



ANSWER BOOK

Discrete semiconductor devices

Electronics · Year 13

AQA 3.13.1.1, 3.13.1.2, 3.13.1.3, 3.13.1.4 · CIE 20.3.4

17 questions · 51 marks

NAVY EDITION

SECTION A · Warm-up

- A1** The gate sits on a thin insulating oxide layer, out of contact with the silicon [2]
beneath, so it behaves as a small capacitor rather than as a conducting terminal and
no steady current can enter it (1). The driver supplies only the brief charging current of
that gate capacitance when the state changes (1). The standard error is to treat the
gate like a bipolar transistor's base and quote a steady input current.
- A2** Below the threshold no proper channel forms, so the drain current is negligible [2]
at any drain voltage within the device's rating (1). Above it the channel opens and
widens, and provided the drain voltage is large enough to keep the channel saturated,
the current climbs approximately with the square of the excess gate voltage above the
threshold (1). Saying the current 'rises steadily' misses both points: a complete answer
names the channel, and the shape is a square law, not a straight line. Both halves are
the idealised model: below threshold a small leakage still flows, and the square law is
the saturated behaviour, not the behaviour at every drain voltage.
- A3** The zener goes across the load, **reverse** biased, so that it sits in breakdown at [2]
its rated voltage (1). The series resistor sits between the raw supply and the diode and
drops whatever the supply has left over, which is what sets the current and lets the
output stay put when the supply wanders (1). Drawing the zener forward biased, or
leaving the series resistor out and shorting the supply through the diode, are the two
standard errors.
- A4** It is used **reverse** biased, so that almost nothing flows in the dark and every [2]
absorbed photon adds to the reverse current (1). The photocurrent is **proportional** to
the illumination, so the response is linear and one constant converts current to
illumination across the range, where a curve would be needed for a device that is not
(1). That constant still comes from a calibration against a known source: linearity saves
the shape of the graph, not the fixing of its scale. Writing 'forward biased', or claiming
the current depends on the applied pd, are the marks most often thrown away here:
the characteristics are flat, so the light sets the current.
- A5** It measures magnetic **flux** density, the Hall voltage across the slab being [2]
proportional to B when the current through the slab is held constant (1). The Hall
voltage is largest when the field is perpendicular to the face of the slab, so the probe is
turned until the reading is a maximum and that value is taken (1). Reading the probe at
any old angle, and quoting the number as though it were B, is the standard error.

- A6** It responds in nanoseconds, while carriers in an LDR take milliseconds to build up and longer to disperse, so an LDR cannot follow anything flickering faster than a few hundred hertz (1). Its photocurrent is proportional to the illumination, whereas an LDR's resistance is not, so the photodiode reproduces the pulse shape faithfully (1). Answering on cost alone earns nothing: the comparison is won on response time and linearity. [2]

SECTION B · Standard

- B1** The excess above threshold is $3.0 - 2.0 = 1.0$ V, so $k = 0.10/1.0^2 = 0.10$ A V⁻² (1). At 4.5 V the excess is $4.5 - 2.0 = 2.5$ V (1), so $I_D = 0.10 \times 2.5^2 = 0.625$ A (1). Squaring the gate voltage itself instead of the excess above the threshold is the standard error, and it gives 2.02 A, three times too big. [3]
- B2** Channel and heater are in series, so $R = 6.0 + 0.12 = 6.12$ Ω and $I = 9.0/6.12 = 1.47$ A (1). Heater pd = $1.47 \times 6.0 = 8.82$ V (1). MOSFET power = $I^2R = 1.47^2 \times 0.12 = 0.26$ W, against 13.0 W in the heater (1). Using the full 9.0 V across the channel instead of I^2R is the standard error; the channel only ever has 0.18 V across it. [3]
- B3** The resistor drops $15 - 5.1 = 9.9$ V, so $I = 9.9/390 = 25.4$ mA (1). The load takes 12 mA of that, leaving $25.4 - 12 = 13.4$ mA in the zener (1). $P = V_Z I = 5.1 \times 13.4 \times 10^{-3} = 68$ mW (1). Dividing the whole 15 V by 390 Ω is the standard error: only the leftover 9.9 V appears across the resistor. [3]
- B4** $V = IR = 24 \times 10^{-6} \times 75 \times 10^3 = 1.8$ V (1). Photocurrent is proportional to illumination, so three times the light gives $3 \times 24 = 72$ μ A (1) and $V = 5.4$ V (2 s.f.) (1). Treating the diode like a resistor, so that trebling the light somehow changes its resistance instead of its current, is the standard error: the flat characteristics mean it behaves as a current source and the light alone sets the current. [3]
- B5** Sensitivity = $2.4/0.20 = 12$ mV T⁻¹ (1), the Hall voltage being proportional to B at constant current (1). Output = $12 \times 0.55 = 6.6$ mV (1). Forgetting that the sensor current must be held constant, and so treating the sensitivity as fixed when it is not, is the standard error; so is dividing the wrong way round and quoting 0.083 T mV⁻¹. [3]
- B6** The resistor drops $9.0 - 5.1 = 3.9$ V, so $I = 3.9/390 = 10.0$ mA (1). Every milliamp the load takes comes out of that current, so the largest load current is 10.0 mA (1), and at that point the zener current has fallen to zero (1). Ask for more and the zener current would have to run backwards, which it cannot: the output sags below 5.1 V and regulation is lost. Quoting the load current at the highest supply voltage is the standard error, because the worst case is always the lowest supply. [3]

