If the electronic noise on the input signal to an Analog/Digital converter (16-bit voltmeter with dynamics ±5 V and 10 kSa/s) is 78 mV effective, what is the number of equivalent bits?
And if the noise increases up to 156mV effective, how does the number of equivalent bits change?
In the latter case, which type of converter might be preferable to use and why?

$$m_e = m - \frac{1}{2}\log_2\left(1 + \frac{\sigma_{ext}^2 + \sigma_{A/D}^2}{\sigma_Q^2}\right)$$

$\sigma_{ext\ rms} = 78\,mV \Rightarrow \sigma_{ext}^2 = 6.084\,mV$

$\sigma_{A/D}^2 = 0$

$$\sigma_Q^2 = \frac{\Delta V^2}{12} = \frac{100}{12 \cdot 2^{32}}$$

$$\Delta V = \frac{D}{2^m} = \frac{10}{2^{16}}$$

$$m_e = 16 - \frac{1}{2}\log_2\left(1 + 6.084 \times 10^{-3} \cdot \frac{12 \cdot 2^{32}}{100}\right)$$

$m_e = 5.2$ bit 10.8 bit loss

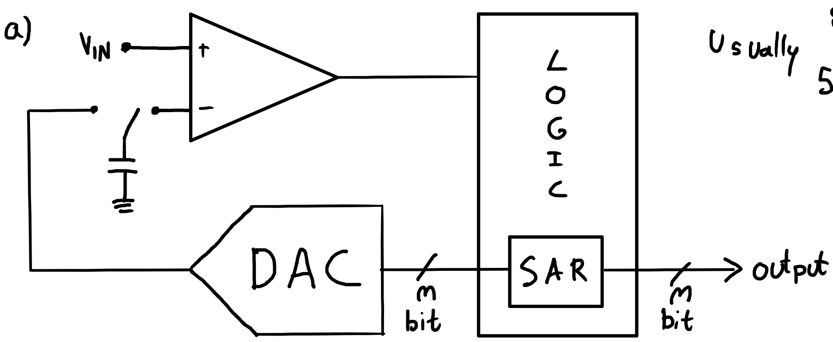
$\sigma_{ext\ rms} = 156\,mV \Rightarrow \sigma_{ext}^2 = 24.336\,mV$

$$\hookrightarrow m_e' = 16 - \frac{1}{2}\log_2\left(1 + 24.336 \times 10^{-3} \cdot \frac{12 \cdot 2^{32}}{100}\right) = 4.2 \text{ bit}$$ 11.8 bit loss

$m_e' = 4.2$
$f_s = 10\,kHz$ $\Rightarrow$ Simple SAR can work or use a faster Flash ADC

A successive approximation A/D converter has a time of a single comparison T_{comp}=100 nm and provides a 12 bit digital output.
a) Draw the block diagram of a successive approximation A/D converter. You have to discuss its operating principle and main characteristics and limitations.
b) Discuss whether the ADC described in point a) is suitable for correctly acquiring and reconstructing a sinusoid at 250 kHz and with an amplitude of 2 V, obtaining a resolution of at least 5 mV.
c) Working at maximum ADC speed, how much memory depth is needed to digitize the sine wave for 1 second.
d) What happens if the ADC considered is not ideal and has internal electronic noise with an (effective) amplitude of 300 µV? What is the number of equivalent bits of the acquisition worth in this case? What is the number of equivalent bits *n_e worth if the electronic noise becomes *σ_{ele}=10 mV?
e) Comment on the result obtained (or expected) for point d). Not having the need to carry out particularly fast measurements, how could we operate to have an equivalent resolution closer to the theoretical one?

a)



Usually 8 to 18 bits
50KHz to 10MHz of Sampling frequency!

Does *n* comparisons using a binary search style algorithm. It sets the value of the bits directly by using the result of the comparison, and stores them in a SAR - Sucessive Approximation Register.

Works by successively comparing the input voltage (V IN) with a voltage generated by auxiliary logic, and changing the value of the generated voltage with the intent of approaching the input value.

Problems:
- Instantaneous noise can lead to wrong comparisons and thus setting the wrong bit.
- Accuracy depends heavily on the internal reference, DAC quality, and comparator noise.

b) $f_{s\,min} = 2 \times f_{signal} = 500\,kHz$ $\qquad f_{s\,min} < f_s$ ✓

$T_s = 12 \cdot T_{Comp} \Rightarrow f_s = \frac{1}{12 \cdot T_{Comp}} = 833\ kHz$

$\Delta V_{min} = 5\,mV$ $\qquad \Delta V_{min} < \Delta V_{ADC}$ ✓

$\Delta V_{ADC} = \frac{4}{2^{12}} = 976\,\mu V \simeq 1\,mV$

It works!

