

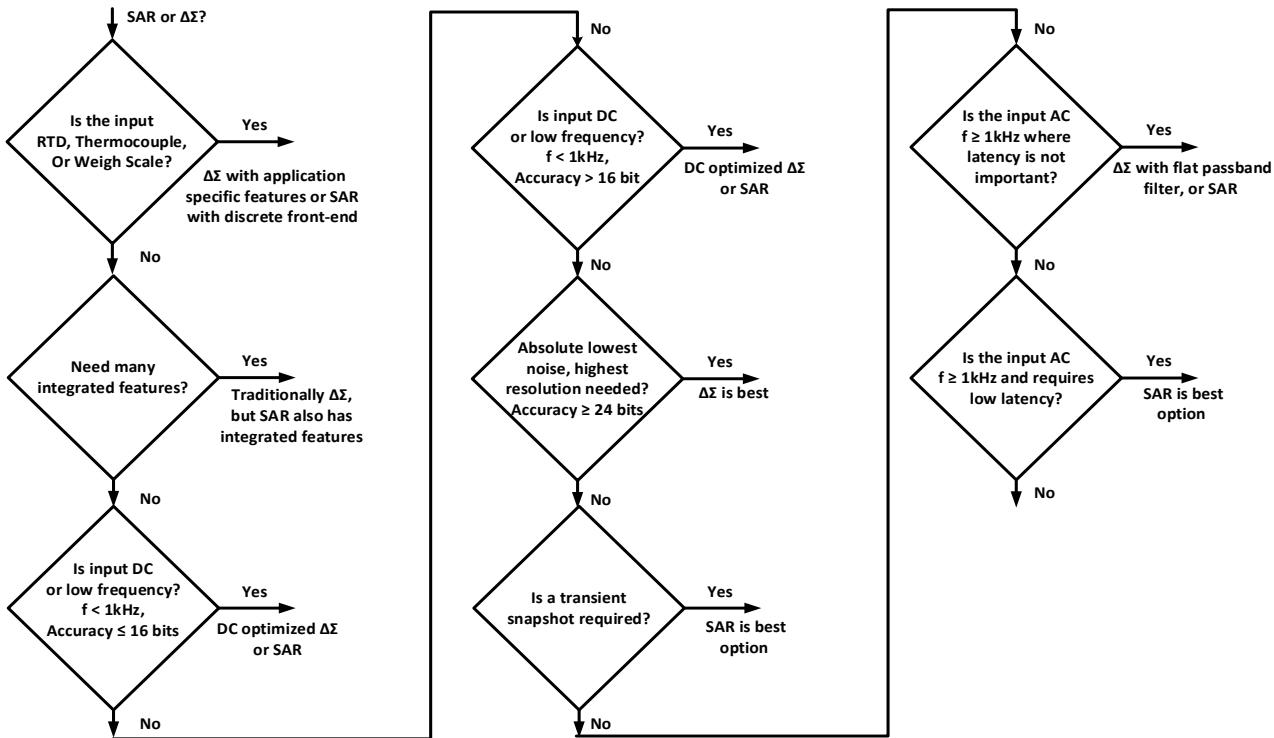
Choosing SAR or Delta-Sigma

TI Precision Labs – ADCs

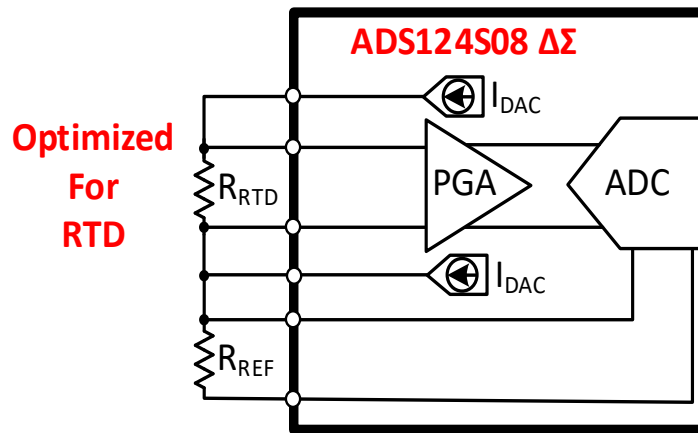
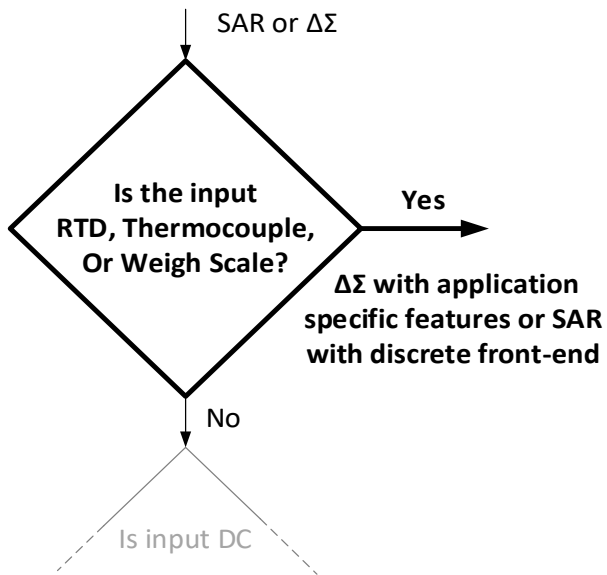
Created by Art Kay and Ryan Andrews

Presented by Ryan Andrews

Choosing SAR vs. delta-sigma decision tree



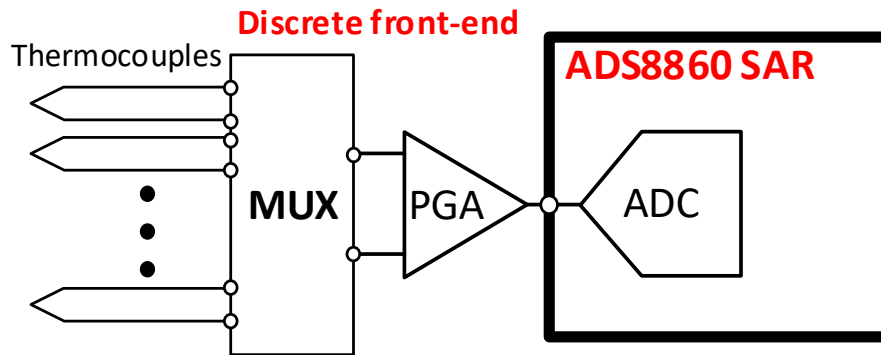
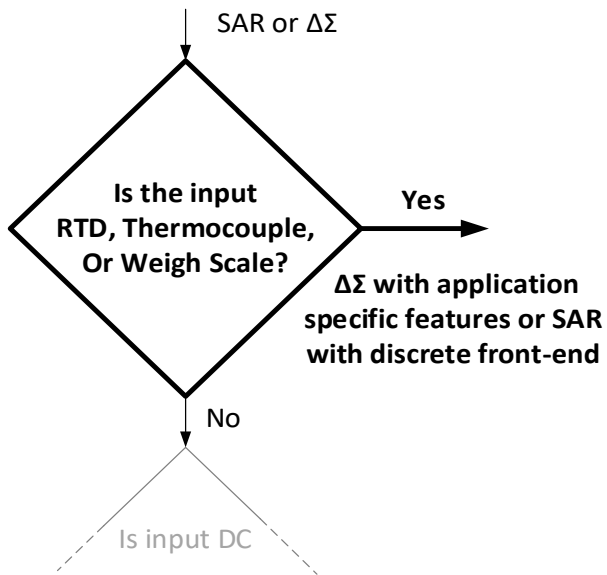
Sensor specific input? delta-sigma option



$\Delta\Sigma$ Option

- Preferred solution
- Application specific integrated features (current sources, gain stage, open sensor detection)
- Resolution (16 to 32 bits)
- Typically lower sampling rate than SAR

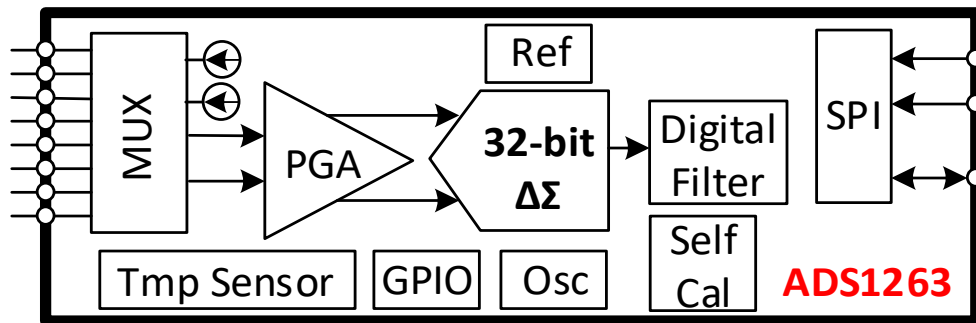
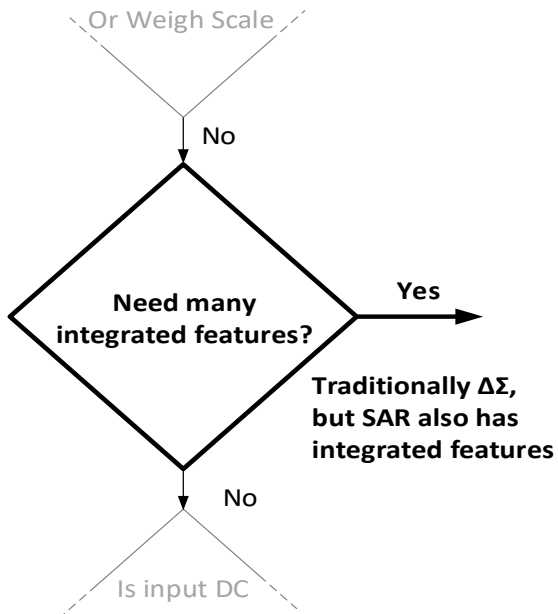
Sensor specific input? SAR option



SAR Option

- Usually requires discrete front-end
- Lower resolution (12 to 16 bits)
- Faster mux scan rate for sensors
- May have lower cost for low-end system
- Infrequently used for these applications

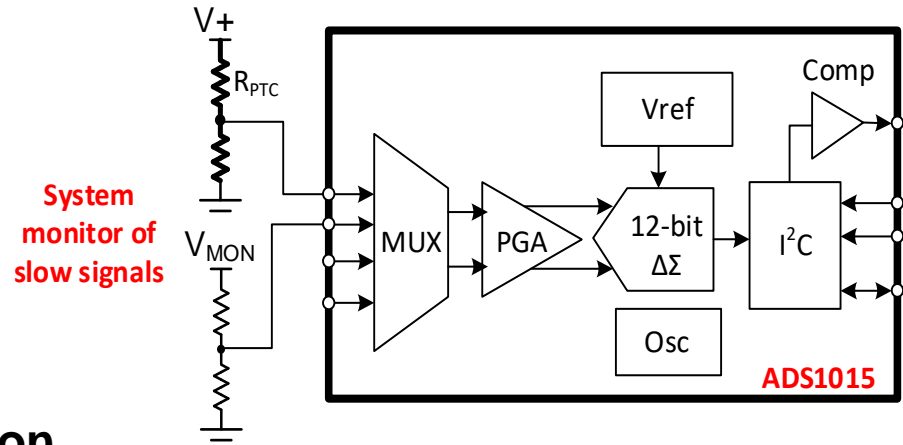
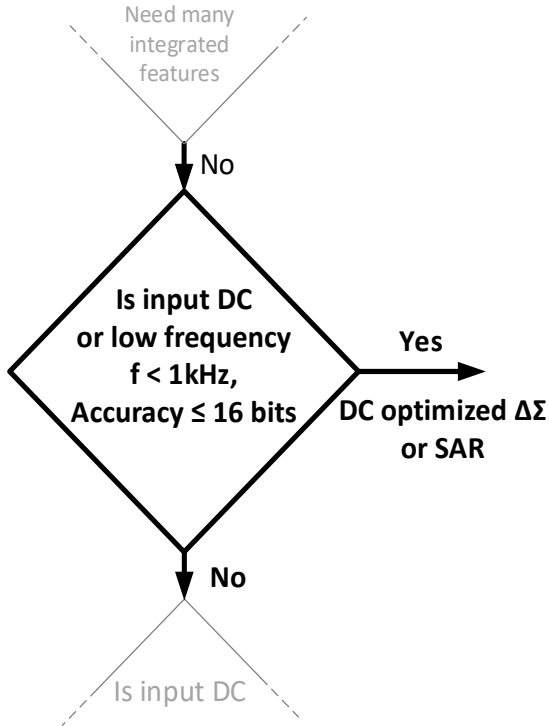
Are integrated features of key importance?



