



ANSWER BOOK

Operational amplifiers

Electronics · Year 13

AQA 3.13.2.1, 3.13.3.2, 3.13.4.1, 3.13.4.2, 3.13.4.4

17 questions · 51 marks

NAVY EDITION

SECTION A · Warm-up

- A1** All four of the following, one mark per two correct (2): infinite open-loop gain; [2]
infinite input resistance, so neither input draws current; zero output resistance, so the
output does not sag under load; and infinite bandwidth. Real chips manage about 10^5 ,
a few megohms and tens of ohms. Writing 'very high gain' alone is the standard error:
the examiner is marking a list of four, so give all four.
- A2** $V_{\text{out}} = A_{\text{OL}}(V_+ - V_-)$ (1). Saturation is what happens when that equation asks for [2]
an output beyond the supply rails: the output cannot pass them, so it sticks a volt or so
inside the rail and stays there, clipping the waveform flat (1). Forgetting that the
amplifier works on the **difference** between the inputs, and applying the gain to one
input alone, is the standard error.
- A3** It gives away most of the available gain (1). In return, any two of: the [2]
closed-loop gain is set by the feedback resistors rather than by the chip; the
bandwidth is far wider; distortion falls; the circuit's behaviour survives a change of chip
(1). Saying feedback 'increases the gain' is the standard error; it reduces it on purpose.
- A4** Negative feedback holds the two inputs within microvolts of each other, and [2]
the non-inverting input is connected to 0 V, so the inverting input is held at 0 V as well
(1) without being connected to earth at all, which is why it is called virtual (1). Saying the
inverting input 'is earthed' is the standard error: it carries the input and feedback
currents, which a real earth connection would swallow.
- A5** The inverting amplifier's output is in antiphase with its input, while the [2]
non-inverting amplifier's output is in phase (1). The non-inverting gain can never fall
below 1, and the signal arrives straight at the op-amp's own input terminal, so the
circuit draws almost nothing from the source and suits a high-resistance sensor (1).
Forgetting the minus sign on the inverting gain is the standard error this question is
built to catch.
- A6** Gain $\times$ bandwidth = constant, the gain-bandwidth product of the chip (1). Ten [2]
times the gain therefore means a tenth of the bandwidth (1). Expecting the two to rise
together is the standard error; they always move in opposite directions.

SECTION B · Standard

- B1** $V_+ - V_- = V_{\text{out}}/A_{\text{OL}} = 13/(1.0 \times 10^5) \text{ (1)} = 1.3 \times 10^{-4} \text{ V}$, that is 130 μV (1). Any larger difference asks for an output beyond the rail, which the amplifier cannot deliver, so it saturates at about +13 V and stays there (1). Multiplying by the open-loop gain instead of dividing is the standard error, and it gives a wholly impossible $1.3 \times 10^6 \text{ V}$. [3]
- B2** Gain = $-R_f/R_{\text{in}} = -82/4.7 \text{ (1)} = -17.4 \text{ (1)}$. $V_{\text{out}} = -17.4 \times 0.25 = -4.36 \text{ V (1)}$, comfortably inside the rails. The minus sign is worth a mark on its own: an inverting amplifier answer written as +4.4 V has thrown it away, and it is the single most common lost mark in this topic. [3]
- B3** Gain = $1 + R_f/R_1 = 1 + 33/2.2 = 1 + 15 = 16 \text{ (2)}$. $V_{\text{out}} = 16 \times 0.60 = 9.6 \text{ V}$, in phase with the input (1). Quoting 15, the bare resistor ratio, is the standard error: the 1 at the front is always there, which is why a non-inverting gain can never fall below one. [3]
- B4** The node is a virtual earth at 0 V, so the whole 0.44 V sits across R_{in} and $I = 0.44/(22 \times 10^3) = 20 \mu\text{A (1)}$. No current enters the op-amp, so all 20 μA continues through R_f (1), and the output sits at $-20 \times 10^{-6} \times 56 \times 10^3 = -1.12 \text{ V (1)}$. The gain equation agrees: $-(56/22) \times 0.44 = -1.12 \text{ V}$. Letting some of the current 'enter the op-amp' is the standard error; the input resistance is taken as infinite, so every microamp that arrives leaves through R_f . [3]
- B5** Bandwidth = gain-bandwidth product/closed-loop gain (1). At a gain of 200: $1.0 \times 10^6/200 = 5.0 \times 10^3 \text{ Hz}$, that is 5 kHz (1). At a gain of 25: $1.0 \times 10^6/25 = 4.0 \times 10^4 \text{ Hz}$, that is 40 kHz (1). Multiplying the gain by the product instead of dividing is the standard error; check that more gain has bought less bandwidth, never more. [3]
- B6** Gain = $-120/6.0 = -20 \text{ (1)}$. The equation asks for $-20 \times 0.90 = -18 \text{ V}$, which lies beyond the -13 V limit, so the amplifier **saturates** at about -13 V and the waveform is clipped flat (1). For linear working $|\text{gain} \times V_{\text{in}}| \leq 13$, so $V_{\text{in}} \leq 13/20 = 0.65 \text{ V (1)}$. Writing -18 V as the answer is the standard error: compute the ideal output, then hold it against the rails before writing it down. [3]
- B7** The output is at the **positive** rail, about +13 V (1). The difference is $2.62 - 2.50 = 0.12 \text{ V}$, roughly a thousand times the 130 μV needed to reach the rail, so the amplifier is driven hard into saturation (1). Multiplying 0.12 V by 10^5 and quoting $1.2 \times 10^4 \text{ V}$ is the standard error; no output ever passes its supply rail. [2]

