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Signals – sensors 2.

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Number representation

- In digital processing, we need numbers to make the necessary calculations.
- Every number must be represented by some electrical value, usually the amplitude of the signal.
- Problem: noise will distort the signal (adding to or substituting from the amplitude).
- If the current amplitude of the noise distort the signal amplitude too much, it will change the represented value.
- We need to keep the unique representation levels as low as possible.

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Binary numbers

- The smallest number representation systems: only two different numbers (0 and 1).
- Larger numbers needs more binary digits.
- The electrical representation is quite simple:
  - We need to define a threshold, usually in the middle of the maximum signal range.
  - If the current amplitude of signal is lower than the threshold, the represented number is 0.
  - If the current amplitude of signal is higher than the threshold, the represented number is 1.
- Binary number representation needs simpler circuits.

Number systems

- Digital equipment can handle binary numbers, but we – humans - can not.
- We mostly use decimal number systems.
- Binary numbers can represent decimal numbers.
- „Place value” is the value of a digit according to its position in the number (in decimal: 1, 10, 100, 1000…).
- In binary number system, the place values are: 1, 2, 4, 8, 16, 32, 64, 128…
- We need to multiply and cumulate the digit value and the place value.

Digital number formats

- Digital microprocessors use n-bit wide data elements (all bits could be „0” or „1”).
- N-bit wide data elements have 2^n bit combinations.
- These bit combinations can be interpreted more than one way.
  - Unsigned integers.
  - Signed integers.
  - Unsigned fractionals.
  - Signed fractionals.

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Unsigned integers

- Simplest way: positive integer numbers. All place-value notation follow the normal notation.
- Value set between 0 and 2^n-1.
  - 0-255 (2^8-1) can be stored in 1 byte (8 bits).
  - 0-65535 (2^15-1) can be stored in 1 word (16 bits).

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Value
128	64	32	16	8	4	2	1	
1	1	1	1	1	1	1	1	255 (A)
0	1	1	1	1	1	1	1	127 (B)
0	1	1	1	1	1	1	0	A+B=126
1	0	0	0	0	0	0	0	A-B=128

Signed integers – two's complement

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- This is the most common way to represent signed numbers in binary computing system.
- In unsigned integer representation, the most significant bit represents the 2^(n-1) place-value notation element.
- In two's complement this MSB represents -2^(n-1).

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Value
-128	64	32	16	8	4	2	1	
1	1	1	1	1	1	1	1	-1 (A)
0	1	1	1	1	1	1	1	127 (B)
0	1	1	1	1	1	1	0	A+B=126
1	0	0	0	0	0	0	0	A-B=-128

Unsigned fractional

- Two different methods: floating point or fix point fractional,
- Fixed point fractional format has fixed number of digits after the radix point, floating point has an additional exponent value.

bit7	Bit6	Bit5	bit4	bit3	bit2	bit1	bit0	Value
0.5	0.25	0.125	0.0625	0.03125	0.015625	0.0078125	0.00390625	
1	1	1	1	1	1	1	1	0.99609375
0	1	1	1	1	1	1	1	0.49609375
0	1	1	1	1	1	1	0	A+B= 0.4921875
1	0	0	0	0	0	0	0	A-B=0.5

