



ANSWER BOOK

Summing and difference amplifiers

Electronics · Year 13

AQA 3.13.4.3

17 questions · 52 marks

NAVY EDITION

SECTION A · Warm-up

- A1** Each input drives its own current V/R into the virtual earth, so each input is amplified by its own gain R_f/R_{in} before it joins the total (1). The output is therefore minus the **weighted** sum, with the weights set by the input resistors (1). Adding the voltages first and applying one gain to the lot is the standard error, and it only ever gives the right answer when every input resistor happens to be equal. [2]
- A2** The inverting input is held at 0 V by the feedback, a virtual earth, so the current through each input resistor is simply that input's voltage divided by its own resistance (1). The op-amp's input resistance is taken as infinite, so no current enters the chip and the whole total leaves through R_f (1). Omitting the second statement is the standard error, and without it the derivation does not close. [2]
- A3** $V_{out} = (V_+ - V_-) \times R_f/R_i$ (1). Subtract first, then multiply by the gain (1). Amplifying each input separately and subtracting afterwards is the standard error: with inputs of a few volts and a gain of a thousand it demands outputs of kilovolts, and the real chip would simply saturate. [2]
- A4** The two leads run side by side, so mains wiring induces the same interference on both; it is common-mode (1). Identical on both inputs, it appears in both terms of $V_+ - V_-$ and cancels before any gain is applied, while the wanted signal, a genuine difference between the leads, survives at full gain (1). Saying the amplifier 'filters out' the hum is the standard error: nothing is filtered, it is subtracted. [2]
- A5** The output cannot pass the rails, so it saturates a volt or so inside the rail and stays there, clipping the waveform flat (1). Every design should end by computing the worst-case output and holding it against the rails (1). Writing down the ideal figure, such as -20 V from a ± 15 V supply, is the standard error, and it is the one examiners mark hardest. [2]
- A6** Every gain is a ratio of real resistors, and real resistors carry a tolerance, commonly 5% or 1%, so two 5% resistors can leave a weight almost 10% adrift (1). Each weight must be accurate to better than half a step of the staircase, or the output stops rising in equal steps with the code (1). Assuming the ideal staircase holds however coarse the resistors are is the standard error, and it is what drives real converters away from this design. [2]

SECTION B · Standard

- B1** Each input sees a virtual earth, so the currents are $0.20/100\text{ k}\Omega = 2\text{ }\mu\text{A}$, $0.30/50\text{ k}\Omega = 6\text{ }\mu\text{A}$ and $0.10/20\text{ k}\Omega = 5\text{ }\mu\text{A}$ (1). They add at the node to $13\text{ }\mu\text{A}$, all of which leaves through R_f (1). $V_{\text{out}} = -13 \times 10^{-6} \times 100 \times 10^3 = -1.30\text{ V}$ (1). Dropping the minus sign is the standard error here, and it costs a mark every time it appears. [3]
- B2** Gains first: $47/47 = 1$ and $47/4.7 = 10$ (1). $V_{\text{out}} = -(1 \times 0.50 + 10 \times (-0.25)) = -(0.50 - 2.50)$ (1) = $+2.0\text{ V}$ (1). Watch the double negative: the negative input, amplified ten times and then inverted along with everything else, leaves the output positive. Working the voltages before the gains, or losing one of the two minus signs, are the standard errors. [3]
- B3** One least significant bit gives $5.0 \times 10/80 = 0.625\text{ V}$, and that is the step (1). The code 0110 is the number 6, so the output magnitude is $6 \times 0.625 = 3.75\text{ V}$ (1). Checking by weights: the 4 bit gives $5.0 \times 10/20 = 2.50\text{ V}$ and the 2 bit gives $5.0 \times 10/40 = 1.25\text{ V}$, total 3.75 V (1), and the output appears as -3.75 V . If the weighted sum disagrees with count $\times$ step, a resistor weight has gone astray; reading the resistor list the wrong way round, so that the MSB gets the $80\text{ k}\Omega$, is the standard error. [3]
- B4** $V_+ - V_- = 3.4120 - 3.3800 = 32.0\text{ mV}$ (1). $V_{\text{out}} = 3.2 \times 10^{-2} \times 50$ (1) = 1.60 V (1). Amplifying V_+ alone would demand $3.4120 \times 50 = 171\text{ V}$, far beyond any rail; subtracting first is what makes the measurement possible, and doing it the other way round is the standard error. [3]
- B5** The hum is identical on both inputs, so it appears in both terms of $V_+ - V_-$ and cancels: its contribution is **zero** (1). The difference left is 12 mV (1), so $V_{\text{out}} = 1.2 \times 10^{-2} \times 200 = 2.4\text{ V}$ (1). Amplifying the hum along with the signal and quoting $0.25 \times 200 = 50\text{ V}$ of interference is the standard error; common-mode means it never reaches the gain stage. [3]
- B6** The equation asks for $-(3 \times 1.0 + 5 \times 2.4) = -15\text{ V}$ (1), beyond the -13 V limit, so the output **saturates** at about -13 V and the waveform is clipped (1). For linear working $3 \times 1.0 + 5V_2 \leq 13$, so $V_2 \leq 2.0\text{ V}$ (1). Reporting -15 V as the output is the standard error: compute the ideal value, then hold it against the rails. [3]
- B7** The largest code is 1111, the number 15, so the full-scale output has magnitude $15 \times 0.625 = 9.375\text{ V}$; the summer inverts, so the output itself runs from 0 V down to -9.375 V (1). There are $2^4 = 16$ distinct levels, from 0 to 15 (1). Multiplying 16 by the step and quoting 10.0 V is the standard error: n bits give 2^n levels but only $2^n - 1$ steps between them. [2]

