MACHAKOS UNIVERSITY

University Examinations for 2018/2019

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF COMPUTING AND INFORMATION TECHNOLOGY

THIRD YEAR SPECIAL/SUPPLEMENTARY EXAMINATION FOR

BACHELOR OF SCIENCE (MATHEMATICS AND COMPUTER SCIENCE)

SMA 130: INTRODUCTION TO ELECTRONICS

DATE: 24/7/2019 **TIME: 8.30-10.30 AM**

INSTRUCTIONS

Answer Question One and Any Other Two Questions.

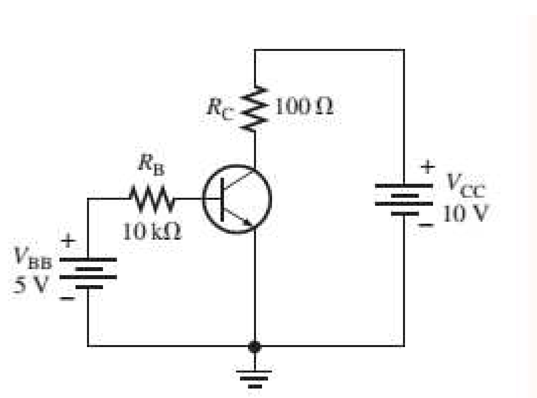
Question 1

a. Explain the difference between a metal, semiconductor and insulator. Use band gap diagrams for illustration.(6 marks)

b. Draw a diagram showing the V-I (voltage-current) characteristics of a pn-diode. Explain the diagram.(4 marks)

c. Discuss how a BJT can be used as:
   i. Amplifier
   ii. Switch(4 marks)

d. Determine I_B, I_C, I_E, V_{BE}, V_{CE} and V_{CB} in the circuit in Fig. Q1-1. The transistor has $\beta_{DC} = 150$.



When the base-emitter junction is forward-biased,

$V_{BE} \cong 0.7\ V$

$I_B = (V_{BB} - V_{BE}) / R_B$

$= (5\ V - 0.7\ V) / 10\ k\Omega = 430\ \mu A$

$I_C = \beta_{DC} I_B$

$= (150)(430\ \mu A)$

$= 64.5\ mA$

$I_E = I_C + I_B$

$= 64.5\ mA + 430\ \mu A$

$= 64.9\ mA$

$V_{CE} = V_{CC} - I_C R_C$

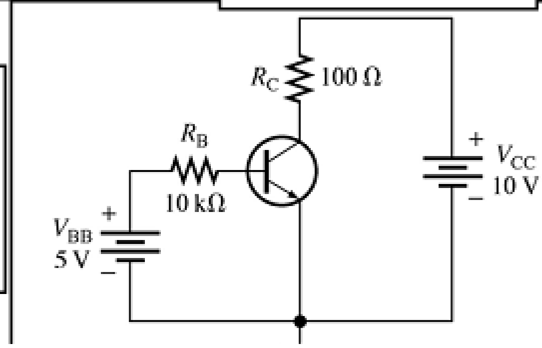
$= 10\ V - (64.5\ mA)(100\ \Omega)$

$= 3.55\ V$

$V_{CB} = V_{CE} - V_{BE}$

$= 3.55\ V - 0.7\ V$

$= 2.85\ V$

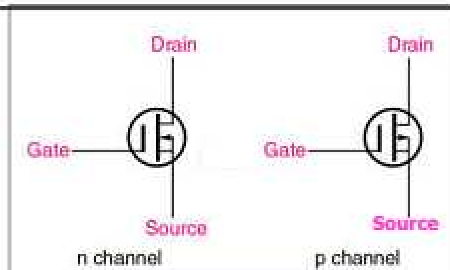


(4 marks)

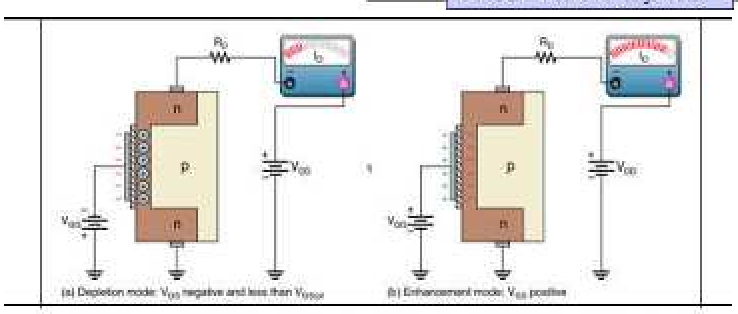
e. Describe the difference between enhancement mode MOSFET and depletion mode MOSFET.