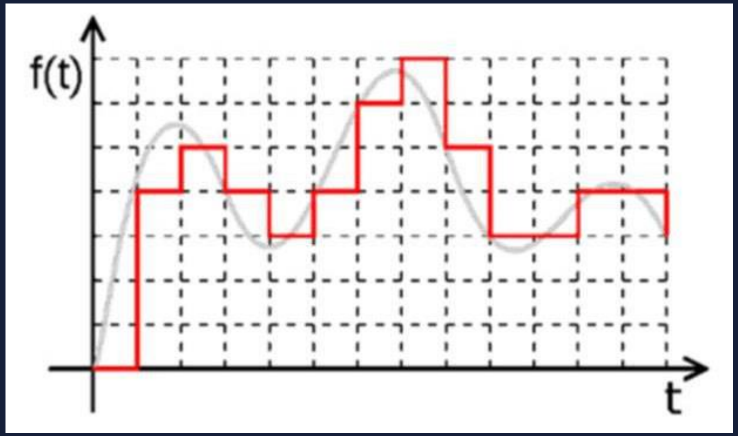
Signed fractional

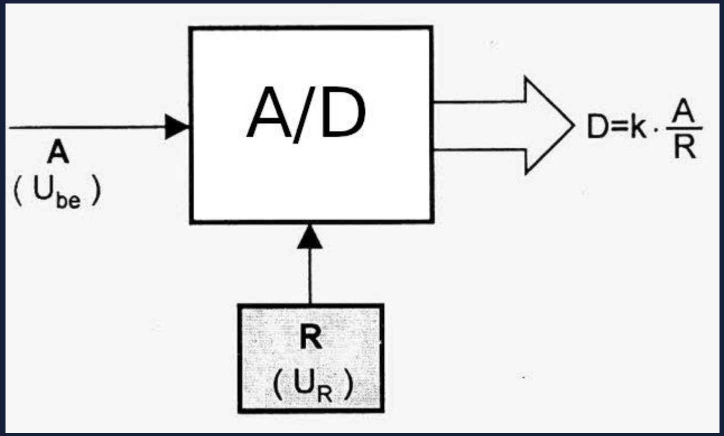
- Can be implemented as floating point or fix point fractionals.
- Fix point fractional has a sign bit and a fix amount of bits as the integer part of the number.
- Example: Q1.7

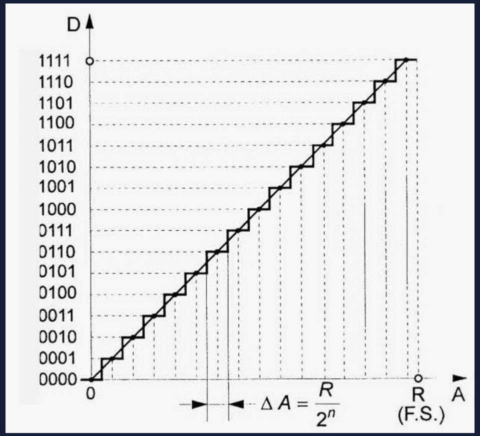
bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Value
-1	0.5	0.25	0.125	0.0625	0.03125	0.015625	0.0078125	
1	1	1	1	1	1	1	1	-0.0078125 (A)
0	1	1	1	1	1	1	1	+0.9921875 (B)
0	1	1	1	1	1	1	0	A+B=0.984375
1	0	0	0	0	0	0	0	A-B=-1

Analog-Digital converters

- The analog signal is sampled at regular intervals.
- Quantization: The sampled signal is assigned a discrete value.
- Encoding: The quantized values are converted into binary code for digital systems.







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ADC resolution

- AD converter must divide the signal amplitude to finite number of discrete quantization levels.
- Number of discrete levels depends on the resolution of ADC output. „n” bit resolution means 2^n levels.
- Increasing the number of levels will decrease the amplitude distortion. This distortion affects as noise in the output signal (Quantization noise).

Quantization noise

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- The input signal's amplitude: 2.048V for full scale.

Resolution (bits)	1 bit represents	Percentage	Theoretical SNR
1	1.024V	50%	~6dB
6	32mV	1.56%	~37dB
8	8mV	0.39%	~48dB
10	2mV	0.098%	~60dB
12	0.5mV	0.024 %	~72dB
16	31uV	0.0015 %	~96dB

Linear and non-linear quantization

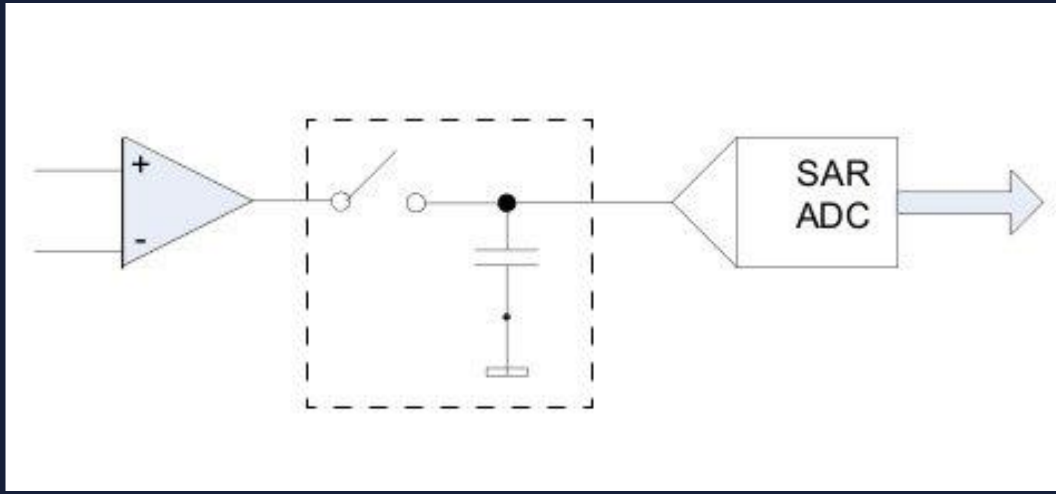
- In linear quantization, noise is depending on the resolution only and not on the current amplitude.
- Some application can benefit from non-linear quantization, where on the lower amplitude range more quantization steps are used.
- For example, our ears are more sensitive to noises on quiet sounds.
- If we decrease quantization noises on the lower amplitude range, the overall – subject – performance will be better.