- B7** The excess above threshold goes from 1.0 V to 4.0 V, a factor of 4, and the [2]
current follows its square, a factor of 16 (1). $I_D = 16 \times 0.10 = 1.6 \text{ A}$ (1). Doubling the gate voltage and expecting four times the current is the standard error: the square law acts on the excess above the threshold, not on V_{GS} itself.

SECTION C · Stretch

- C1** Worst case for the resistance is the lowest supply, where its drop is only 9.0 – [7]
5.1 = 3.9 V (1). It must still carry the load's 15 mA plus the zener's 5.0 mA, that is 20 mA, so
 $R \leq 3.9 / (20 \times 10^{-3}) = 195 \Omega$ (1). With $R = 180 \Omega$ the resistor carries 21.7 mA at 9.0 V in,
comfortably above the 20 mA needed (1). At 15.0 V in the resistor carries $9.9 / 180 = 55$
mA (1), and with the load disconnected all of it goes through the zener, giving $P = 5.1 \times$
 $55 \times 10^{-3} = 280 \text{ mW}$ (1), inside the 400 mW rating (1). The resistor itself dissipates 9.9×55
 $\times 10^{-3} = 0.54 \text{ W}$, so a 1 W resistor is needed (1). Two standard errors sink this design:
testing the resistance at the highest supply instead of the lowest, and testing the
zener's power with the load connected instead of disconnected. The worst case for
current is minimum supply; the worst case for zener power is maximum supply with no
load.
- C2** Charge needed: $Q = CV = 1.5 \times 10^{-9} \times 5.0 = 7.5 \times 10^{-9} \text{ C}$ (1). At a steady 4.0 mA, t [4]
 $= Q/I = 7.5 \times 10^{-9} / (4.0 \times 10^{-3})$ (1) = $1.87 \times 10^{-6} \text{ s}$, about 1.9 μs (1). Once the gate is charged
the current falls to **zero**, because the oxide insulates the gate from the channel (1).
Quoting a steady gate current of 4.0 mA is the standard error; the 4.0 mA flows only
while the gate capacitance is charging.
- C3** Sensitivity = $2.4 / 0.20 = 12 \text{ mV T}^{-1}$, so the peak output is $12 \times 0.45 = 5.4 \text{ mV}$ (1). [4]
Pulse rate = $120 / 2.0 = 60$ pulses per second (1). Four magnets give four pulses per
revolution, so the shaft turns $60 / 4 = 15$ times a second (1), that is $15 \times 60 = 900$
revolutions per minute (1). Reporting 60 rev s^{-1} , one pulse per revolution, is the standard
error: count the magnets before dividing.
- C4** At 3 units the photocurrent is $3 \times 20 = 60 \mu\text{A}$ (1). $R = V/I = 2.5 / (6.0 \times 10^{-5}) = 41.7$ [4]
 $\text{k}\Omega$ (1). With $43 \text{ k}\Omega$ the pd is $6.0 \times 10^{-5} \times 43 \times 10^3 = 2.58 \text{ V}$ (1). An LDR takes milliseconds for
its carriers to build up and disperse, so at 1 MHz, a microsecond per bit, it could not
follow the light at all, while a photodiode responds in nanoseconds (1). Two standard
errors here: dividing current by voltage and quoting $24 \mu\text{A V}^{-1}$ as a resistance, and
arguing the comparison on cost rather than on response time and linearity.