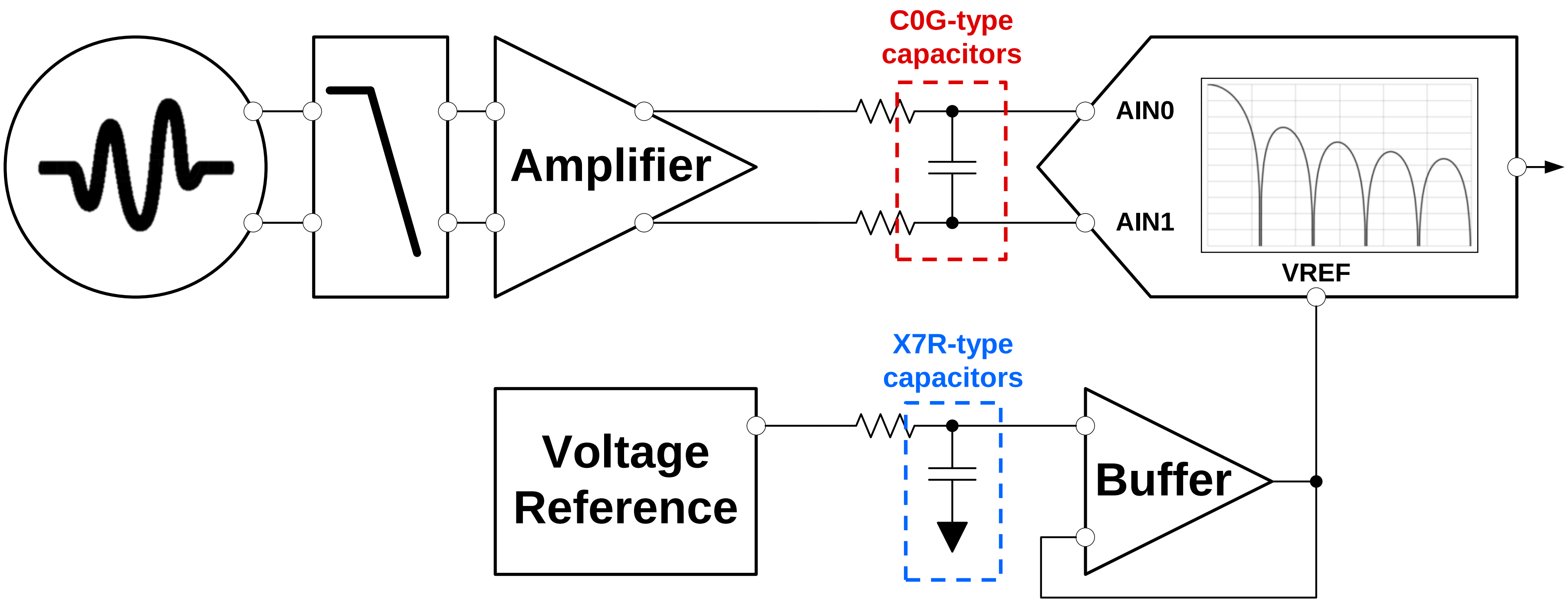
Low frequency noise	0.1 Hz ≤ f ≤ 10 Hz		3		$\mu V_{PP}/V$

One simple way to reduce reference noise is to use a low-noise reference.

Shown here is the functional block diagram and noise table for the REF6025, the voltage reference used in the previous Precision Labs module on reference noise. When choosing a reference, keep in mind the effective noise bandwidth of the reference path, along with the digital filter cutoff if applicable, dictates how much low frequency versus broadband noise you can expect. Different voltage references will have different specs, so just choosing a reference with minimal low frequency noise may not help your higher bandwidth system, for example.