Sample and hold circuit 1.

- Quantization process needs time.
- In that time period the input signal must not change its amplitude. If amplitude changes during quantization, the result will be distorted.
- Sample and hold circuit captures an analog signal and holds it during the analog-to-digital conversion process.
- This circuit components (especially capacitors) may degrade the ADC performance.

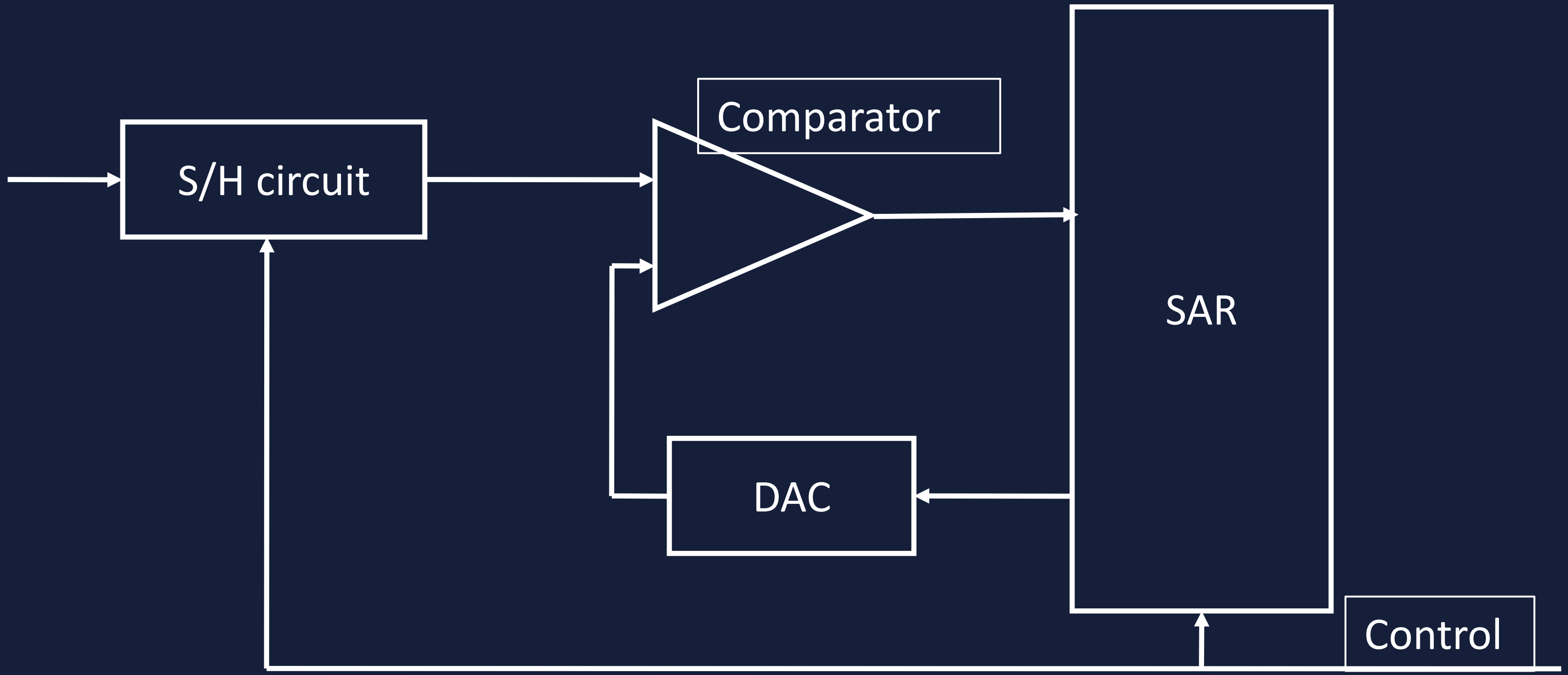
Sample and hold circuit 2.