SECTION C · Stretch

- C1** Overall gain = $3.0 / (15 \times 10^{-3}) = 200$ (1). One stage of gain 200 would be flat only [7]
to $1.0 \times 10^6 / 200 = 5$ kHz, far short of 25 kHz (1). The most any single stage may have is $1.0 \times 10^6 / (25 \times 10^3) = 40$ (1). Two inverting stages of gain -20 and -10 multiply to +200, and each sits under 40 (1). Their bandwidths are $1.0 \times 10^6 / 20 = 50$ kHz and $1.0 \times 10^6 / 10 = 100$ kHz, both clear of 25 kHz (1). Bandwidth here is the -3 dB point, which is not the same as flat: each stage is already falling before its own corner, and at 25 kHz the two together leave the output about 1.2 dB down. A response that must be flat rather than merely wide enough needs its corners further out still. Output = $15 \times 10^{-3} \times 200 = 3.0$ V (1), well inside the ± 13 V rails, and the two inversions cancel so the output is in phase with the sensor (1). Three standard errors are waiting here: adding the stage gains instead of multiplying them, forgetting that two inverting stages restore the phase, and checking the gain-bandwidth product against the overall gain rather than against each stage's own gain.
- C2** The input resistance of an inverting amplifier is R_{in} itself, because the far end of [4]
that resistor is a virtual earth (1). $R_f = 25 \times 4.7 = 117.5$ k Ω (1). With 120 k Ω the gain is $-120 / 4.7 = -25.53$ (1), an error of $(25.53 - 25) / 25 = 2.1\%$ (1). Quoting the input resistance as $R_{in} + R_f$, or dropping the minus sign from the designed gain, are the two standard errors.
- C3** Reference = $12 \times 10 / (10 + 10) = 6.0$ V (1). The sensing divider gives $12 \times 4.7 / (R_{LDR} +$ [4]
4.7), and the output changes state when that equals 6.0 V (1), which needs $R_{LDR} = 4.7$ k Ω (1). As the light falls the LDR's resistance rises, so the non-inverting input falls below the reference and the output swings to the **negative** rail (1). Two standard errors: forgetting that the divider hands back $R_i / (R_i + R_f)$ of the supply rather than some convenient fraction like a tenth, and assuming the LDR's resistance falls in the dark when it rises.
- C4** Bandwidth at open loop = $1.0 \times 10^6 / (1.0 \times 10^5)$ (1) = 10 Hz (1). Above that the gain [4]
falls in proportion to frequency, the product staying at 1.0 MHz all the way down to a gain of one at 1 MHz. A closed-loop gain of 1000 gives a bandwidth of $1.0 \times 10^6 / 1000 = 1$ kHz (1), so the response is already falling at 100 kHz; 100 kHz demands a gain of no more than 10 (1). Treating the open-loop gain as available at every frequency is the standard error, and it is exactly what the falling line on a gain-frequency graph exists to contradict.