Data Provided: You may need to use the following physical constants:

Charge on electron:	$q = -1.602 \times 10^{-19}$ C
Free electron rest mass:	$m_0 = 9.110 \times 10^{-31}$ kg
Speed of light in vacuum:	$c = 2.998 \times 108$ m s^{-1}
Planck's constant:	$h = 6.626 \times 10^{-34}$ Js
Boltzmann's constant:	$k = 1.381 \times 10^{-23}$ JK^{-1}
Melting point of ice:	0°C = 273.2 K
Permittivity of free space:	$\varepsilon_0 = 8.85 \times 10^{-12}$ Fm^{-1}
Permeability of free space:	$\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1}

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DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

EEE225 Analogue and Digital Electronics

Answer **ALL** questions.

Part A: State whether each of the following statements is TRUE or FALSE and justify your answer with a brief (2 lines maximum) justification.

1) The conductivity of n-type silicon varies significantly as the room temperature changes.

False: The n-type doping level determines the conductivity and only extreme temperatures will cause any change.

(2)

2) High doping in semiconductors can enable higher temperature device operation.

True: Higher doping means that the semiconductor can go to higher temperatures before it starts to act like an intrinsic semiconductor.

(2)

3) The built-in voltage (or contact potential) in a p-n junction is approximately equal to the band-gap of the semiconductor.

True: The Fermi-levels are close to the conduction and valence band-edges on either side of the junction.

(2)

4) Metal-semiconductor schottky junctions are usually used when high speed switching is required.

True: Most metal-semiconductor diodes are n-type and utilise electrons only, which are faster than holes.

(2)

5) You can differentiate between an LED and a laser by the amount of optical power they emit.

False: The power is irrelevant. A laser has stimulated emission with a much narrower linewidth and the photons are all coherent, compared to the LED which has spontaneous emission.

(2)

6) Any semiconductor material that can be used to make a solar-cell can also be used to make a photodiode.

True: Both devices rely on the efficient absorption of photons and their conversion to a photocurrent.

(2)

7) When a silicon p-n junction diode is exposed to sunlight, you can obtain a voltage at the terminals that is approximately equal to the built-in voltage.

False: You will get a voltage but it will be at best about 60-70% of the built-in voltage as that will be sufficient to balance the photo-generated current.

(2)

8) In a perfectly compensation doped semiconductor, the concentration of acceptors and donors falls to below the intrinsic carrier concentration.

False: It is the net electron and hole concentration that decrease in compensation doping – the acceptor and donor concentrations do not change.

(2)

9) Most Blu-Ray DVD players use the semiconductor material InGaAs ($E_g = 0.7$ eV) to make the blue lasers.

False: The small band-gap of InGaAs means that it can make good infra-red lasers for 1550nm telecommunication applications.

(2)

10) In an enhancement mode MOST, the drain current can vary linearly with drain voltage.

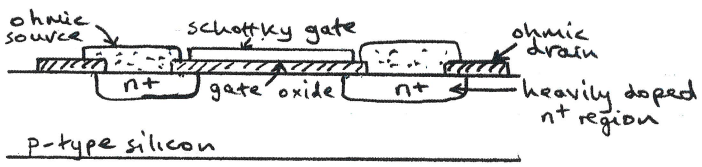
True: Provided you are in not in the saturation region, i.e. $V_d < (V_g - V_T)$, the drain current increases linearly with drain voltage.

(2)

Part B: Question 11

a) Sketch, label and discuss briefly the conduction mechanisms in an induced channel Metal Oxide Semiconductor Transistor (MOST). Identify all the significant parts of the device.

Q 3(a)



$V_s = 0$, $V_g = +$ive, $V_d = +$ive

At low V_g, holes repelled from under gate. At higher V_g, electrons form a conducting channel. V_{ds} causes causes current to flow between source to drain

(10)

b) The unsaturated drain characteristic of such a device as in (a) can be represented by:

$$I_d = \frac{\mu_e C_g}{l^2}\left[V_g - V_T - \frac{V_d}{2}\right]V_d$$

where the symbols have their usual meaning.

i) Under what voltage conditions does saturation of the drain current happen? What is the transconductance in the saturation region? Show that the transconductance is simply given by twice the ratio of the saturated drain current to drain voltage.

