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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

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SECTION A · Warm-up

A1 All four of the following, one mark per two correct (2): infinite open-loop gain; 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 common error: the examiner is marking a list of four, so give all four. [2]

A2 $V_{out} = A_{OL}(V_+ - V_-)$ (1). Saturation is what happens when that equation asks for 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 common error. [2]

A3 It gives away most of the available gain (1). In return, any two of: the 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 common error; it reduces it on purpose. [2]

A4 Negative feedback holds the two inputs within microvolts of each other, and 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 common error: it carries the input and feedback currents, which a real earth connection would swallow. [2]

A5 The inverting amplifier's output is in antiphase with its input, while the 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 common error this question is built to catch. [2]

A6 Gain × bandwidth = constant, the gain-bandwidth product of the chip (1). Ten times the gain therefore means a tenth of the bandwidth (1). Expecting the two to rise together is the common error; they always move in opposite directions. [2]

SECTION B · Standard

B1 $V_+ - V_- = V_{out}/A_{OL} = 13/(1.0 \times 10^5)$ (1) $= 1.3 \times 10^{-4}$ 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 common error, and it gives a wholly impossible 1.3×10^6 V. [3]

B2 Gain $= -R_f/R_{in} = -82/4.7$ (1) $= -17.4$ (1). $V_{out} = -17.4 \times 0.25 = -4.36$ 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 $= 1 + R_f/R_1 = 1 + 33/2.2 = 1 + 15 = 16$ (2). $V_{out} = 16 \times 0.60 = 9.6$ V, in phase with the input (1). Quoting 15, the bare resistor ratio, is the common 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 $I = 0.44/(22 \times 10^3) = 20$ μA (1). No current enters the op-amp, so all 20 μA continues through R_f (1), and the output sits at $-20 \times 10^{-6} \times 56 \times 10^3 = -1.12$ V (1). The gain equation agrees: $-(56/22) \times 0.44 = -1.12$ V. Letting some of the current 'enter the op-amp' is the common 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: $1.0 \times 10^6/200 = 5.0 \times 10^3$ Hz, that is 5 kHz (1). At a gain of 25: $1.0 \times 10^6/25 = 4.0 \times 10^4$ Hz, that is 40 kHz (1). Multiplying the gain by the product instead of dividing is the common error; check that more gain has bought less bandwidth, never more. [3]

B6 Gain $= -120/6.0 = -20$ (1). The equation asks for $-20 \times 0.90 = -18$ 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 $|\text{gain} \times V_{in}| \leq 13$, so $V_{in} \leq 13/20 = 0.65$ V (1). Writing -18 V as the answer is the common 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 $2.62 - 2.50 = 0.12$ 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 1.2×10^4 V is the common error; no output ever passes its supply rail. [2]

SECTION C · Stretch

C1 Overall gain = 3.0/(15 × 10^{-3}) = 200 (1). One stage of gain 200 would be flat only to 1.0 × 10^{6}/200 = 5 kHz, far short of 25 kHz (1). The most any single stage may have is 1.0 × 10^{6}/(25 × 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 × 10^{6}/20 = 50 kHz and 1.0 × 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 × 10^{-3} × 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 common 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. [7]

C2 The input resistance of an inverting amplifier is R_{in} itself, because the far end of that resistor is a virtual earth (1). R_f = 25 × 4.7 = 117.5 kΩ (1). With 120 kΩ 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 common errors. [4]

C3 Reference = 12 × 10/(10 + 10) = 6.0 V (1). The sensing divider gives 12 × 4.7/(R_{LDR} + 4.7), and the output changes state when that equals 6.0 V (1), which needs R_{LDR} = 4.7 kΩ (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 common errors: forgetting that the divider hands back $R_1/(R_1 + R_f)$ of the supply rather than some convenient fraction like a tenth, and assuming the LDR's resistance falls in the dark when it rises. [4]

C4 Bandwidth at open loop = 1.0 × 10^{6}/(1.0 × 10^{5}) (1) = 10 Hz (1). Above that the gain 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 × 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 common error, and it is exactly what the falling line on a gain-frequency graph exists to contradict. [4]