Integrated Features

- $\Delta\Sigma$ often has strong integration, but SAR also can include features
- Examples include current sources, reference, digital filters, threshold detects, PGA, temperature sensors, self-calibration, multiplexer, oscillators, RMS calculation, CRC calculation

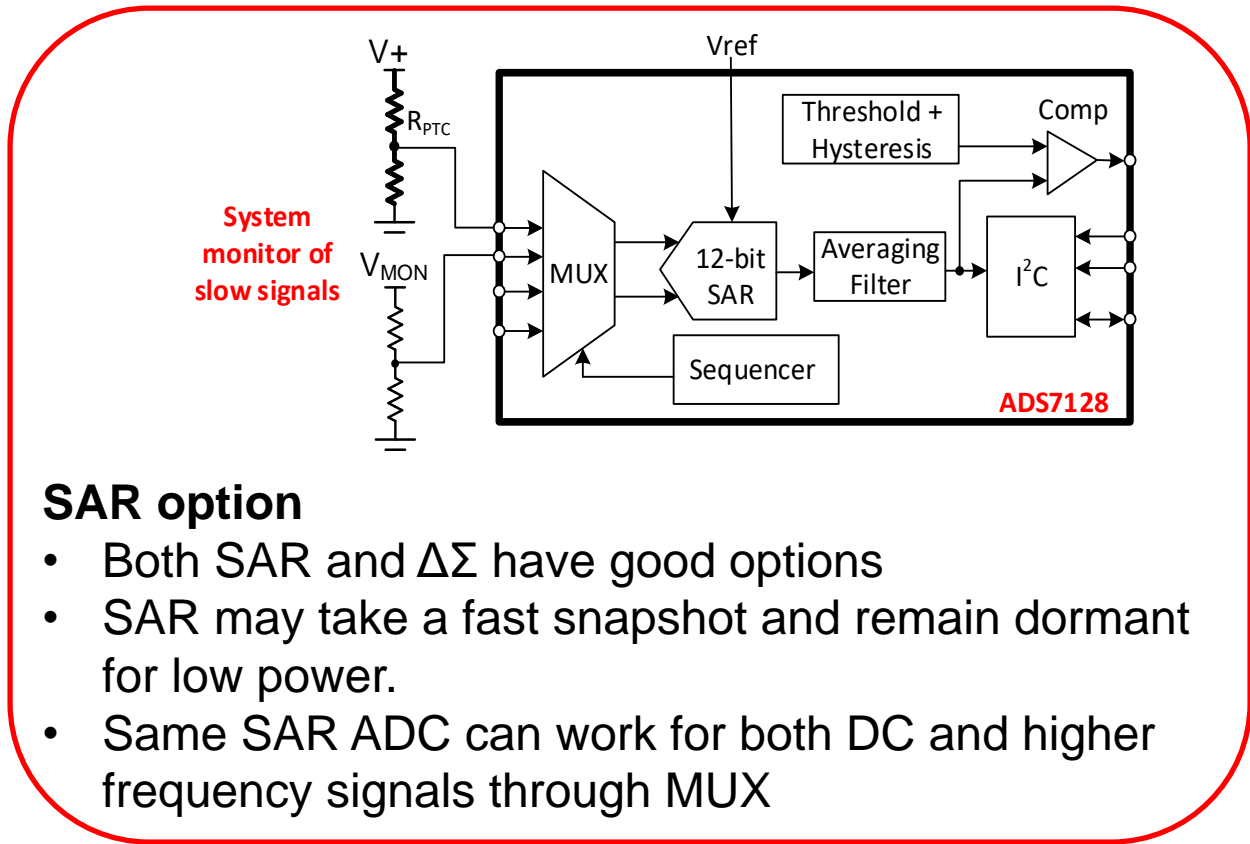
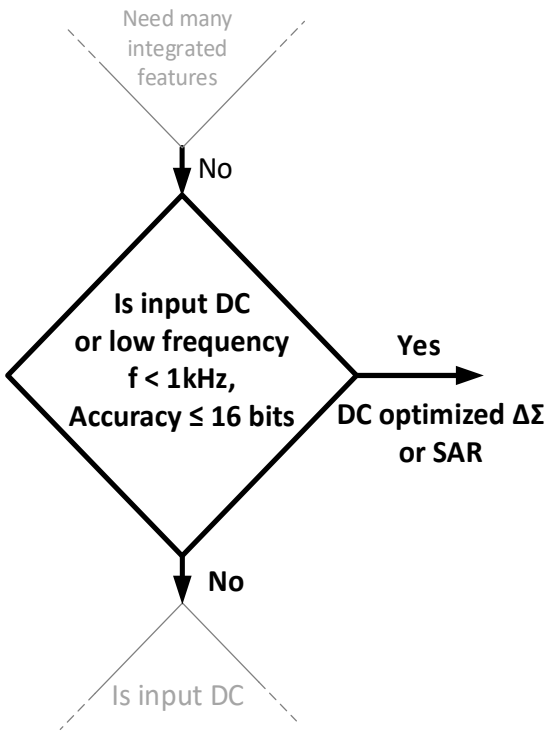
DC, accuracy ≤ 16 bits: delta-sigma option



$\Delta\Sigma$ Option

- Both SAR and $\Delta\Sigma$ have good options
- $\Delta\Sigma$ higher resolution (16 bits) than comparable SAR
- $\Delta\Sigma$ lower sampling rate (kSPS) than comparable SAR
- Small size available for both
- Single-cycle settling for multiplexed systems

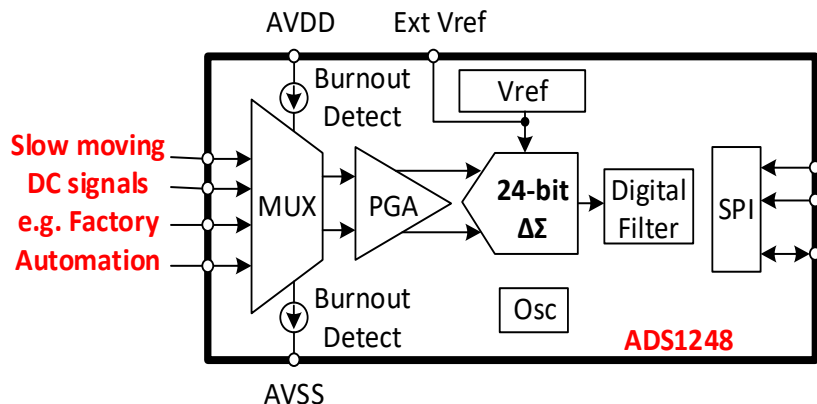
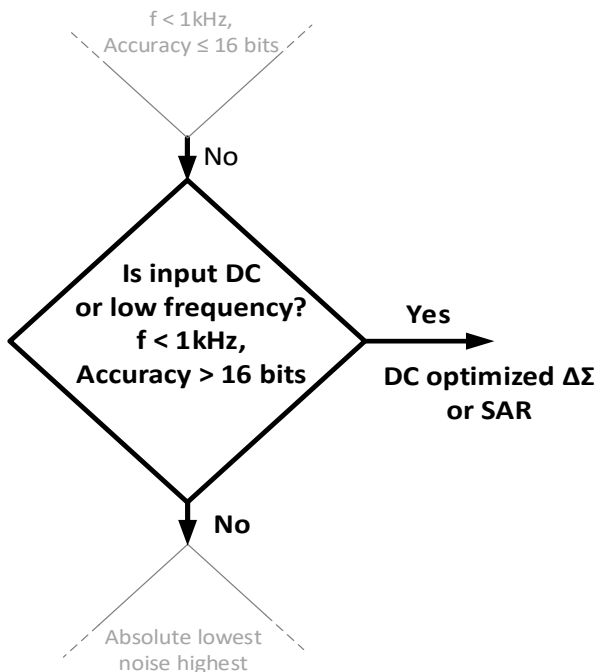
DC, accuracy ≤ 16 bits: SAR option



SAR option

- Both SAR and $\Delta\Sigma$ have good options
- SAR may take a fast snapshot and remain dormant for low power.
- Same SAR ADC can work for both DC and higher frequency signals through MUX

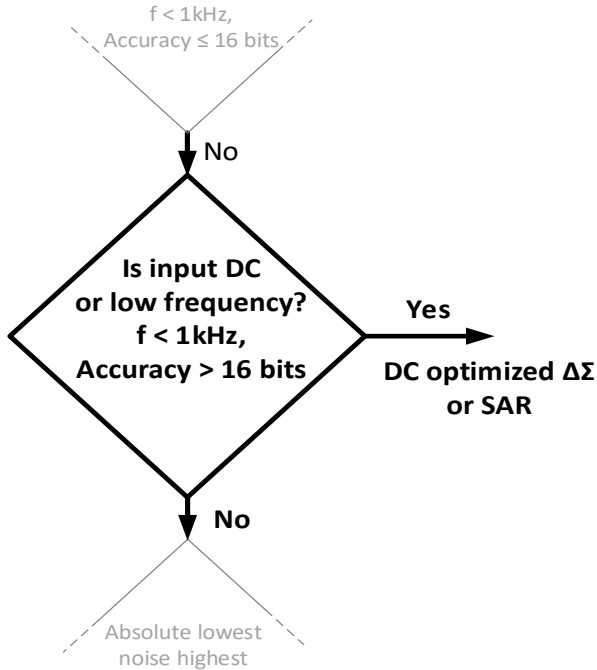
DC, accuracy > 16 bits: delta-sigma option



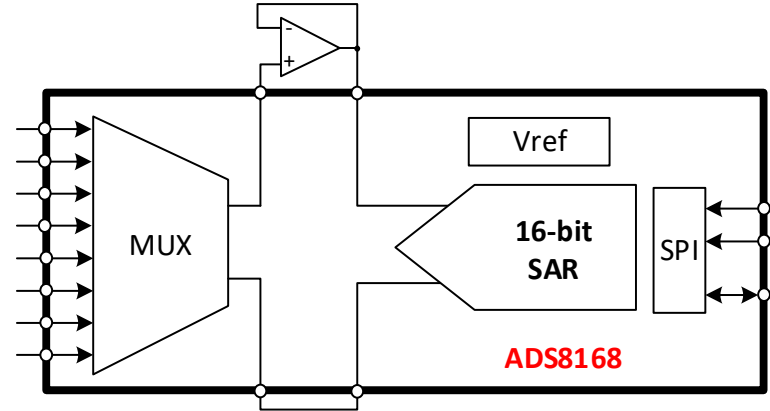
$\Delta\Sigma$ is the best option for DC, high precision