c) 12 bit => 2 byte per comparison

1 s @ $f_s = 833.333$ kHz => 833 333 complete comparisons

Total? $2 \times 833\,333 = 1\,666\,666$ bytes! $\qquad 2^{-20}$ byte = M byte

$$\frac{1\,666\,666}{2^{20}} = 1.59\,MB \simeq 1.6\,MByte!$$

d) $\sigma_{AD_{rms}} = 300\,\mu V$ $\qquad \sigma_Q^2 = \frac{\Delta V^2}{12}$ $\quad \Delta V \simeq 1\,mV!$

$$m_e = m - \frac{1}{2}\log_2\left(1 + \frac{\sigma_{AD}^2 + \overbrace{\sigma_{Ext}^2}^{\approx 0}}{\sigma_Q^2}\right) \Leftrightarrow m_e = 12 - \frac{1}{2}\log_2\left(1 + \frac{(300 \times 10^{-6})^2}{\frac{(1 \times 10^{-3})^2}{12}}\right) = 11.47\ bit$$

$\sigma_{AD}^* = 10\,mV$

$$m_e^* = m - \frac{1}{2}\log_2\left(1 + \frac{\sigma_{AD}^{*2}}{\sigma_Q^2}\right) \Leftrightarrow m_e^* = 6.88\ bit$$

e) We could just average the results!

With a data acquisition schedule, with bipolar input dynamics, you have to measure the following signals on a electronic board:

V_1 power supply voltage of a USB connection (+5 V);

V_2 signal from the digital clock: TTL square wave (0-5 V) at 18 000 Hz;

V_3 voltage generated at the ends of a circuit with 4 AAA batteries placed in series (each battery delivers a voltage of 1.5 V);

V_4 alternating square wave of peak-to-peak amplitude 6 V with a period of 1 ms;

V_5 s analog signal with 20 kHz bandwidth, dynamics ± 100 mV and required resolution $\Delta V \leq 0.1$mV.

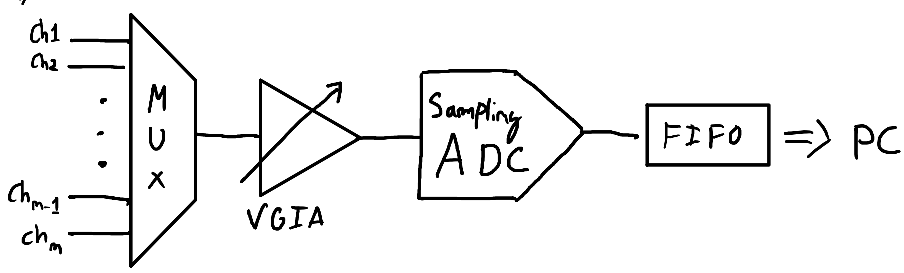
a) You have to describe briefly the structure and functioning of a data acquisition (DAQ) board, explaining the functions of its main blocks.

b) Evaluate the sampling frequency f_c, the acquisition mode and the number of channels of the card to sample correctly "simultaneously" all the signals.

c) Set the optimal gain for each channel, knowing that the A/D converter has a bipolar dynamics [- 5 V ;+5 V] and the selectable gains are G_i = 0.5, 1, 10 and 100.

d) Evaluate the number of bits of the DAQ necessary for the specific application.

a)



Multiplexer (Mux): Allows to select which channel will be adquired, and if single or differential mode.

Virtual Gain Instrumentation Amplifier: Allows to set different gains for each channel while adquiring it to take advantage of the complete dynamic of the ADC.

Sampling and ADC: Quantizes in time and amlitude and converts to bits.

FIFO: Memory first in first out that send the data to the PC. If possible using DMA

b) $V_1 \Rightarrow$ No freq. requirements

$V_2 \Rightarrow f = 18\,kHz \rightsquigarrow$ Digital signal 2 points per period

$f_{S2} = 36\,kHz$

$V_3 \Rightarrow$ No freq. requirements

$V_4 \Rightarrow T = 1ms \Rightarrow f = 1\,kHz \rightsquigarrow$ square wave and acquire the needed harmonics

$f_{S4} = 5\,kHz$

$V_5 \Rightarrow Bw = 20\,kHz \Rightarrow$ By Nyquist theorem we should acquire at twice the bandwidth

$f_{S5} = 40\,kHz$

$f_S = Max\{f_{S_m}\} = 40\,kHz \qquad f_{DAQ} = m\,f_S = 5 \cdot 40 = 200\,kHz$

V_4 requires differential mode $\Rightarrow 5 \times 2 \rightsquigarrow 10$ channels in differential mode

If possible adquire V_2 using a digital channel, so 8+1 channel and use 160 kHz

c) $D_{ADC} = \pm 5$

$G = \{0.5, 1, 10, 100\}$

$D_{DAQ} = \{\pm 10, \pm 5, \pm 0.5, \pm 0.05\}$

$V_1: D = 5V \Rightarrow G_1 = 1$

$V_2: D = 5V \Rightarrow G_2 = 1$

$V_3: D = 6V \Rightarrow G_3 = 0.5$

$V_4: D = \pm 3V \Rightarrow G_4 = 1$

$V_5: D = \pm 0.1 \Rightarrow G_5 = 10$

d) Only V_5 has resolution requirements:

$\Delta V < 0.1\,mV$

$\Delta V = \frac{D}{2^m} \Leftrightarrow 0.1 \times 10^{-3} = \frac{1}{2^m} \Leftrightarrow$

$\Leftrightarrow m \geq \log_2\left(\frac{1}{0.1 \times 10^{-3}}\right) = 13.3$

At least $m = 14$ bit