Depletion Mode With a negative gate voltage, the negative charges on the gate repel conduction electrons from the channel, leaving positive ions in their place. Thereby, the n channel is depleted of some of its electrons, thus decreasing the channel conductivity. The greater the negative voltage on the gate, the greater the depletion of n-channel electrons. At sufficiently negative gate-to-source voltage, $V_{GS(off)}$, the channel is totally depleted and drain current is zero.

Enhancement Mode With a positive gate voltage, more conduction electrons are attracted into the channel, thus increasing (enhancing) the channel conductivity.

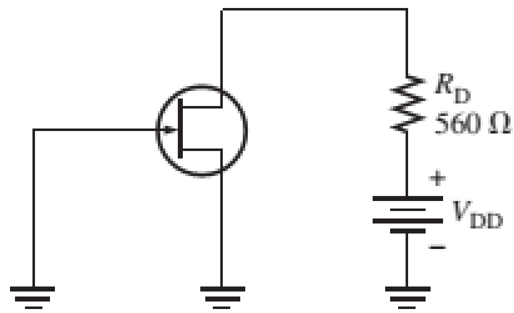


D-MOSFET schematic symbols.



(4 marks)

f. For the JFET in Fig. Q1-2, $V_{GS(off)}$=-4V and I_{DSS} = 12 mA. Determine the minimum value of V_{DD} required to put the device in constant current region of operation when V_{GS}=0V.

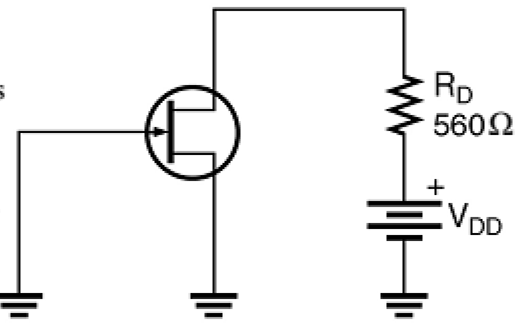


Since $V_{GS(off)} = -4$ V, $V_P = 4$ V.

The minimum value of V_{DS} for

the JFET to be in its constant-current area is

$$V_{DS} = V_P = 4 \text{ V}$$



In the constant-current area with $V_{GS} = 0$ V,

$$I_D = I_{DSS} = 12 \text{ mA}$$

The drop across the drain resistor is

$$V_{RD} = I_D R_D = (12 \text{ mA})(560\Omega) = 6.72 \text{ V}$$

Apply Kirchhoff's law around the drain circuit.

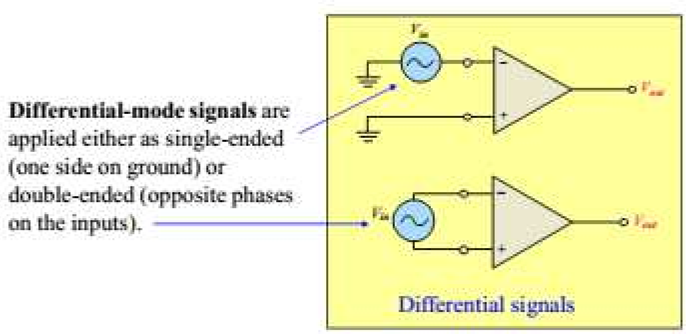
$$V_{DD} = V_{DS} + V_{RD} = 4 \text{ V} + 6.72 \text{ V} = 10.7 \text{ V}$$

This is the value of V_{DD} to make $V_{DS} = V_P$ and put the device in the constant-current area.

(4 marks)

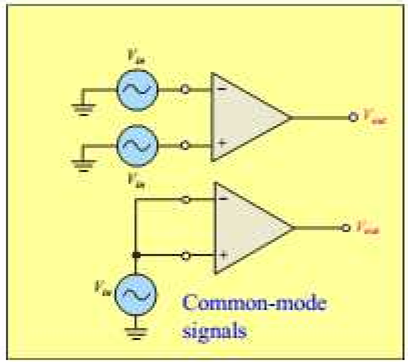
g. Describe the difference between the following operation amplifier terms.

i. Common mode vs differential mode



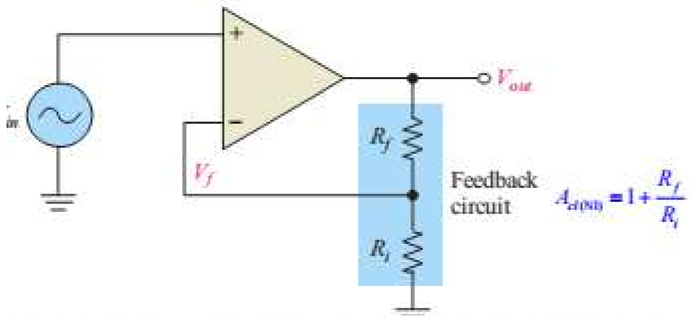
Common-mode signals are applied to both sides with the same phase on both.