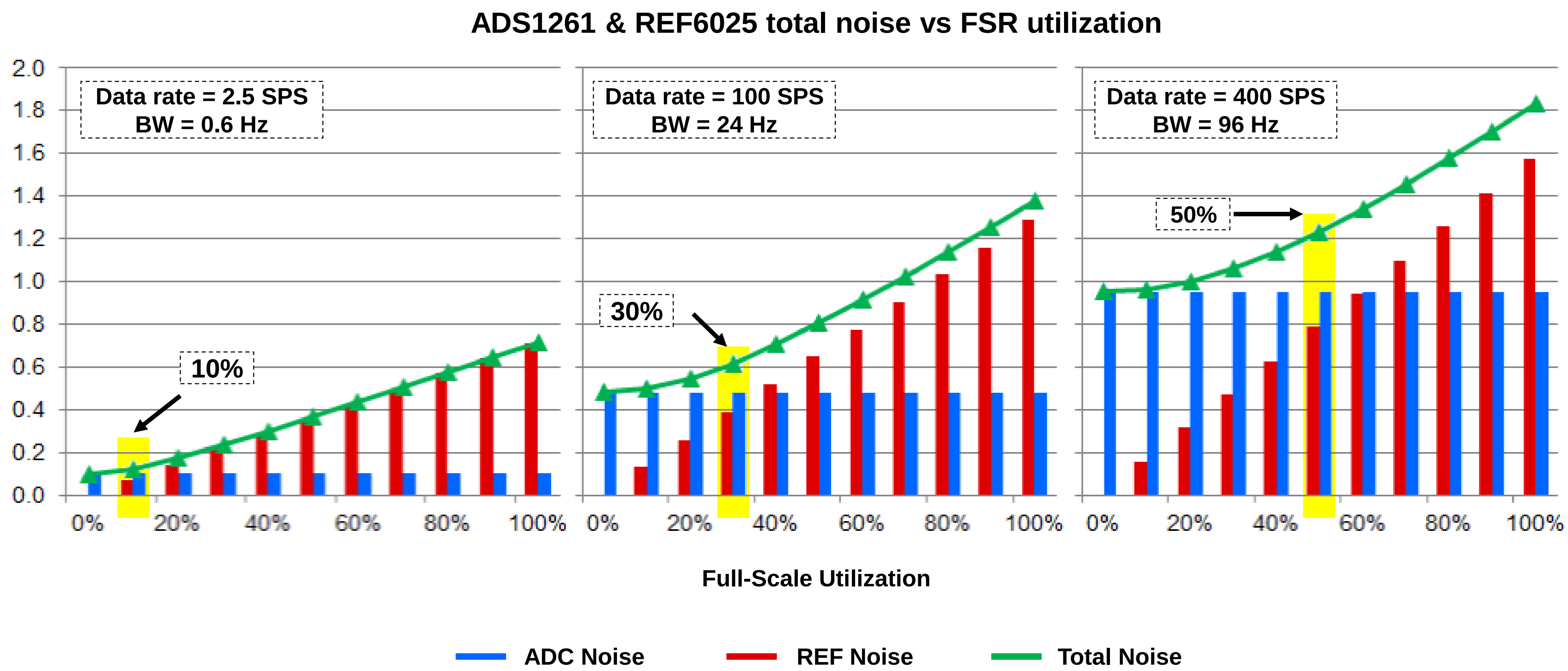
Minimizing reference noise – analog filter BW



Another method to reduce the amount of reference noise passed into the system is to limit the overall bandwidth seen by the voltage reference.

Typically, the lowpass filter at the voltage reference output can have a very low cutoff frequency due to the voltage reference's virtually-constant DC output voltage. Therefore, reference filters may employ higher-capacitance, X7R-type capacitors, compared to the recommended C0G-type capacitors for input signal path filters. For each filter type, low-drift, low-impedance resistors less than 10 kilo ohms should be used. Larger impedances lead to increased thermal noise that may begin to dominate the signal chain noise.