(b) Saturation occurs when $V_d = V_g - V_T$

The drain current is then given by

$$I_{ds} = \frac{\mu_e C_g}{l^2} \frac{V_d^2}{2}$$

Transconductance, $g_m = \left.\frac{\partial I_d}{\partial V_g}\right|_{V_d}$ in saturation region

So $g_m = \frac{\mu_e C_g}{l^2} V_d$ [3]

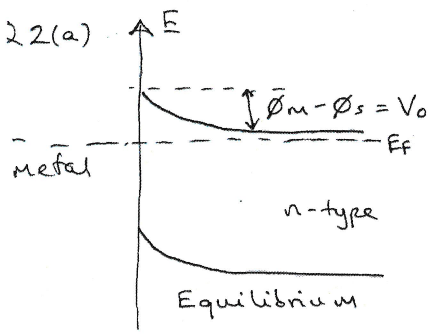
By substituting into above eqns

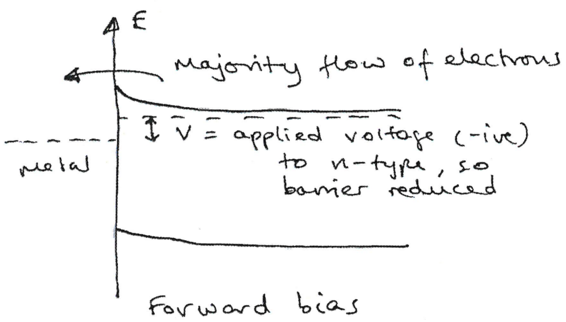
$$\frac{\mu_e C_g}{l^2} = \frac{g_m}{V_d} = \frac{2 I_{ds}}{V_d^2}$$

so $g_m = \frac{2 I_{ds}}{V_d}$ [2]

(10)

c) Sketch the schematic band diagram of a rectifying (schottky) metal-semiconductor junction in equilibrium when the semiconductor is n-type, identifying clearly the built-in (contact) potential and the Fermi-level. State clearly the relative work functions for the metal and semiconductor.





$\emptyset_m > \emptyset_s$ for schottky on n-type semiconductor

[Most got this bit correct]

(4)

(10)

Questions 12 – 23 are about the building blocks of analogue circuits. Answer all questions.

