

8.6 ADC, DAC and sensors

Name: _____ Class: _____ Date: _____

Total: 22 marks

KEY WORDS ADC • resolution • LSB

Objective

Quantise with resolution and range arithmetic, wire sensors with correct impedance, and read a datasheet as the contract it is – every conversion checked against the LSB scale and the full-scale limits.

1 Key knowledge and worked examples

■ Resolution is pure arithmetic

An N-bit **ADC** over V_{ref} has one **LSB** $= V_{ref}/2^N$. The code for voltage V is $round(V/V_{ref} \times 2^N)$ (clamped); the reverse is $code \times V_{ref}/2^N$.

■ Worked example: the 12-bit mid-scale check

$V_{ref} = 3.3$ V, $N = 12$: $LSB = 3.3/4096 = 0.806$ mV. A 1.65 V input reads $1.65/3.3 \times 4096 = 2048$ exactly – mid-scale is a self-checking point (half the range, half the codes). A 2.5 V sensor output reads $2.5/3.3 \times 4096 = 3103$, and the quantisation error is at most $\pm \frac{1}{2} LSB = \pm 0.4$ mV – smaller than any sensor's own accuracy, which is why 12 bits suffice for analog sensors.

■ The signal chain and its contract

Sensor $\rightarrow$ conditioning (amplify/offset/filter) $\rightarrow$ ADC. The **sample-and-hold** charges through the source impedance: the datasheet's maximum (often ~ 50 k Ω at full speed) bounds the sensor network – a divider feeding the ADC directly can be **WRONG** at speed, not merely inaccurate. An **anti-alias filter** (EE06) must precede the sampler. The **DAC** is the mirror: $V_{out} = code/2^N \times V_{ref}$.

2 Practice

2.1 A 10-bit ADC with $V_{ref} = 5$ V: the LSB in mV, and the code for a 3.3 V input. [3]

2.2 A DAC with 8 bits and $V_{ref} = 3.3$ V: output voltage for code 128. [2]

2.3 A thermistor divider reads 2.1 V into the ADC of 2.1's $V_{ref} = 2.5$ V, 10-bit. Compute the code. [2]

3 Exam-style questions

3.1 A 3-axis accelerometer outputs 0–3.3 V for $-2g \dots +2g$, sampled by a 12-bit ADC with $V_{ref} = 3.3$ V at 1 kHz per axis.

Compute the LSB in mV and in mg (milli-g). A reading of 2048 on the X axis is 0 g; compute the codes for +1 g and -1 g, then the mg value of a reading of 2100. The vibration spec requires resolving 10 mg: state whether the ADC meets it. Finally, the sensor's output impedance is 10 k Ω and the ADC's maximum source impedance at 1 kHz is 50 k Ω : state whether a direct connection is valid. [8]

3.2 A light sensor current (0–100 μA) is read through a 10 $\text{k}\Omega$ resistor into the same 12-bit, 3.3 V ADC.

Compute the voltage at full current and the utilised fraction of the ADC range. Compute the LSB in μA (through the resistor), and the code for a 50 μA light level. Then propose a change that uses more of the range (resistor value), recompute the LSB in μA , and state the constraint the new resistor value must satisfy at the ADC input. [7]

Solutions

2.1

- $\text{LSB} = 5/1024 = 4.88 \text{ mV}$.
- $\text{Code} = 3.3/5 \times 1024 = 675.8 \rightarrow 676$.

2.2

- $128/256 \times 3.3 = 1.65 \text{ V}$ (mid-scale again – half the codes, half the reference).

2.3

- $\text{Code} = 2.1/2.5 \times 1024 = 860$.

3.1

- LSB : $3.3/4096 = 0.806 \text{ mV}$; in g: 4 g spans 4096 codes $\rightarrow 4096/4 = 1024$ codes per g $\rightarrow 0.977 \text{ mg per LSB}$.
- $+1 \text{ g} = 2048 + 1024 = 3072$; $-1 \text{ g} = 2048 - 1024 = 1024$.
- Reading 2100: $(2100 - 2048) \times 0.977 = 50.8 \text{ mg}$.
- $10 \text{ mg} \approx 10.2$ LSB-levels of resolution needed vs an LSB of 0.977 mg : the ADC resolves $\sim 10\times$ finer than required ✓ meets it (with sensor noise the real limit, not the quantisation).
- Source impedance $10 \text{ k}\Omega \leq 50 \text{ k}\Omega$ maximum ✓ direct connection valid (the sample-and-hold settles within the sampling window).

3.2

- Full current: $100 \mu\text{A} \times 10 \text{ k}\Omega = 1.0 \text{ V} - 1.0/3.3 = 30\%$ of the range.
- LSB in current: $0.806 \text{ mV}/10 \text{ k}\Omega = 80.6 \text{ nA} \approx 0.081 \mu\text{A}$.
- $50 \mu\text{A}$: $50 \mu\text{A} \times 10 \text{ k}\Omega = 0.5 \text{ V} \rightarrow 0.5/3.3 \times 4096 = 621$.
- To use the full range: $R = 3.3 \text{ V}/100 \mu\text{A} = 33 \text{ k}\Omega \rightarrow \text{LSB becomes } 0.806 \text{ mV}/33 \text{ k}\Omega = 24.4 \text{ nA}$ ($3.3\times$ finer).
- Constraint: the $33 \text{ k}\Omega$ source must still be $\leq$ the ADC's maximum source impedance ($50 \text{ k}\Omega$ ✓ here – but with the sensor's own output impedance added, the total must be re-checked).