Minimizing reference noise – digital filter BW



TEXAS INSTRUMENTS

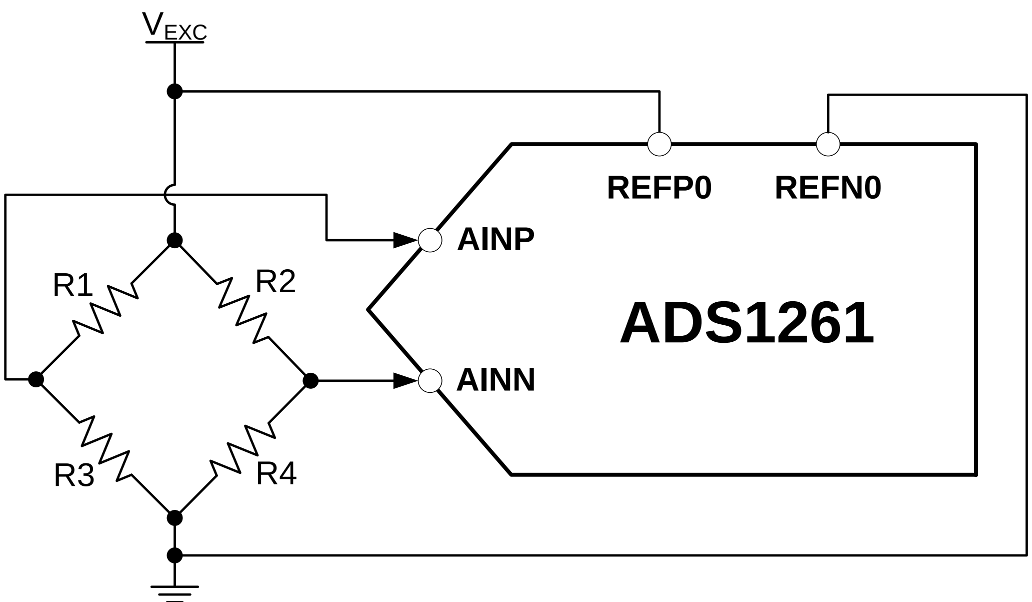
Another common way to reduce the system noise bandwidth for delta-sigma ADCs is to reduce the digital filter bandwidth by slowing down the output data rate.

Shown here are three full-scale utilization plots at different bandwidths using the ADS1261, the 24-bit delta-sigma ADC used in the previous Precision Labs modules on reference noise. The reference used is the REF6025. The first plot shows a noise bandwidth of 0.6 Hertz at 2.5 samples per second, where the total noise is only 700 nanovolts RMS at full-scale. Compare that to the middle plot that shows the total noise approximately doubling to 1400 nanovolts RMS at full-scale for 24 hertz bandwidth at 100 samples per second. The last plot shows the noise performance when the ADC digital filter's bandwidth is 96 hertz, and has the highest total noise at full-scale.

You can also see that as the noise bandwidth increases from left to right, the total noise plot becomes linear at a higher full-scale utilization. This is equivalent to the point where your system dynamic range is maximized, and is generally the largest utilization factor where the ADC noise is still greater than the reference noise. So, reducing your ADC bandwidth reduces the total system noise, but you also reach the dynamic range limit at a much smaller input voltage

Ultimately, while these methods can mitigate reference noise for many applications, your system may have fixed parameters such as settling time or sensor-output voltage that make these techniques harder to employ. In these instances, you can also reduce the amount of reference noise passing into the system by choosing an appropriate reference configuration including ratiometric, internal, or external

Reference configuration – ratiometric



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Advantages

- Lowest reference noise & drift
- Minimal PCB area required
- Low cost

Disadvantages

- Only possible for certain applications (where sensor excitation is necessary)

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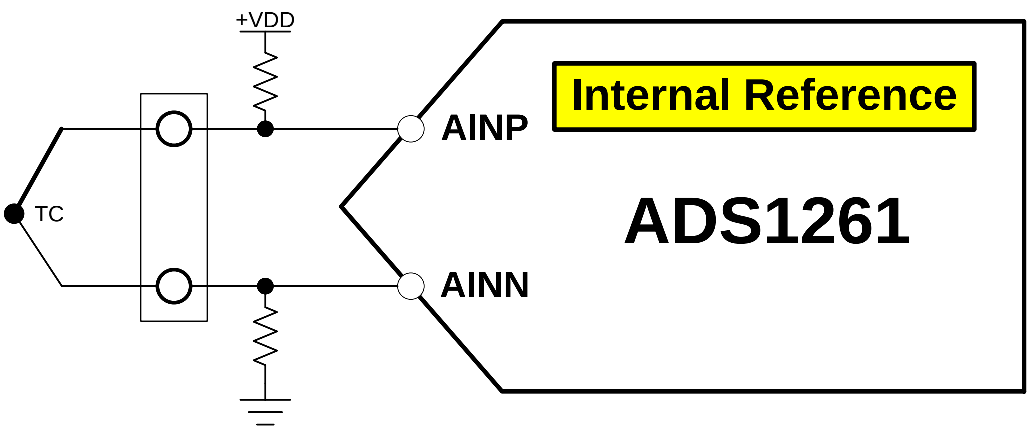
Where sensor excitation is necessary, such as measuring resistive bridges or resistance temperature detectors (RTDs), use a ratiometric configuration. A ratiometric reference configuration uses the same excitation source for the analog input and the reference voltage, as illustrated by this resistive bridge measurement.