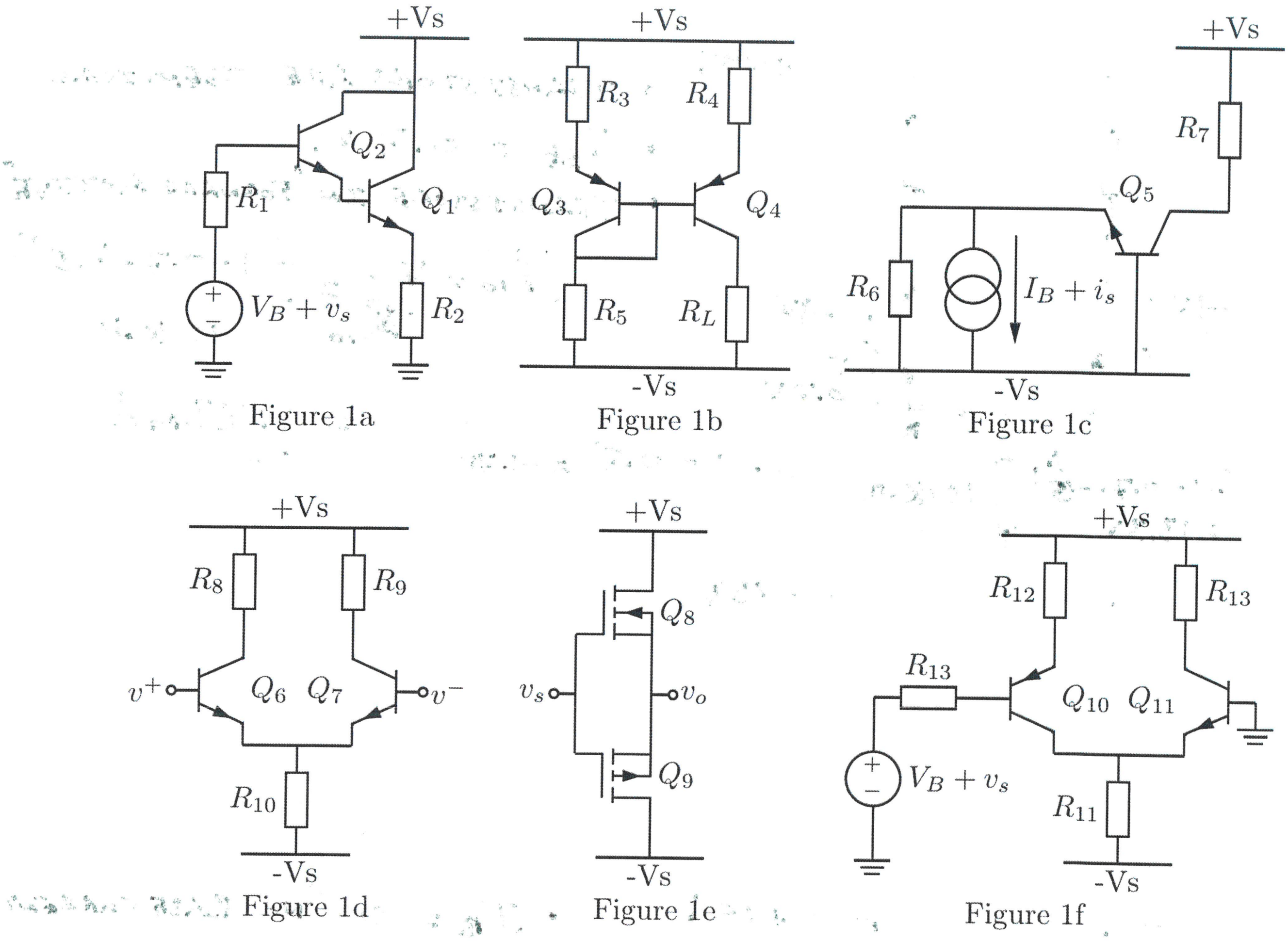


Figure 1: Some Common Analogue Transistor Circuit Blocks

12 Identify the circuits in Figure 1 by writing the letters A to F next to the names below. *Some Letters may fall into two categories.* **{1 mark for each correct assignment}**

Emitter follower	A	Differential amplifier	D	Cascode	F
Common base	C	Push pull	E	Current Mirror	B
Common collector	A	Darlington	A	Common Emitter	

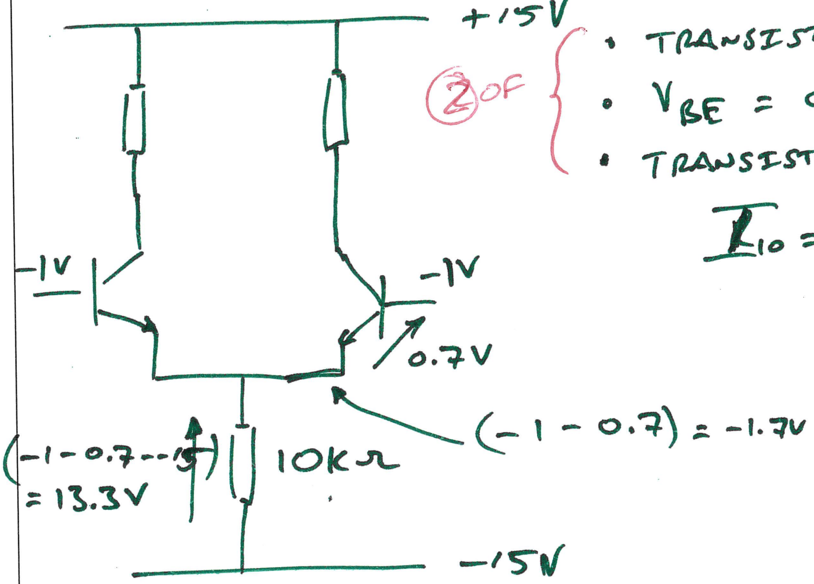
8

13 Using the column headings below list the transistors in Figure 1 according to type. **{1 mark for each correct}**

	NPN and N Channel	PNP and P Channel
	Q1, Q2, Q5, Q6, Q7, Q8, Q11	Q3, Q4, Q9, Q10

11

14 In Figure 1d, $+V_s = 15$ V, $-V_s = -15$ V, $v^+ = v^- = -1$ V and $R_{10} = 10$ kΩ. Find $I_{R_{10}}$. State two assumptions you made. **{3 marks}**



2 of
- TRANSISTORS ARE IDENTICAL
- $V_{BE} = 0.7$ V.
- TRANSISTORS IN "FORWARD ACTIVE"