- Both SAR and $\Delta\Sigma$ have options
- $\Delta\Sigma$ typically has lowest overall noise
- $\Delta\Sigma$ may have integrated 50/60Hz filter noise rejection
- $\Delta\Sigma$ typically does not require external amplifier
- $\Delta\Sigma$ frequently has integrated PGA

DC, accuracy > 16 bits: SAR Option



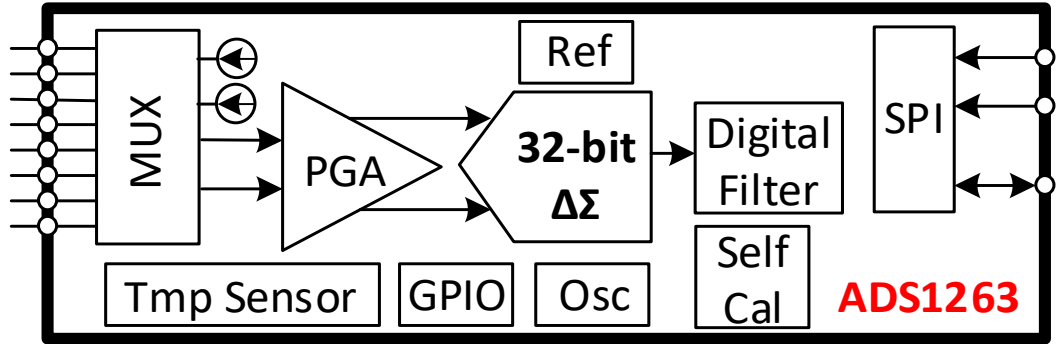
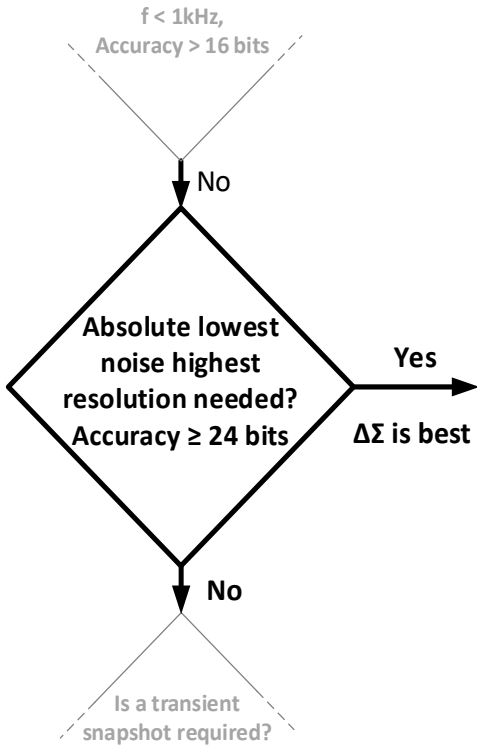
Slow moving
DC signals
e.g. Factory
Automation



High resolution SAR for some DC applications

- Both SAR and $\Delta\Sigma$ have options (normally $\Delta\Sigma$)
- One channel may be used for higher frequency
- SAR may take a fast snapshot and remain dormant
- May require external amplifiers
- SAR resolution up to 20 bits available

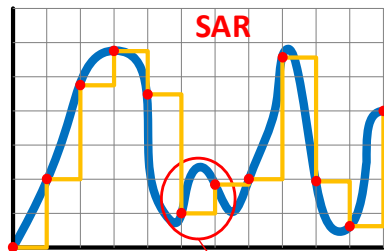
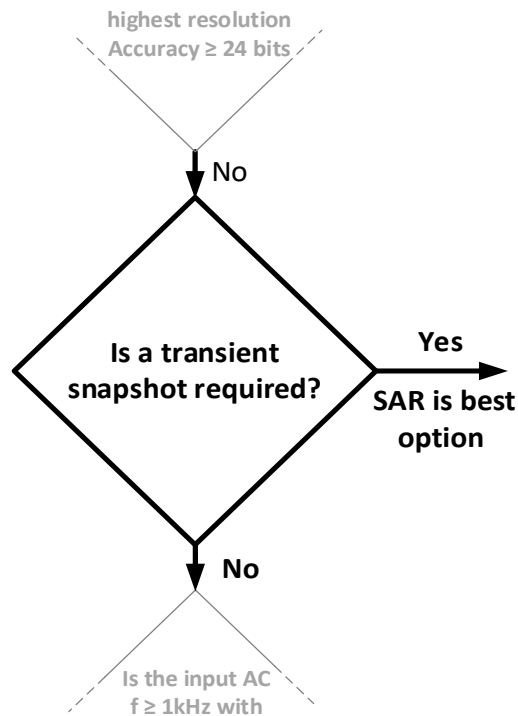
DC, accuracy ≥ 24 bits, ultra low-noise: delta-sigma



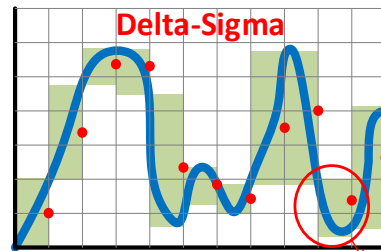
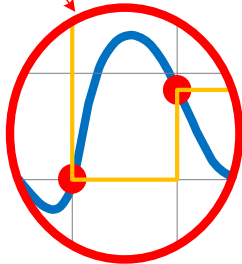
High resolution SAR for some DC applications

- $\Delta\Sigma$ is the best choice for highest resolution
- Up to 32 bits available
- Total integrated noise is $7 \text{ nV}_{\text{RMS}}$!
- Digital filter for lowest noise and 50/60 Hz rejection

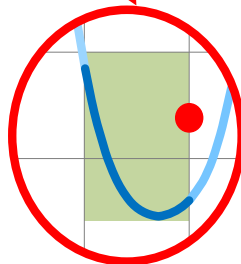
Is a transient snapshot required?



SAR:
Red dot indicates the "snap-shot" captured



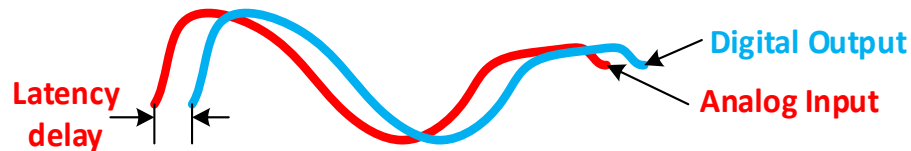
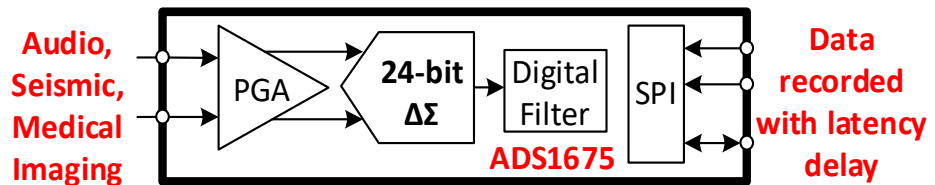
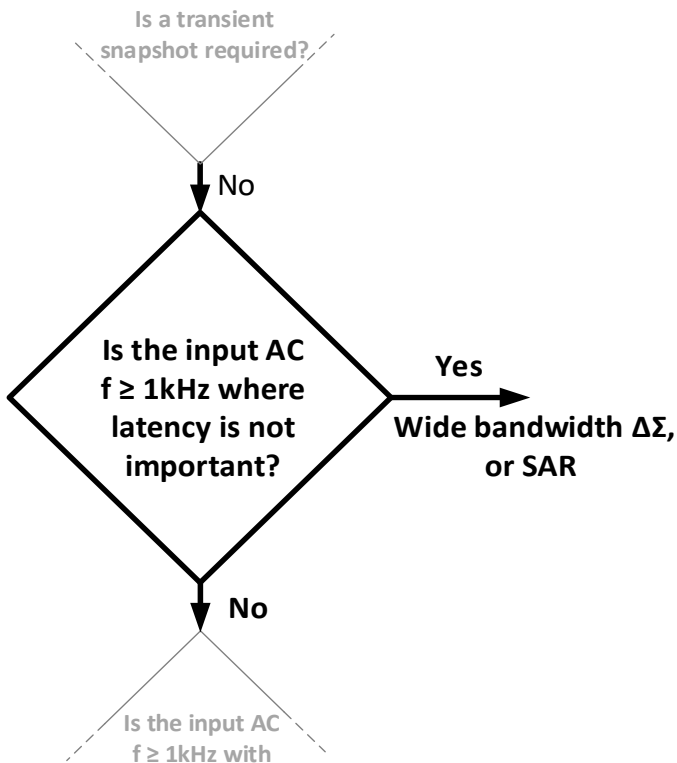
Delta-Sigma:
Red dot indicates the average of the signal in the green sampling interval



Different sampling approaches

- SAR uses sample-and-hold to take a snap shot of signal at an instant in time
- $\Delta\Sigma$ averages signal over a time interval

AC, latency not important



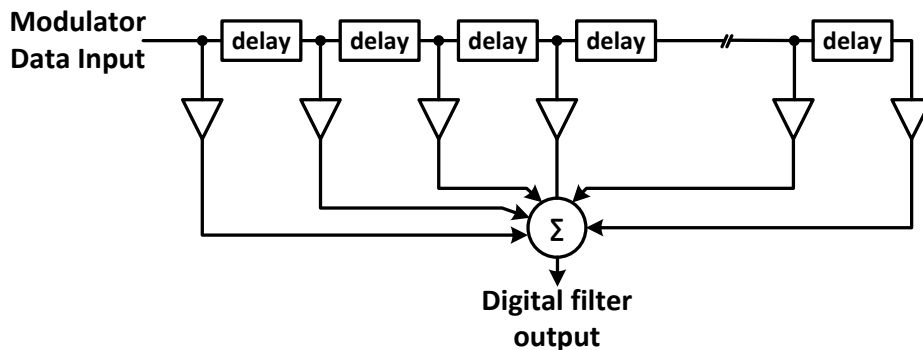
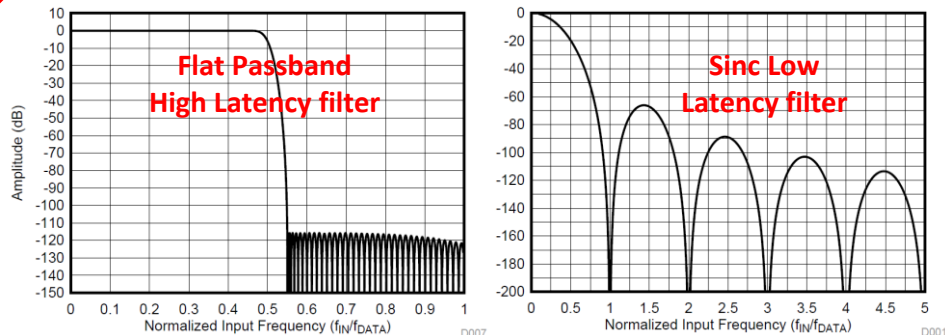
Both SAR and $\Delta\Sigma$ can work

- Used in applications where a delay between input and recorded data is not an issue
- The natural choice for highest resolution is $\Delta\Sigma$
- $\Delta\Sigma$ devices uses high latency flat passband digital filter