Since both the input and reference share an excitation source, VEXC, any noise or drift in the excitation source affects the measurement and the reference equally. To verify this is true, the formulas in the bottom left show that the ADC's output code is proportional to the input signal divided by the excitation voltage. Moreover, the ADC's input voltage, VIN, is the excitation voltage attenuated by a resistor divider. When you combine these results, the final output code equation shows that the result is independent of the excitation voltage, which is the desired result. Using a ratiometric reference configuration enabled noise performance that is much closer to the shorted-input case. In general, this configuration yields the lowest amount of total noise compared to the other two configurations.

The main disadvantage of the ratiometric reference is that it can only be used for applications where sensor excitation is necessary. As a result, if the system doesn't require sensor excitation, you must choose one of the other two reference configuration options.

Reference configuration – internal



Advantages

- Reduces PCB area + power consumption & cost
- Suitable for many applications

Disadvantages

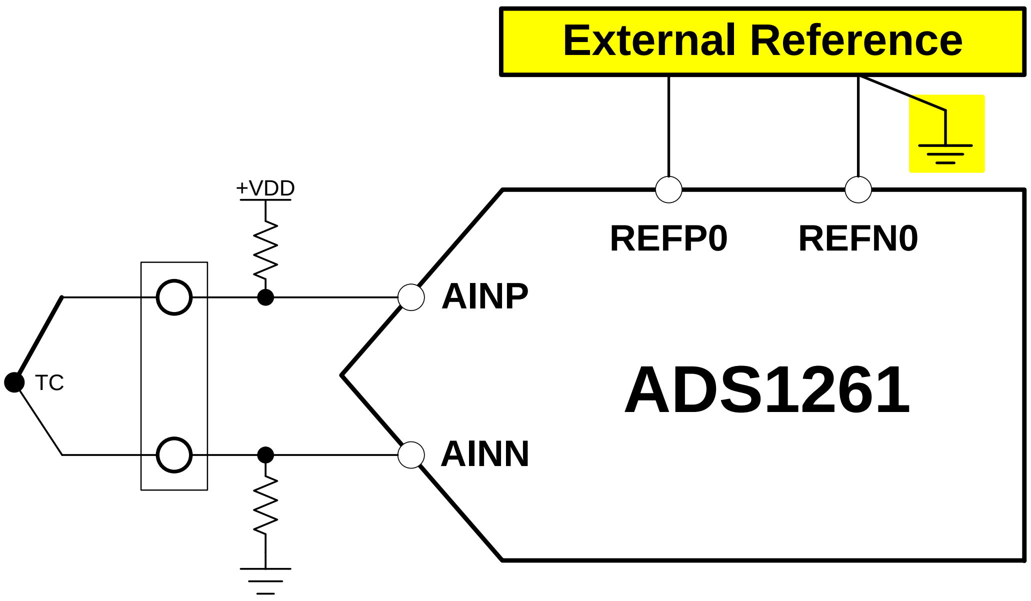
- Higher (relative) noise
- Higher (relative) drift

As an example, the system shown here is measuring a thermocouple. Thermocouples do not require external excitation to operate, which means you cannot use a ratiometric reference configuration if you needed to measure a thermocouple. Instead, many ADCs integrate a precision voltage reference, including the ADS1261 that was used on the previous slide. The ADS1261's voltage reference is generally suitable for many applications.