SECTION C · Stretch

- C1** Seven doublings from the MSB give $R_{LSB} = 10 \times 2^7 = 1280 \text{ k}\Omega$ (1). Step = $5.0 \times 10/1280 = 3.91 \times 10^{-2} \text{ V}$, that is 39.1 mV (1). Full scale = $(2^8 - 1) \times \text{step} = 255 \times 3.91 \times 10^{-2} = 9.96 \text{ V}$ in magnitude, the inverting output running from 0 V down to -9.96 V (1). Half a step is 19.5 mV (1), and the MSB contributes the full 5.0 V, so its weight must be right to $19.5/5000 = 0.39\%$ (1). Eight precision resistors are therefore needed, spanning 10 k Ω to 1280 k Ω , a range of 128 to 1, each held to about 0.4% (1). That is why real converters abandon the weighted-resistor design in favour of an R-2R ladder, which needs only two resistor values (1). Two standard errors here: multiplying by 256 rather than 255 when finding full scale, and comparing half a step with the output rather than with the contribution of the bit whose resistor is in question. [7]
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- C2** Each gain is R_f/R_{in} , so $R_{in} = R_f/\text{gain}$: 100 k Ω , 50 k Ω and 20 k Ω (2). $V_{out} = -(1 \times 0.10 + 2 \times 0.15 + 5 \times 0.02) = -(0.10 + 0.30 + 0.10) = -0.50 \text{ V}$ (1). Multiplying R_f by the gain instead of dividing is the standard error, and it makes the loudest channel the one with the biggest resistor, which is backwards. [4]
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- C3** $V_+ - V_- = 2.5085 - 2.5000 = 8.5 \text{ mV}$ (1). Gain = $4.0/(8.5 \times 10^{-3}) = 471$ (1), so $R_f = 471 \times 1.0 \text{ k}\Omega \approx 471 \text{ k}\Omega$ (1). Fed to an inverting amplifier of the same gain, the standing 2.5085 V would demand an output of about 1.2 kV, so the amplifier would sit saturated at a rail and the strain signal would be invisible (1). The standing level is exactly what the subtraction is there to remove; forgetting to subtract before applying the gain is the standard error. [4]
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- C4** The sensor's 0.50 V span must become a 5.0 V span, so its gain is $5.0/0.50 = 10$ and $R_1 = 100/10 = 10 \text{ k}\Omega$ (2). At the bottom of the range the sensor alone would give $-10 \times 1.00 = -10.0 \text{ V}$, so the reference must contribute +10.0 V; with a reference of -1.00 V that needs a gain of 10 as well, giving $R_2 = 10 \text{ k}\Omega$ (1). Check: at 1.00 V in, $V_{out} = -(10 \times 1.00 + 10 \times (-1.00)) = -0.0 \text{ V}$ (1). At 1.50 V in, $V_{out} = -(10 \times 1.50 - 10) = -5.0 \text{ V}$ (1), inside the rails. The standard error is to treat the reference channel as a fixed voltage added at the output rather than as another weighted input; it has its own gain R_f/R_2 like every other channel. [5]
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