- S&H circuit has two modes:
  - Sampling. In this case, the input switch is closed, input signal will charge the capacitor.
  - Holding. The input switch is open, capacitor will hold the previous input amplitude.



Analog to Digital Converter types - SAR

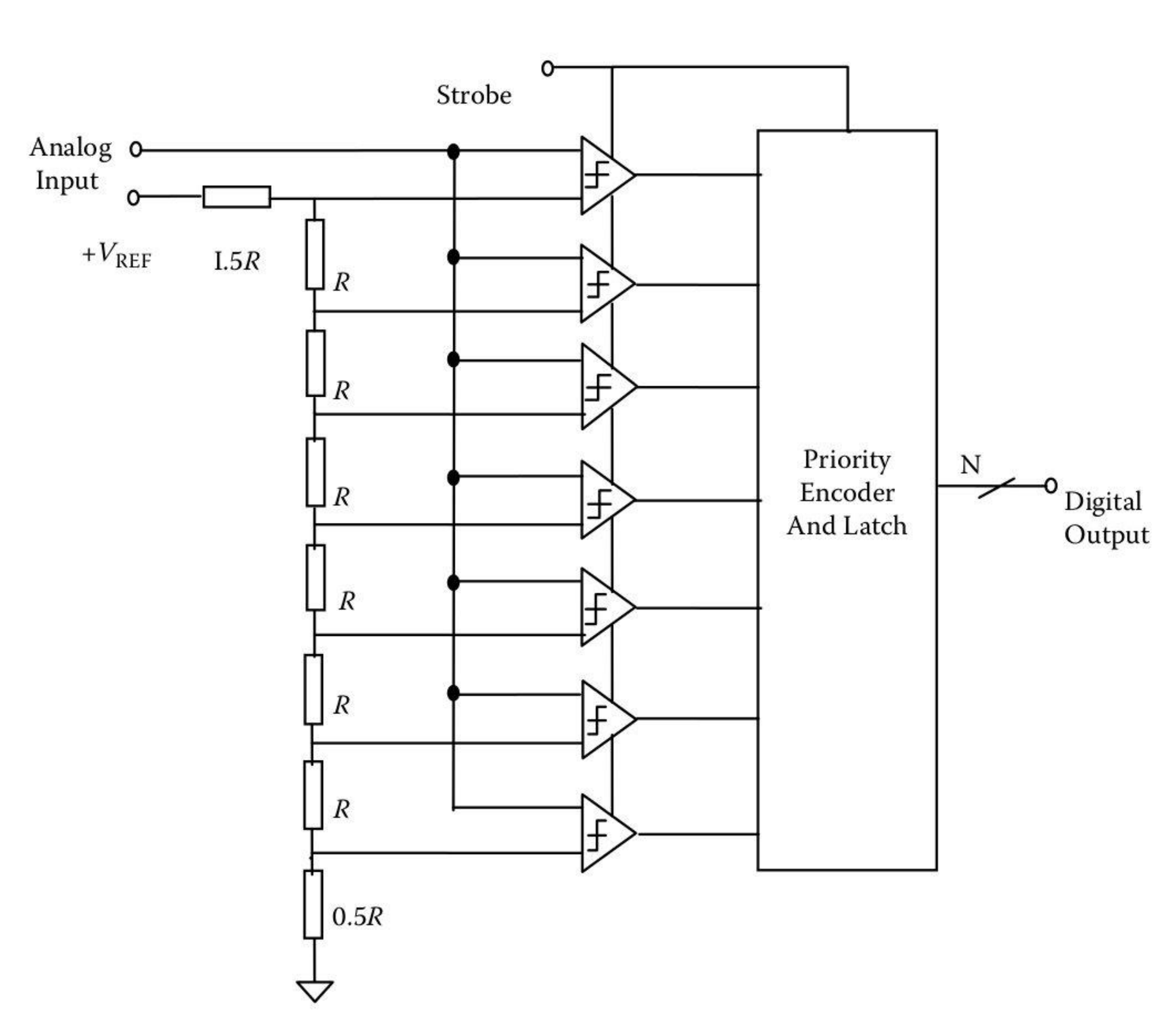
- Successive Approximation Register ADC is a popular architecture.
- For sampling frequencies up to a few megasamples per second (MSPS).