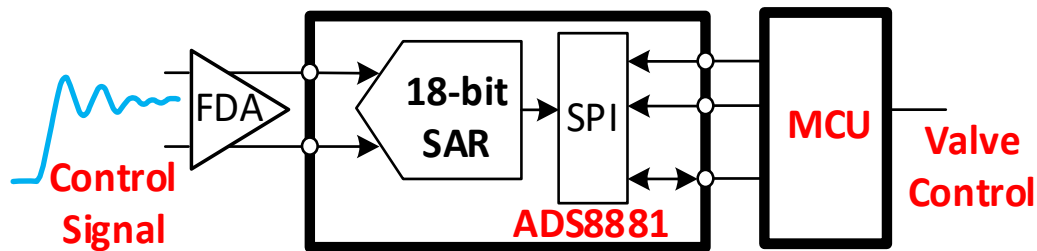
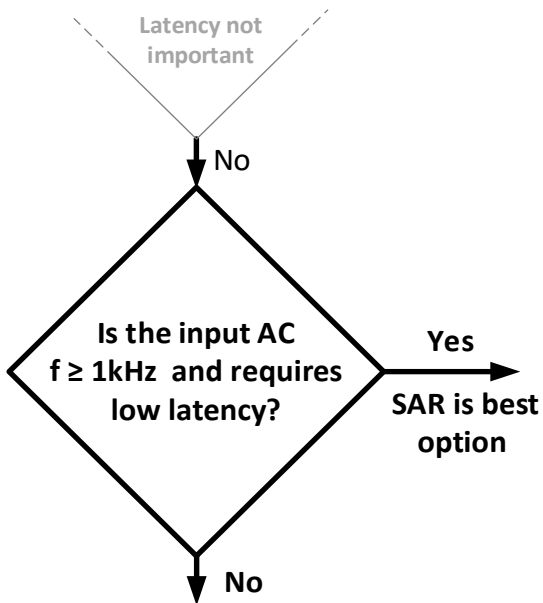
How do you know how much latency is in a delta-sigma?

$\Delta\Sigma$ Latency

- Flat Passband type filter
 - ✓ High latency (e.g. 50 cycles)
 - ✓ AC in passband not attenuated
 - ✓ Stopband steep attenuation
- Sinc type filter
 - ✓ Low latency (e.g. 1-3 cycles)
 - ✓ Passes DC but attenuates AC
 - ✓ Can be used for 50/60Hz rejection



AC, latency is important



SAR is best choice for low latency

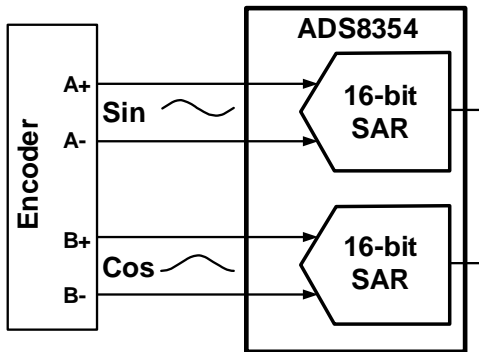
- AC or transient input that requires an immediate response (e.g. ≤ 1 cycle delay)
- Examples: control systems, safety relays, position sensors

Still not sure?...

Choosing between two equivalent options

- Solution size, or total power consumption
- Ease of use
 - Some SAR ADCs have simple configurations (No registers. Power-up and go.)
 - Delta-Sigma ADCs incorporate digital filters to simplify antialiasing design
- Are pin-for-pin upgrades available?
 - Device families offers options and future upgrade paths
- Integrated features (e.g. PGA, voltage reference, digital filters)
- External supporting circuitry required (e.g. driver amplifiers, voltage references, crystal oscillators)
- Key analog specifications: Noise, SNR, THD, linearity
 - SAR vs. Delta-Sigma is no longer the important comparison
- Performance is not always the key concern. Integrated ADCs in MCUs can offer greater convenience at lower cost.
 - SAR vs. Delta-Sigma topology selection is determined by the MCU

Summary: SAR vs. delta-sigma ADCs

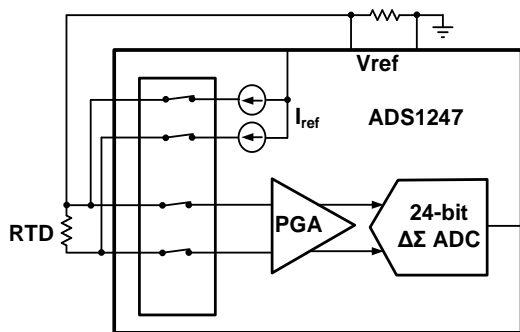


SAR

- Low latency matters
- Needed to capture transient snapshots

Example applications:

- Motor control
- Power quality measurement
- Safety relays
- Test and measurement (scope)
- Mechanical shock
- Control loop systems

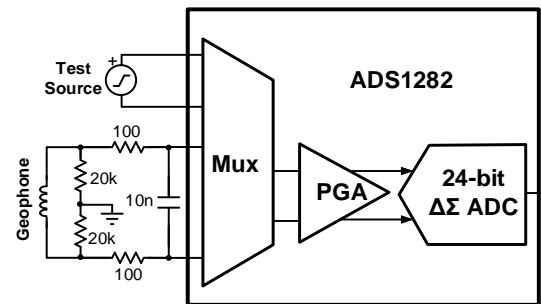


DC Optimized $\Delta\Sigma$

- Offset, drift, linearity, and noise
- Integrated features
- Sensor specific inputs

Example applications:

- RTD, thermocouple
- Weigh scale, pressure sensor
- Precision dc measurements



Wide Bandwidth $\Delta\Sigma$

- SNR, THD, SINAD
- Used when latency does not matter
- Selectable digital filter response

Example applications:

- Audio
- Imaging, ultrasound
- Seismic
- ECG, vibration analysis
- Test and measurement

**Thanks for your time!
Please try the quiz.**

Questions: Choosing between SAR & delta-sigma

1. What kind of ADC is best for measuring an RTD or thermocouple temperature sensor?
 - a. SAR
 - b. DC optimized delta-sigma
 - c. Wide bandwidth delta-sigma

2. (T/F) Wide bandwidth delta-sigma converters will always use a high-latency filter.
 - a. True
 - b. False

Questions: Choosing between SAR & delta-sigma

3. Which of the following is true?
 - a. SAR converters are used for low latency DC measurements
 - b. SAR converters integrate current sources and PGAs.
 - c. SAR converters take a snapshot of transient signals
 - d. SAR converters use a high-latency, integrated digital filter

4. (T/F) A wide bandwidth delta-sigma converter would be a good choice in cases where low-latency AC measurements are required. For example, a controls system.
 - a. True
 - b. False



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Choosing SAR or Delta-Sigma

TI Precision Labs – ADCs

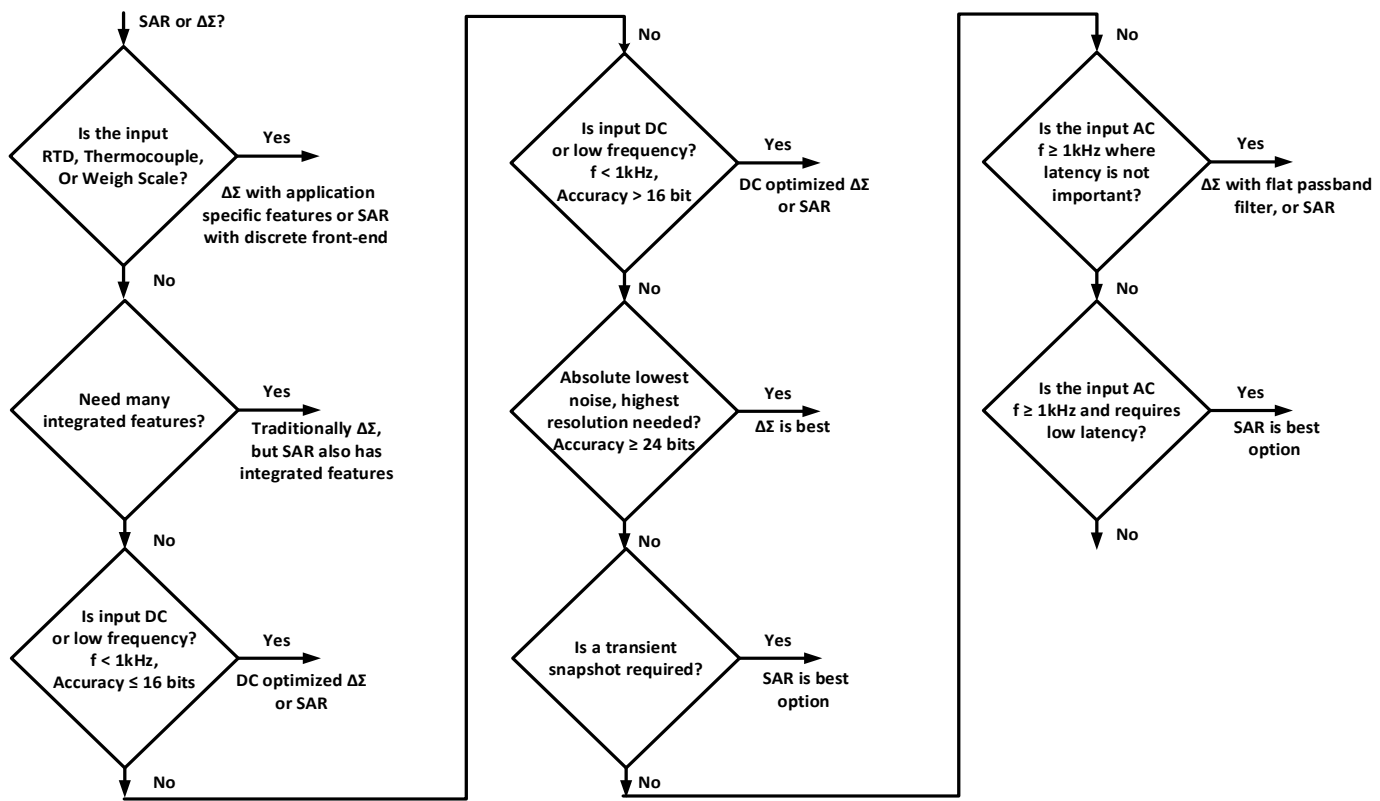
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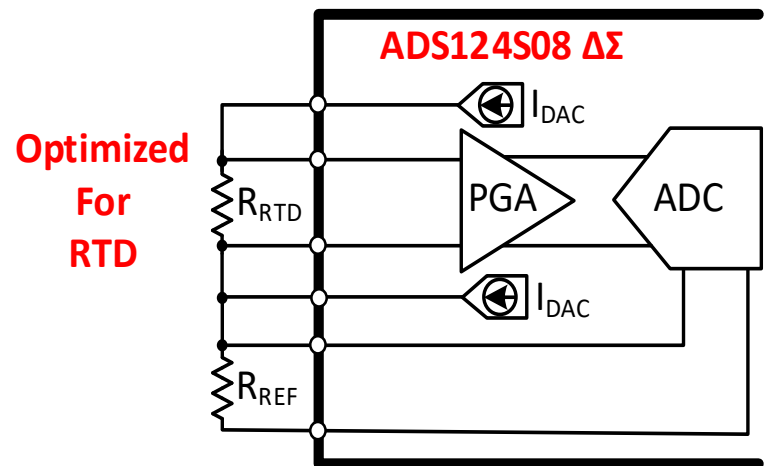
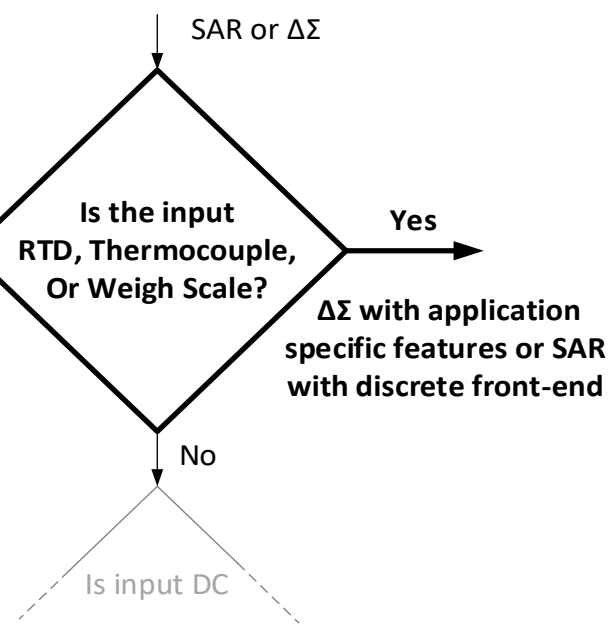
Hello, and welcome to the TI Precision Lab series that looks at the decision process for choosing either a SAR or delta-sigma converter. This video will cover a step-by-step decision tree to help find the best converter for your application. The concepts used in this decision process were reviewed in the previous videos. So let's get started!