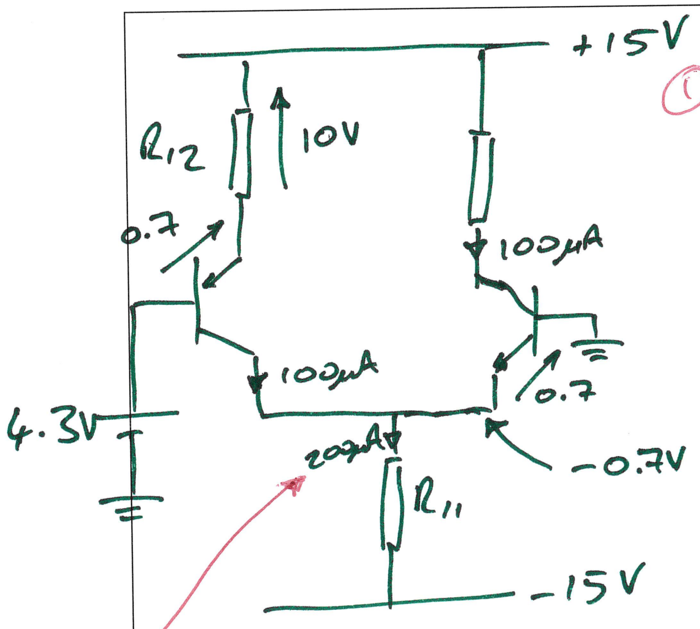
$$I_{10} = V/R_{10} = \frac{(-1-0.7-(-15))}{10k\Omega}$$

$$= \underline{\underline{1.33mA}} \quad 1$$

15 Is the input described in Question 14 *common mode* or *differential* mode? **{1 mark}**

Common mode

16 In Figure 1f, $+V_s = 15$ V, $-V_s = -15$ V, $V_B = 4.3$ V and the collector currents of both transistors are 100 μA. Find values of R_{11} and R_{12} that would satisfy these DC conditions. State one assumption you have made. **{6 marks}**



1 FOR GETTING $I_{R_{11}}$

1 of
- $I_B = 0$ (NO BASE CURRENT)
- $V_{BE} = 0.7$V

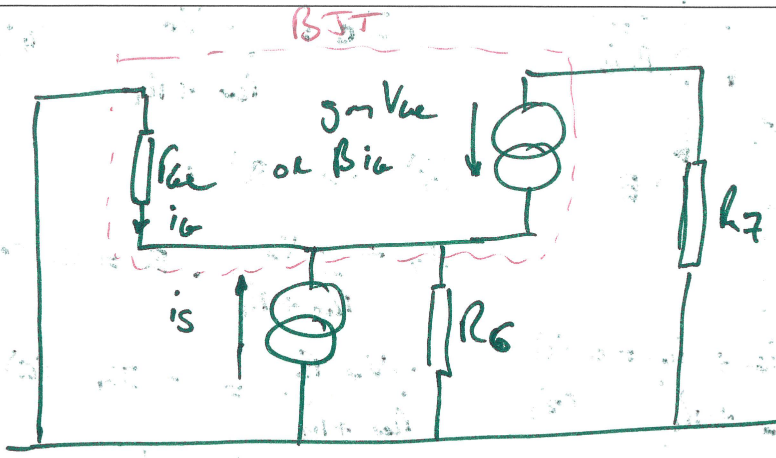
$$V_{R_{12}} = +15 - 0.7 - 4.3 = 10V. \quad 1$$

$$R_{12} = V/I = 10/100\mu A = \underline{\underline{100k\Omega}} \quad 1$$

$$V_{R_{11}} = (-0.7 - (-15)) = 14.3V \quad 1$$

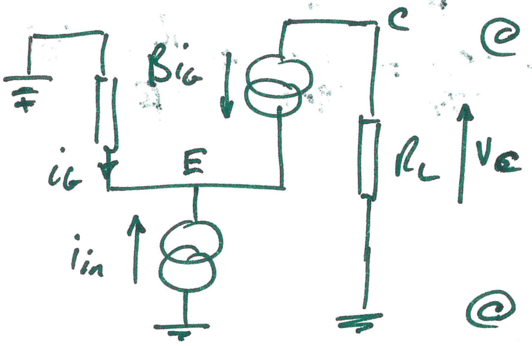
$$R_{11} = V/I = \frac{14.3}{200\mu A} = \underline{\underline{71.5k\Omega}} \quad 1$$

17 Draw the small signal equivalent circuit of Figure 1c and label all components. **{3 marks}**



1 For BJT
1 For R_7
1 For i_s

18 Derive an expression for the transimpedance (collector voltage/input current, v_c/i_{in}) of Fig. 1c. **{7 marks}**
Hint: Start by summing currents at the emitter.