SAR operation

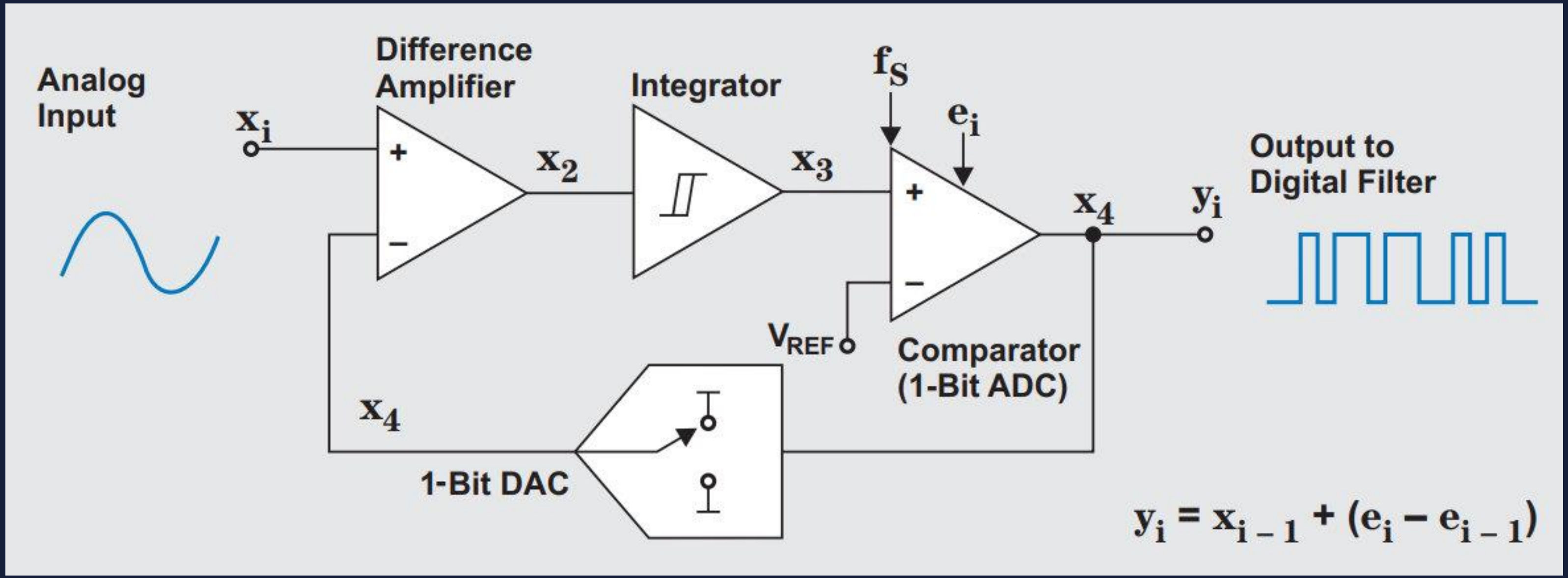
- Conversion starts with the set of SAR. All bits will be zero except the most significant bit.
- DAC in SAR output will convert this digital value to analog.
- If this signal is greater than input signal, the MSB will remain „1”, otherwise it will reset to „0”.
- Next bit will be set, DAC converts this new value to analog. Comparator will set or reset the next bit.
- Repeat these steps for all bits of SAR.
- Every conversation needs „n” steps, where „n” is the ADC resolution.

Analog to Digital Converter types - flash converter



Analog to Digital Converter types – Delta Sigma converters

- It using a 1-bit ADC with oversampling.
- The output of the Sigma-delta modulator provides a bit stream output.
- It needs a decimator to convert this stream into n-bit samples.



Analog to Digital Converter types – sawtooth type

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- Easy to implement but quite slow conversion.
- The sawtooth signal generator provides a sawtooth waveform.
- When amplitude starts increasing, a counter is starting to count.
- If the amplitude reach the current input level, the comparator stops the counter.