Choosing SAR vs. delta-sigma decision tree



For reference, this is the entire decision tree that we will cover in this video. As we progress, we will step through each decision and provide supporting details and examples to clarify the choice we make.

Sensor specific input? delta-sigma option



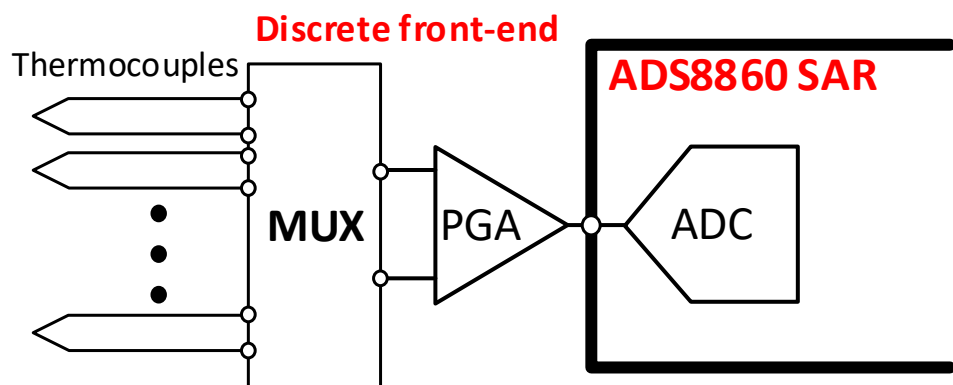
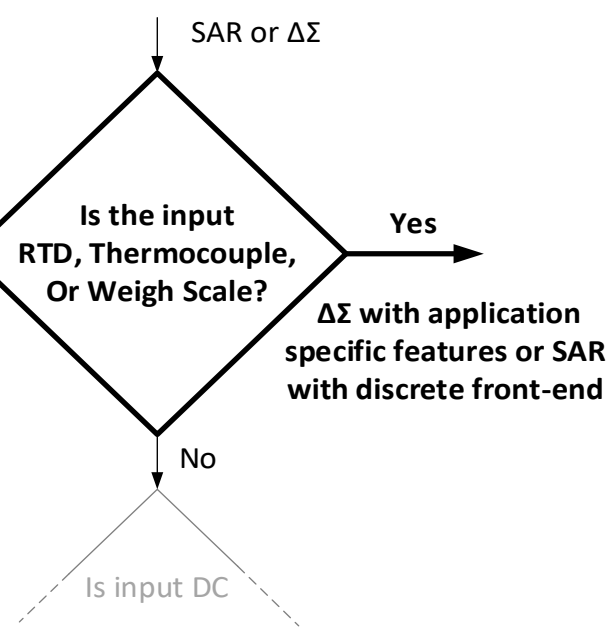
Optimized
For
RTD

$\Delta\Sigma$ Option

- Preferred solution
- Application specific integrated features (current sources, gain stage, open sensor detection)
- Resolution (16 to 32 bits)
- Typically lower sampling rate than SAR

The decision tree starts with sensor specific inputs. There are a number of delta-sigma converters specifically designed to measure a certain type of sensor. Examples include RTDs, thermocouples, and weigh scales. These sensor specific products normally have a wide range of integrated features that facilitate the measurement of a specific sensor. For example, an RTD solution will include precision excitation current sources. Thermocouples frequently have open sensor detection, and a local temperature sensor for cold junction compensation. Typically, these type of converter are optimized for DC signals and have high resolution. In most cases, this kind of application will be measured using a delta-sigma, but there may some exceptions.

Sensor specific input? SAR option

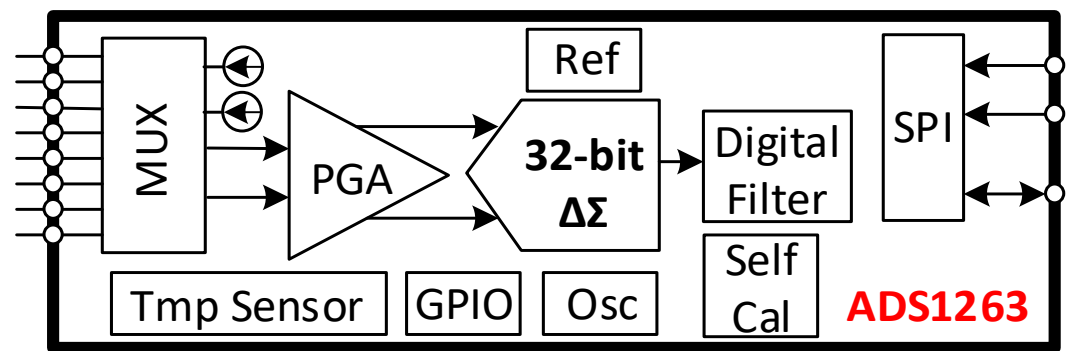
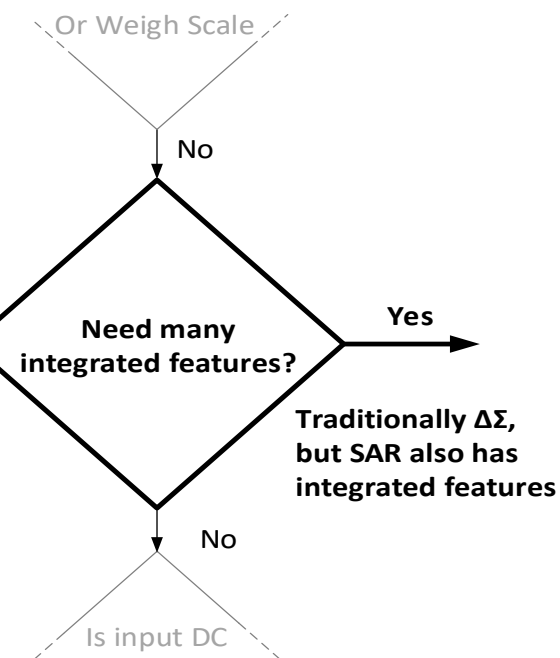


SAR Option

- Usually requires discrete front-end
- Lower resolution (12 to 16 bits)
- Faster mux scan rate for sensors
- May have lower cost for low-end system
- Infrequently used for these applications

The SAR may be used for measuring sensor outputs when a lower resolution system is sufficient and a fast scan rate is desired. This slide shows an example where multiple thermocouples are connected via a multiplexer to a discrete PGA and a SAR converter. Keep in mind that the multiplexer and PGA are a discrete front-end, and the delta-sigma option integrated these components. As mentioned previously, the delta-sigma is more common for low frequency type sensors, but there can always be exceptions based on cost or other criteria.

Are integrated features of key importance?

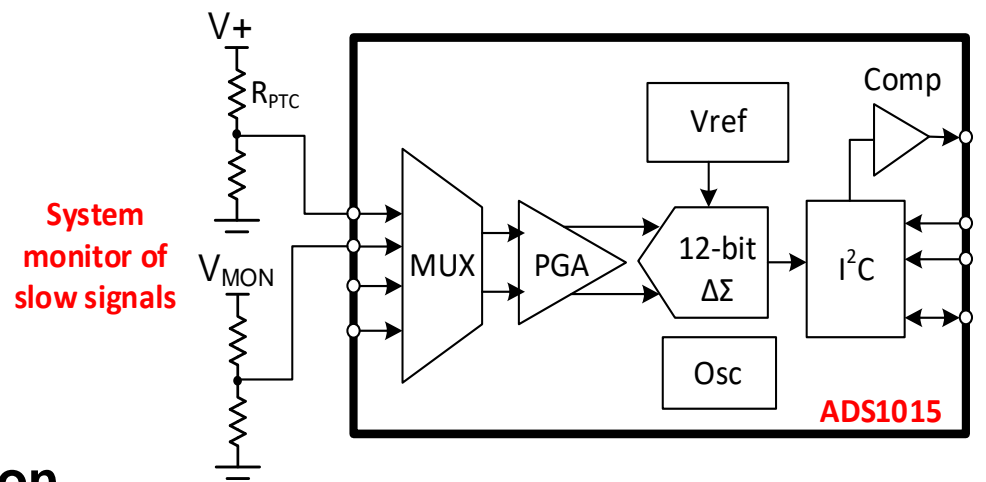
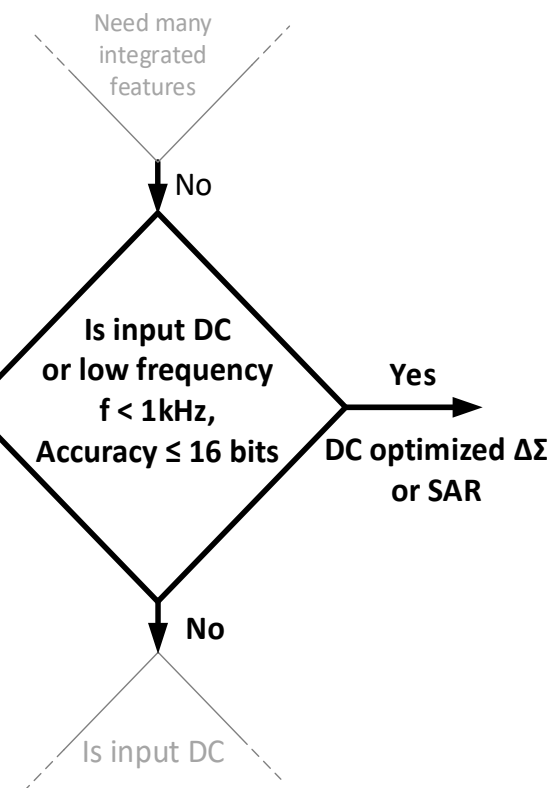


Integrated Features

- $\Delta\Sigma$ often has strong integration, but SAR also can include features
- Examples include current sources, reference, digital filters, threshold detects, PGA, temperature sensors, self-calibration, multiplexer, oscillators, RMS calculation, CRC calculation

In the previous decision, we saw that some delta-sigma converters include integrated features for sensor signal conditioning. However, this is not exclusive to sensor specific products. Many useful features may be integrated that are general purpose in nature. For example, some devices include filters, voltage references, threshold detectors, programmable gain amplifiers, oscillators, RMS and CRC calculations as well. Traditionally, delta-sigma converters tend to include more integrated features, but lately this is becoming common in SAR converters too.