2 Small sig. model

@ E: $i_{in} + i_b + \beta i_b = 0$ (1) 1

$i_{in} + \beta(i_b + 1) = 0$ (2)

But $\beta >> 1$ so... 1 Assumption

$i_{in} + \beta i_b \approx 0$ (3)

@ C: $V_c = -\beta i_b \cdot R_L$ (4) 1

Solve (4) for i_b:

$i_b = \frac{-V_c}{\beta R_L}$ (5)

(5) → (3):

$i_{in} + \frac{-V_c}{\cancel{\beta} R_L} \cancel{\beta} \approx 0$ (6)

1 Substitution or similar.

$i_{in} \approx V_c / R_L$ (7)

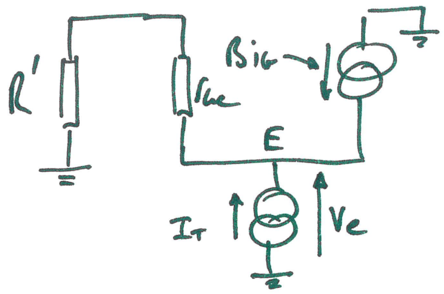
$i_{in} / V_c \approx 1 / R_L$ (8)

$V_c / i_{in} \approx R_L$ (9) 1 Result

19 Why is R_6 is often neglected in the calculation of transimpedance for this circuit. **{2 marks}**

Ideal Norton source has parallel resistance → ∞. Input impedance of common base is usually very low so R_6 tends not to have much effect. It's a current sharing circuit from the small signal model point of view and R_6 gets almost no share.

20 Derive an expression for the output impedance of the circuit in Fig 1a. hint: remove R2 and use a current source to drive the emitter of Q1. **{7 marks}**



@E: $I_T + \beta i_b + i_b = 0$ (1)

$V_e = -i_b(r_{be} + R')$ (2)

From (1) $I_T + I_B(\beta + 1) = 0$ (3)

But assume $\beta >> 1$ ($\therefore \beta + 1 \approx \beta$)

$\therefore I_T + \beta I_B = 0$ (4)

Solve (2) for I_B...

$$I_B = \frac{-V_e}{r_{be} + R'} \quad (5)$$

(5) → (4)

$$I_T + \frac{-V_e \beta}{r_{be} + R'} = 0 \quad (6)$$

Solve for $R_o = V_e / I_T$ ...

$$R_o = \frac{r_{be} + R'}{\beta} \quad (7)$$

But $\frac{r_{be}}{\beta} = 1/g_m$ $\therefore r_{be} = \beta / g_m$

$$\therefore R_o = V_e / I_T = 1/g_m + R'/\beta \quad (8)$$

Now R' is total resistance looking from Q2's base into Q1's emitter so...

$$R_o = \frac{1}{g_{m2}} + \frac{\frac{1}{g_{m1}} + \frac{R_1}{\beta_1}}{\beta_2} \quad (9)$$

21 Hence or otherwise describe the impedance transforming nature of the transistor in a few sentances. **{3 marks}**

- Transistor is a current and voltage controlled device. The current and voltage are bound together by the device characteristics: the current and the voltage both exist in order to drive a transistor's electrodes for example the base. The idea of current and voltage flowing into and being on the base node means that we can calculate a resistance "looking into" the electrode (e.g. into the base node)

- The small signal model shows some connection between input and output because the emitter terminal features in both base and collector circuits, consiquently some coupling can exist between the input and output networks.

- The collector – emitter part of the small signal model is controlled by the base emitter voltage or base current so, provided the emitter is not grounded, the components in the collector circuit can influence the resistance seen looking into the base. Similarly both the base and collector circuits can influence the resistance seen looking into the emitter and the base and emitter circuit can both influence the resistance looking into the collector. The strength of the effect of the influence is dependent on β or g_m (depending wheather the transistor is considered a current controlled device or a voltage controlled device).