The integrated reference also eliminates the added cost, area and power consumed by an external reference. However, in general, internal references have higher noise and higher drift compared to precision external references, making them less suitable for some high-precision, high-accuracy systems

If the specifications of an integrated voltage reference are not sufficient for your system, you can choose an external reference source assuming your ADC includes external reference inputs

Reference configuration – external



Advantages

- Lower reference noise
- Lower reference drift

Disadvantages

- Generally higher power
- Added cost & board space
- REF & ADC noise are uncorrelated

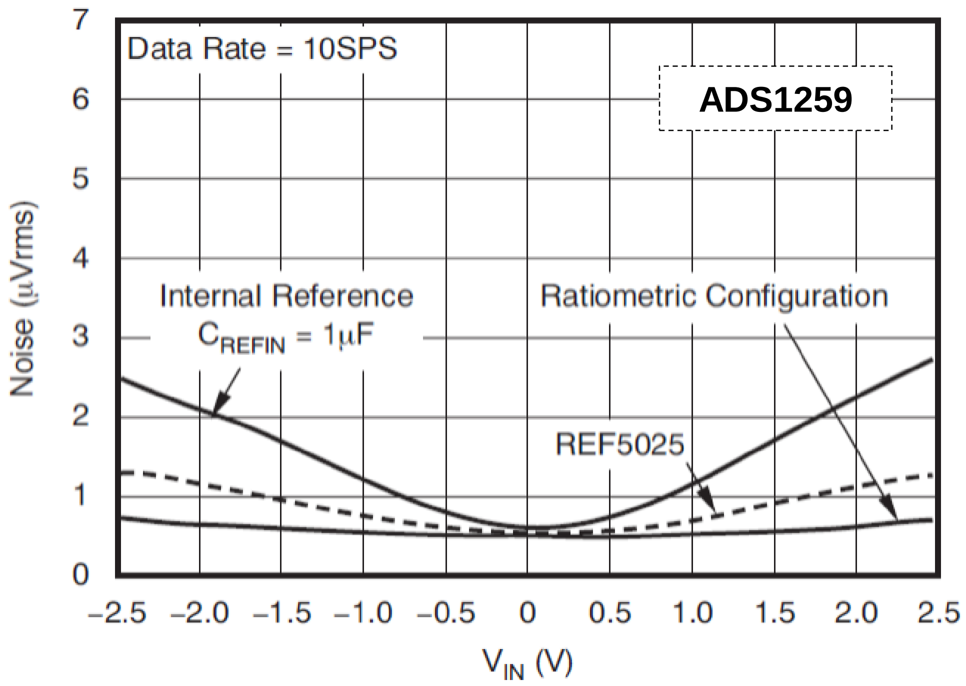
As shown, the ADS1261 also include differential reference inputs to accommodate external reference sources. External references generally benefit from lower noise and better drift parameters relative to integrated references.

This increased performance comes at the expense of higher power consumption, additional cost and increased PCB area. Also, since the ADC and voltage reference do not share the same die, their temperature drift specifications may no longer be correlated as is the case with an integrated reference. Therefore, the ADC and reference can drift independently and in opposite directions, causing greater inaccuracy. To avoid this issue, ensure that both devices are connected to a good thermally-conductive ground plane.

A helpful hint when connecting an ADC to an external reference source is to route the ADC's negative external reference input back to the ground pin of the external reference instead of connecting it directly to the PCB's ground plane. This makes a "star" ground connection that helps avoid ground plane noise pickup on the negative reference input and maintains precision measurement results.

The next slide quantifies these results by looking at the noise performance for each configuration using the same ADC.

Total noise for different configurations



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This plot taken directly from the ADS1259 datasheet shows the relative reference noise plots for the different reference configurations: internal, external using the REF5025, and ratiometric.

This plot confirms the claims made throughout this presentation, which are summarized in the table on the right. Using the internal reference increases the total system noise by a factor of five compared to the baseline ADC noise only, while the external reference increases the total noise by a factor of 2.5. Comparatively, the ratiometric configuration only increases the total noise by 40% at full-scale. This configuration allows you to use the entire full-scale range of the ADS1259 without increasing total noise by a significant amount, resulting in the best overall system noise performance.

In all of these configurations however, it is important to remember that reference noise has such a noticeable effect on system noise because higher-resolution ADCs are being used. These 24-bit converters already offer low noise performance, making the reference noise relatively more apparent to the system. If your system was using lower resolution ADCs, the reference configuration may be less critical for your system. This topic is discussed in more detail in the previous Precision Labs module that covers how reference noise affects signal chain performance.

Thanks for your time! Please try the quiz.

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

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