DC, accuracy ≤ 16 bits: delta-sigma option

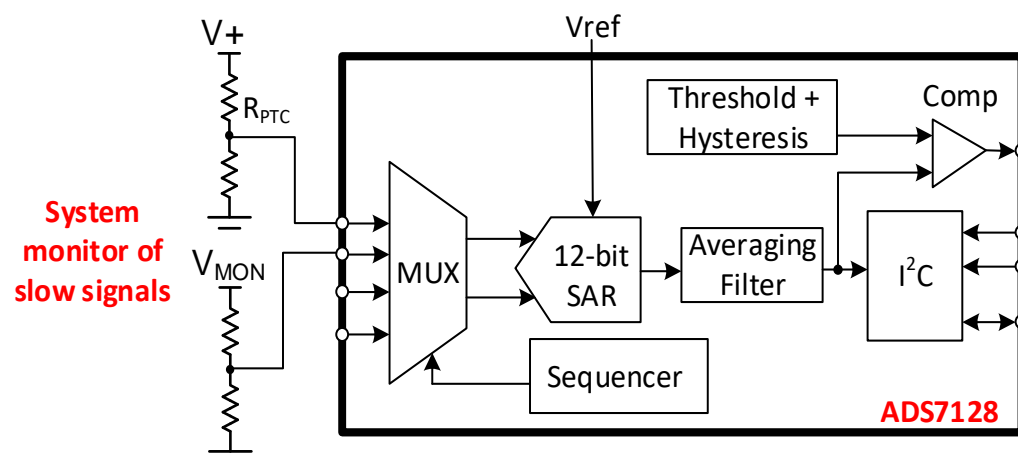
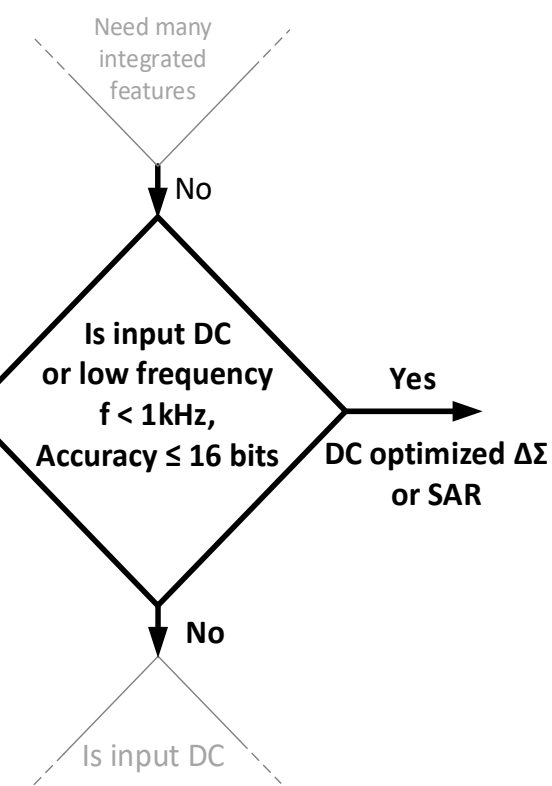


$\Delta\Sigma$ Option

- Both SAR and $\Delta\Sigma$ have good options
- $\Delta\Sigma$ higher resolution (16 bits) than comparable SAR
- $\Delta\Sigma$ lower sampling rate (kSPS) than comparable SAR
- Small size available for both
- Single-cycle settling for multiplexed systems

The next decision to consider is whether the application requires DC accuracy but low resolution. Is a SAR or delta-sigma better for measuring low frequency signals for converters with less than or equal to 16 bits? It turns out that in this case both types of converters have excellent options here. In this slide we focus on the delta-sigma option. This kind of delta-sigma would use a low latency digital filter to minimize noise. They also will frequently include an integrated multiplexer and PGA. Typically, this kind of converter is referred to as general purpose delta-sigma ADC. These devices can be found in very small packages and often will have a lower price point.

DC, accuracy ≤ 16 bits: SAR option

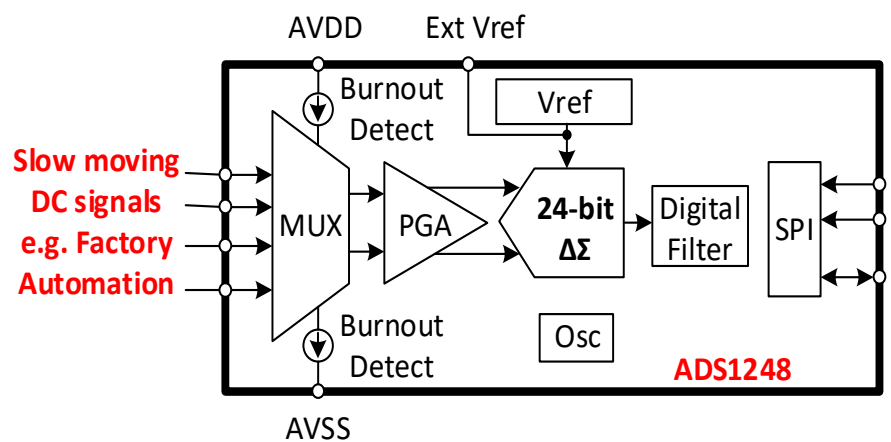
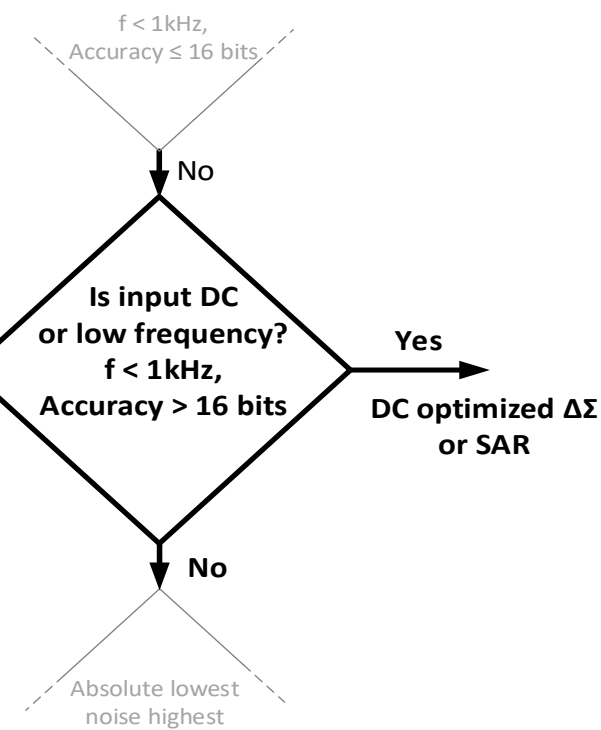


SAR option

- Both SAR and $\Delta\Sigma$ have good options
- SAR may take a fast snapshot and remain dormant for low power.
- Same SAR ADC can work for both DC and higher frequency signals through MUX

This slide shows the SAR option of the general purpose converter. One advantage of the SAR converter is that it may be used to take a fast snapshot of the DC input signals and then it enter a low power state. Also, there may be an application where most of the signals in the system are DC, but some signals require a faster sampling rate. In this case, the SAR may be the best option. If all the inputs are DC, than you can choose either solution based on cost, package size, or other specifications.

DC, accuracy > 16 bits: delta-sigma option

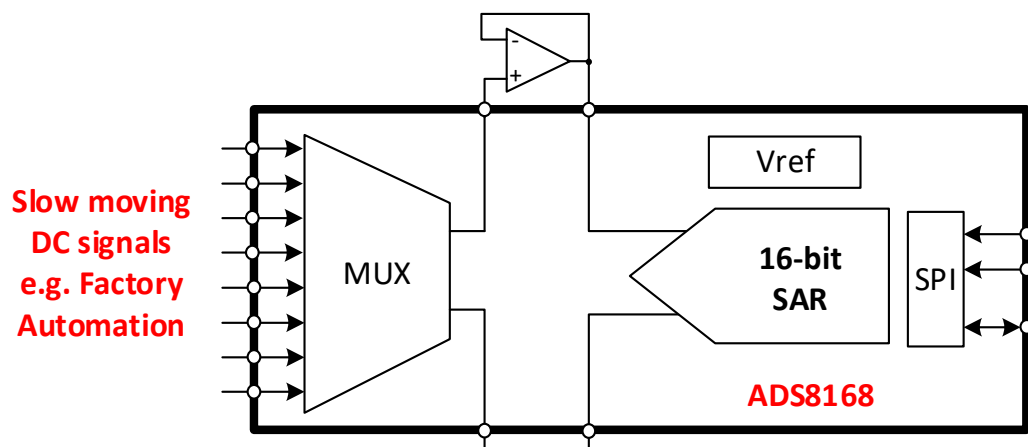
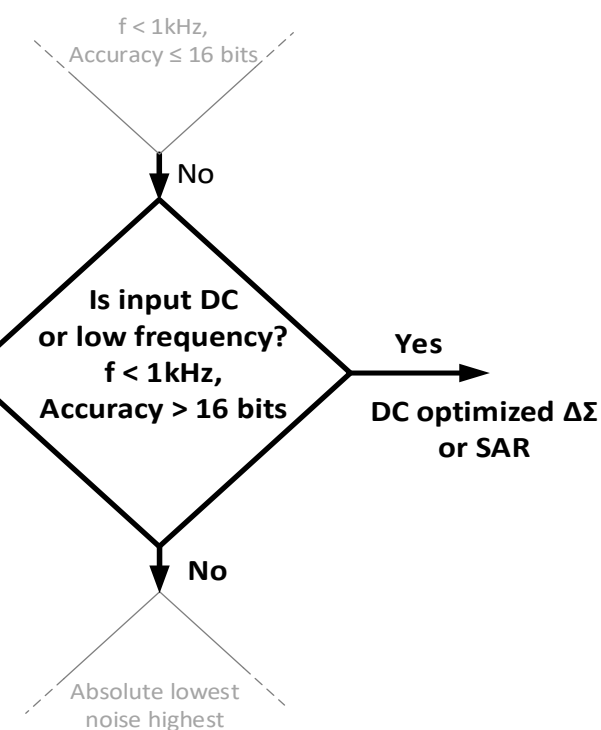


$\Delta\Sigma$ is the best option for DC, high precision

- Both SAR and $\Delta\Sigma$ have options
- $\Delta\Sigma$ typically has lowest overall noise
- $\Delta\Sigma$ may have integrated 50/60Hz filter noise rejection
- $\Delta\Sigma$ typically does not require external amplifier
- $\Delta\Sigma$ frequently has integrated PGA

When monitoring DC signals with a high resolution requirement, the delta-sigma converter will usually be the best solution. Remember, the delta-sigma uses noise shaping and an internal digital filter to get very low noise. Also, some will integrate a 50/60Hz rejection filter. Finally, many delta-sigma converters integrate a high-impedance PGA, so an external amplifier is not required. Let's look at a SAR option.

DC, accuracy > 16 bits: SAR Option

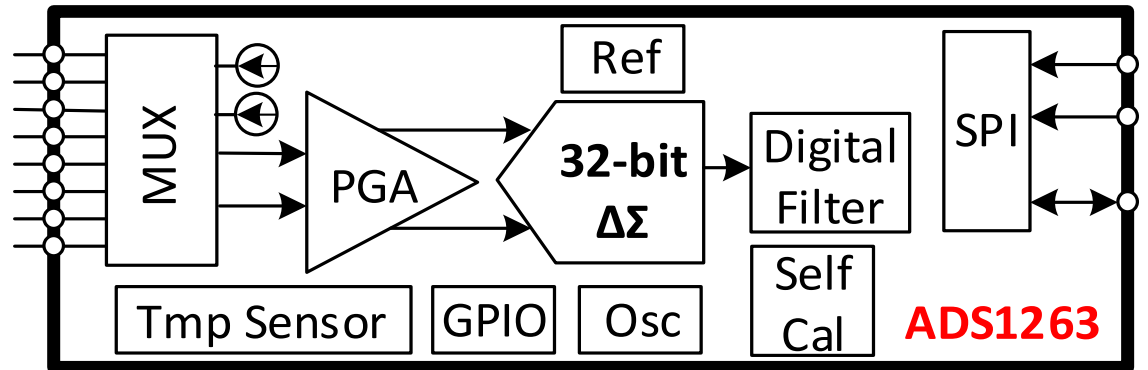
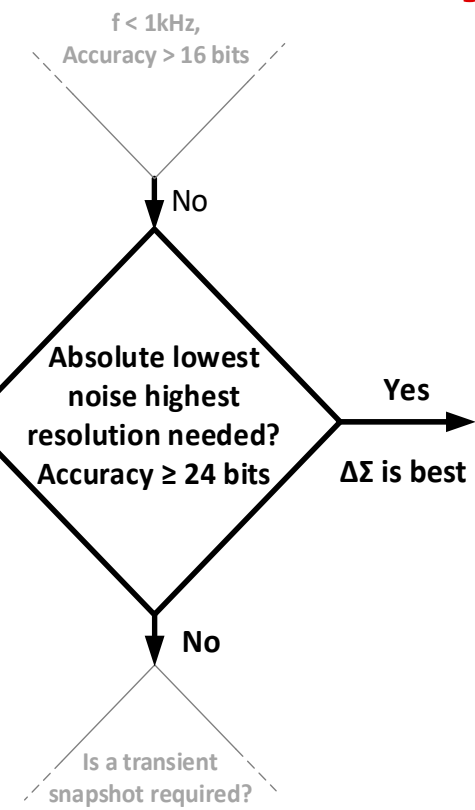


High resolution SAR for some DC applications

- Both SAR and $\Delta\Sigma$ have options (normally $\Delta\Sigma$)
- One channel may be used for higher frequency
- SAR may take a fast snapshot and remain dormant
- May require external amplifiers
- SAR resolution up to 20 bits available

Here we show a higher resolution SAR converter being used to monitor DC signals. Normally, a delta-sigma would be used for this kind of application, but a SAR may be useful if one signals is higher frequency, or if the system is used to take a snapshot and remain dormant between samples. SAR converters do have high resolution options, but typically the high resolution SAR is not used to monitor DC signals.

DC, accuracy ≥ 24 bits, ultra low-noise: delta-sigma

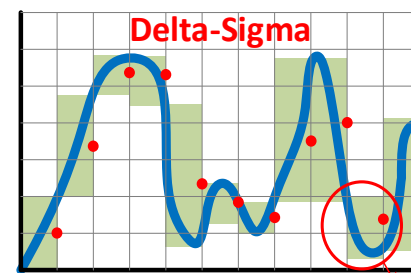
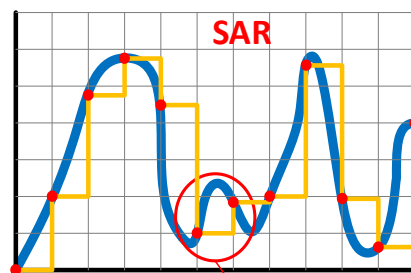
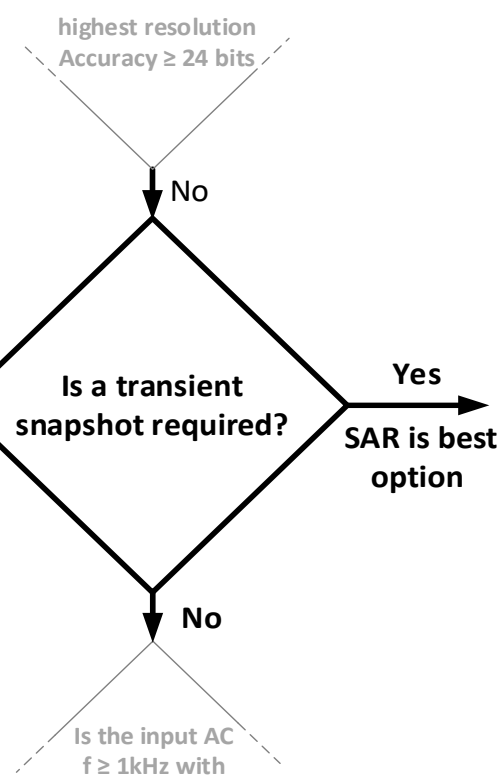


High resolution SAR for some DC applications

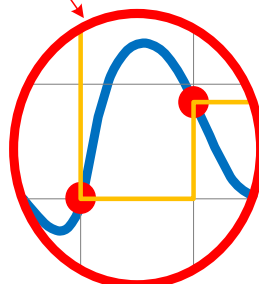
- $\Delta\Sigma$ is the best choice for highest resolution
- Up to 32 bits available
- Total integrated noise is $7 \text{ nV}_{\text{RMS}}$!
- Digital filter for lowest noise and 50/60 Hz rejection

Finally, for the ultimate low noise DC precision measurements, delta-sigma converters are the best option. These devices can have resolution up to 32 bits and can ultra low noise. The ADS1263, for example, has a total integrated noise of only $7 \text{ nV}_{\text{rms}}$. Furthermore, the integrated digital filter can be configured to reject both 50 and 60 Hz noise.

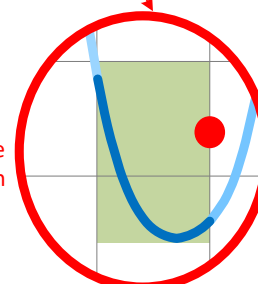
Is a transient snapshot required?



SAR:
Red dot indicates
the "snap-shot"
captured



Delta-Sigma:
Red dot indicates
the average of the
signal in the green
sampling interval

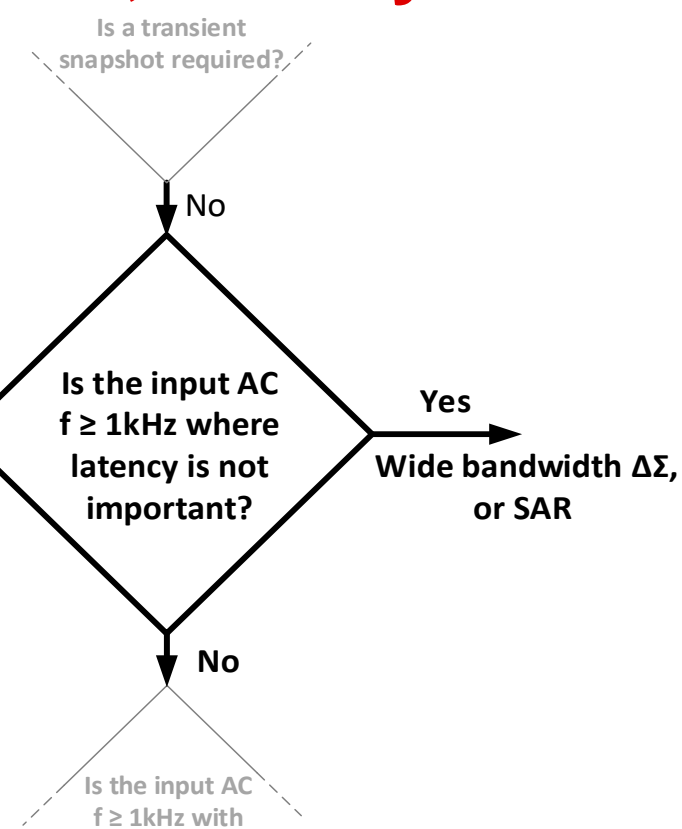


Different sampling approaches

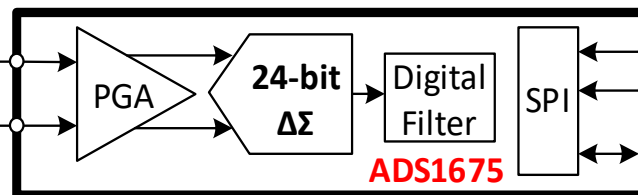
- SAR uses sample-and-hold to take a snap shot of signal at an instant in time
- $\Delta\Sigma$ averages signal over a time interval

Some measurement applications need to take a snapshot of a transient signal at a specific time in order to capture some key event. For example, a protection relay application needs to capture a transient fault voltage in order to activate a protection circuit. In this kind of application, the SAR converter is best choice as the sample-and-hold input will capture the waveform at a precise instant in time. The delta-sigma, on the other hand, averages several input samples over a time interval, which introduces latency. The diagram on this slide illustrates the snap-shot action of the SAR and the averaging of the delta-sigma.

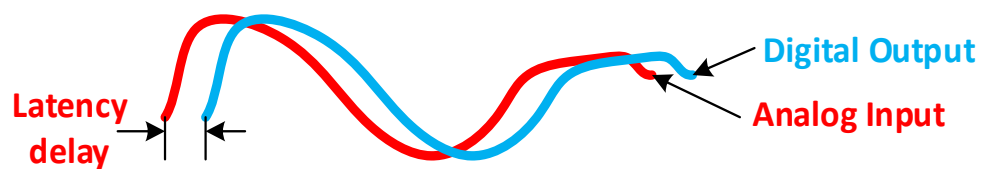
AC, latency not important



Audio,
Seismic,
Medical
Imaging



Data
recorded
with latency
delay



Both SAR and $\Delta\Sigma$ can work

- Used in applications where a delay between input and recorded data is not an issue
- The natural choice for highest resolution is $\Delta\Sigma$
- $\Delta\Sigma$ devices use high latency flat passband digital filter

When higher frequency AC signals need to be measured, a wide bandwidth delta-sigma converter or a SAR converter can be used. For the delta-sigma option, these devices will contain a wide bandwidth, flat passband filter with higher latency. Remember that latency is essentially a delay between the input signal and the digitized output signal. The delta-sigma option can only be used in cases where low-latency is not important. For example, a short delay may not impact an audio, seismic, or medical imaging application. In the next slide we will do a quick review of what causes latency.

How do you know how much latency is in a delta-sigma?

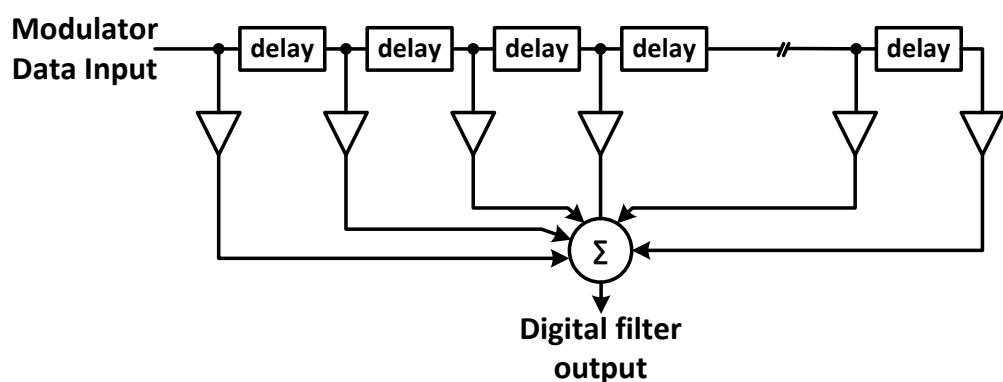
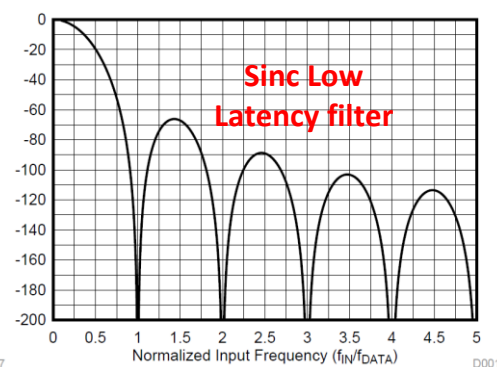
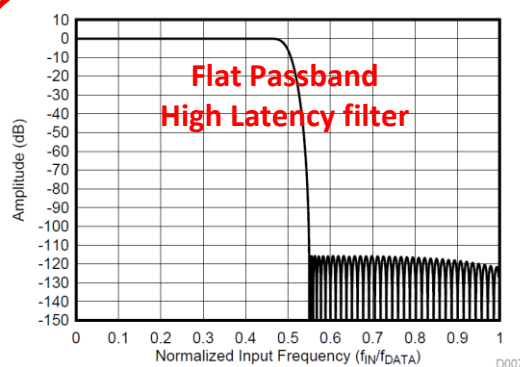
$\Delta\Sigma$ Latency

Flat Passband type filter

- ✓ High latency (e.g. 50 cycles)
- ✓ AC in passband not attenuated
- ✓ Stopband steep attenuation

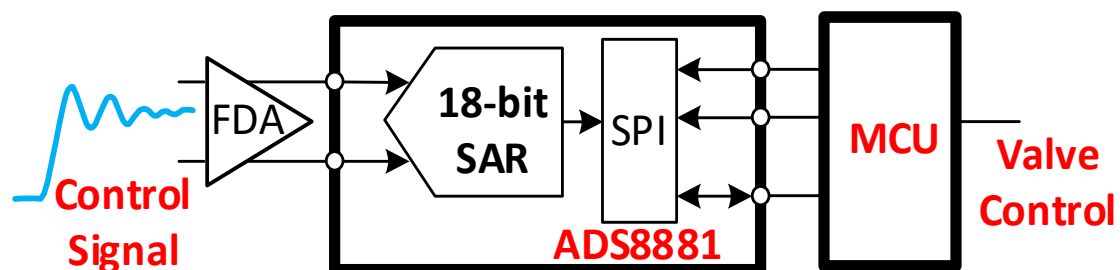
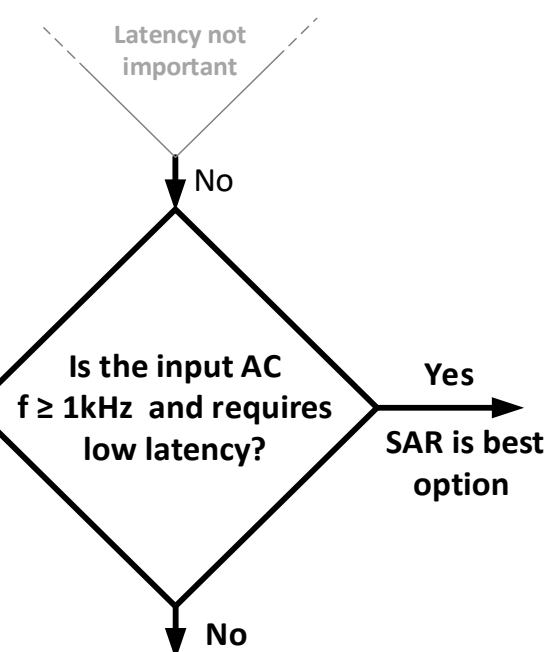
Sinc type filter

- ✓ Low latency (e.g. 1-3 cycles)
- ✓ Passes DC but attenuates AC
- ✓ Can be used for 50/60Hz rejection



High latency is mostly associated with wide bandwidth delta-sigma converters. SAR converters do not have this issue because they do not contain digital filters. The problem is related to the implementation of the flat passband filter. This filter has many delay elements and each element introduces one conversion cycle of latency. A typical flat passband filter can have 50 or more cycles of latency. Delta-sigma converters can also use the low latency Sinc filter. However, this type of filter is not optimized for wideband operation due to their passband attenuation. Thus, wide bandwidth delta sigma converters will always have latency delays to consider.

AC, latency is important



SAR is best choice for low latency

- AC or transient input that requires an immediate response (e.g. ≤ 1 cycle delay)
- Examples: control systems, safety relays, position sensors

In applications where both wide bandwidth and low latency are required, the SAR converter is the best choice. Some examples where low latency is required include control systems, safety relays, and position sensors. Basically, any application where an immediate response is required for digitized input signals should use a SAR.

Still not sure?...

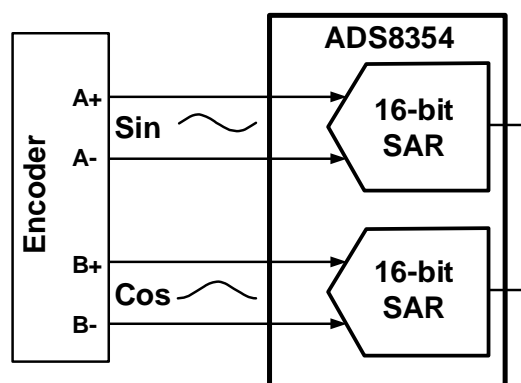
Choosing between two equivalent options

- Solution size, or total power consumption
- Ease of use
 - Some SAR ADCs have simple configurations (No registers. Power-up and go.)
 - Delta-Sigma ADCs incorporate digital filters to simplify antialiasing design
- Are pin-for-pin upgrades available?
 - Device families offers options and future upgrade paths
- Integrated features (e.g. PGA, voltage reference, digital filters)
- External supporting circuitry required (e.g. driver amplifiers, voltage references, crystal oscillators)
- Key analog specifications: Noise, SNR, THD, linearity
 - SAR vs. Delta-Sigma is no longer the important comparison
- Performance is not always the key concern. Integrated ADCs in MCUs can offer greater convenience at lower cost.
 - SAR vs. Delta-Sigma topology selection is determined by the MCU



That completes the decision tree for choosing between a SAR and delta-sigma converter. You may find that in many cases, both types of converters are viable options. So then how do you choose? Some things to consider are overall solution size, power consumption, and ease of use. Sometimes the features in heavily integrated devices can be very helpful, but in other cases they add unneeded complexity. If you want a very simple converter without configuration registers or any features, some SAR converters may be a good option. On the other hand, sometimes the integrated features can eliminate the need for supporting peripheral components. Driver amplifiers, voltage references, and crystal oscillators add area, cost and complexity to your system design. If these are integrated, that can be very helpful. Sometimes a performance specification like SNR or THD may be your key decision criteria. In some cases the ADC may be integrated into your microcontroller, so the converter topology may be pre-determined.

Summary: SAR vs. delta-sigma ADCs

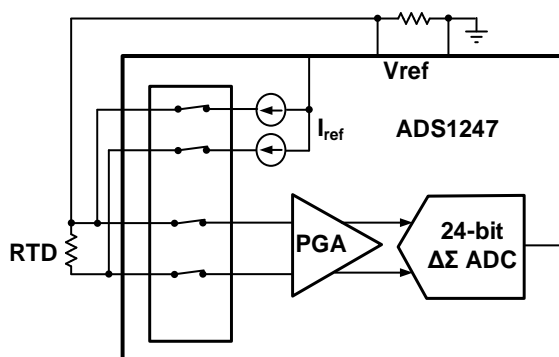


SAR

Low latency matters
 Needed to capture transient snapshots

Example applications:

- Motor control
- Power quality measurement
- Safety relays
- Test and measurement (scope)
- Mechanical shock
- Control loop systems

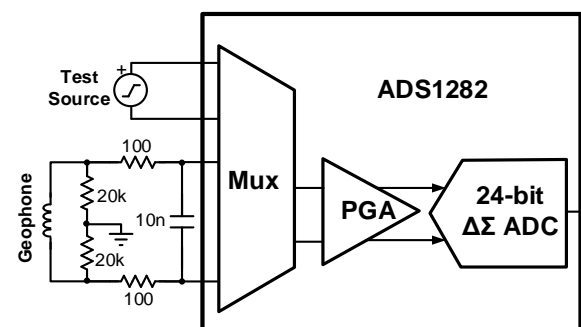


DC Optimized $\Delta\Sigma$

- Offset, drift, linearity, and noise
- Integrated features
- Sensor specific inputs

Example applications:

- RTD, thermocouple
- Weigh scale, pressure sensor
- Precision dc measurements



Wide Bandwidth $\Delta\Sigma$

- SNR, THD, SINAD
- Used when latency does not matter
- Selectable digital filter response

Example applications:

- Audio
- Imaging, ultrasound
- Seismic
- ECG, vibration analysis
- Test and measurement



That concludes the introduction and comparison of SAR and delta-sigma converters. This slide reviews the three key options that we considered. The SAR converter is mostly used to capture transient snapshots, and for AC applications where low latency is important. It can also be a good choice for small, general purpose converters.

The DC optimized delta-sigma converter can have very high resolution and low noise. Frequently this kind of converter can be used for low frequency sensors like RTDs.

Wide bandwidth delta-sigma converters can be used for many of the applications that SAR converters are used for. However, they cannot be used where low latency is required.

Thanks for your time! Please try the quiz.



That concludes this theory part of the video – thank you for your time! Keep watching to try the quiz and check your understanding of this video's content.

Questions: Choosing between SAR & delta-sigma

1. What kind of ADC is best for measuring an RTD or thermocouple temperature sensor?
 - a. SAR
 - b. DC optimized delta-sigma
 - c. Wide bandwidth delta-sigma

2. (T/F) Wide bandwidth delta-sigma converters will always use a high-latency filter.
 - a. True
 - b. False

Question 1: What kind of ADC is best for measuring an RTD or thermocouple temperature sensor?

- a. A SAR
- b. A DC optimized delta-sigma
- c. A wide bandwidth delta-sigma

The answer is b.) a DC optimized delta-sigma often includes useful features for sensor-specific applications.

Question 2: True or False. Wide bandwidth delta-sigma converters will always use a high-latency filter?

The answer is True. These filters offer a flat passband at the cost of added filter delay elements and higher latency.

Questions: Choosing between SAR & delta-sigma

3. Which of the following is true?
- a. SAR converters are used for low latency DC measurements
 - b. SAR converters integrate current sources and PGAs.
 - c. SAR converters take a snapshot of transient signals
 - d. SAR converters use a high-latency, integrated digital filter
4. (T/F) A wide bandwidth delta-sigma converter would be a good choice in cases where low-latency AC measurements are required. For example, a controls system.
- a. True
 - b. False

Question 3: Which of the following is true?

- a. SAR converters are used for low latency DC measurements
- b. SAR converters integrate current sources and PGAs.
- c. SAR converters take a snapshot of transient signals
- d. SAR converters use a high-latency, integrated digital filter

The answer is c.) A SAR converter is optimized for fast, low-latency measurements and typically does not include these other features.

Question 4: True or false. A wide bandwidth delta-sigma converter would be a good choice in cases where low-latency AC measurements are required. For example, a controls system.

The answer is false. A wide bandwidth delta-sigma would introduce too much delay, so a SAR is probably the best choice.



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