Usually, common-mode signals are from unwanted sources, and affect both inputs in the same way. The result is that they are essentially cancelled at the output.

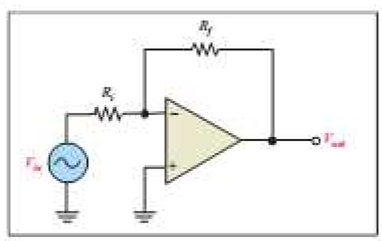


ii. Non-inverting vs inverting amplifier

A **noninverting amplifier** is a configuration in which the signal is on the noninverting input and a portion of the output is returned to the inverting input.



An **inverting amplifier** is a configuration in which the non-inverting input is grounded and the signal is applied through a resistor to the inverting input.



(4 marks)

Question 2

a. Describe the difference between avalanche breakdown and Zener breakdown.

Zener Breakdown

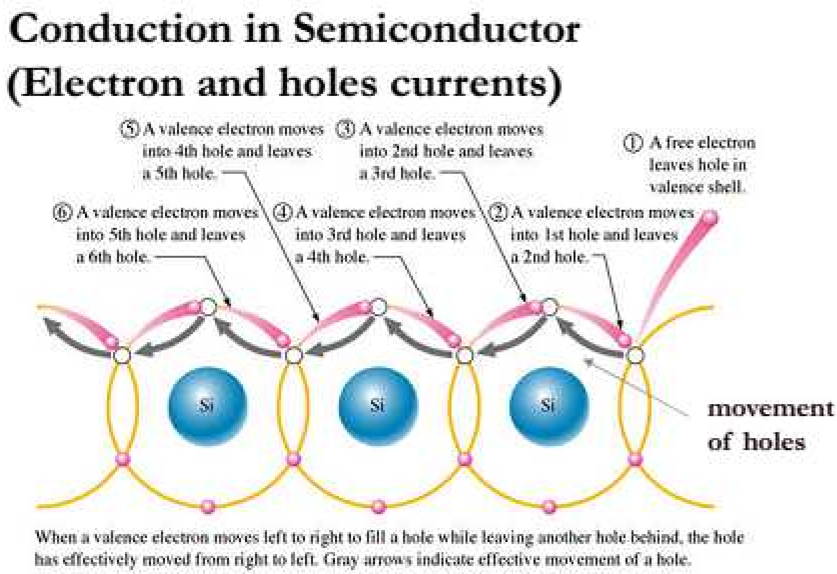
- Zener breakdown phenomena occurs in a pn junction diode with heavy doping & thin junction (means depletion layer width is very small).
- When we increase the reverse voltage across the pn junction diode, what really happens is that the electric field across the diode junction increases
- This results in a force of attraction on the negatively charged electrons at junction.
- This force frees electrons from its covalent bond and moves those free electrons to conduction band.
- When the electric field increases (with applied voltage), more and more electrons are freed from its covalent bonds. This will result in electron-hole pairs being created.
- So a net current is developed and it increases rapidly with increase in electric field.

Avalanche Breakdown

- Avalanche breakdown occurs in a pn junction diode which is moderately doped and has a thick junction (means its depletion layer width is high).
- Avalanche breakdown usually occurs when we apply a high reverse voltage across the diode (obviously higher than the zener breakdown voltage,say Vz).
- So as we increase the applied reverse voltage, the electric field across junction will keep increasing.
- If applied reverse voltage is Va and the depletion layer width is d; then the generated electric field can be calculated as Ea =Va/d
- This generated electric field exerts a force on the electrons at junction and it frees them from covalent bonds.
- These free electrons will gain acceleration and it will start moving across the junction with high velocity.
- This results in collision with other neighboring atoms.
- These collisions in high velocity will generate further free electrons.
- These electrons will start drifting and electron-hole pair recombination occurs across the junction.
- This results in net current that rapidly increases.
- Avalanche breakdown occurs at a voltage (Va) which is higher than zener breakdown voltage (Vz).

(4 marks)

b. Explain how hole current come about in semiconductors.



(3 marks)

c. Explain the effect of temperature in conduction in a semiconductor.

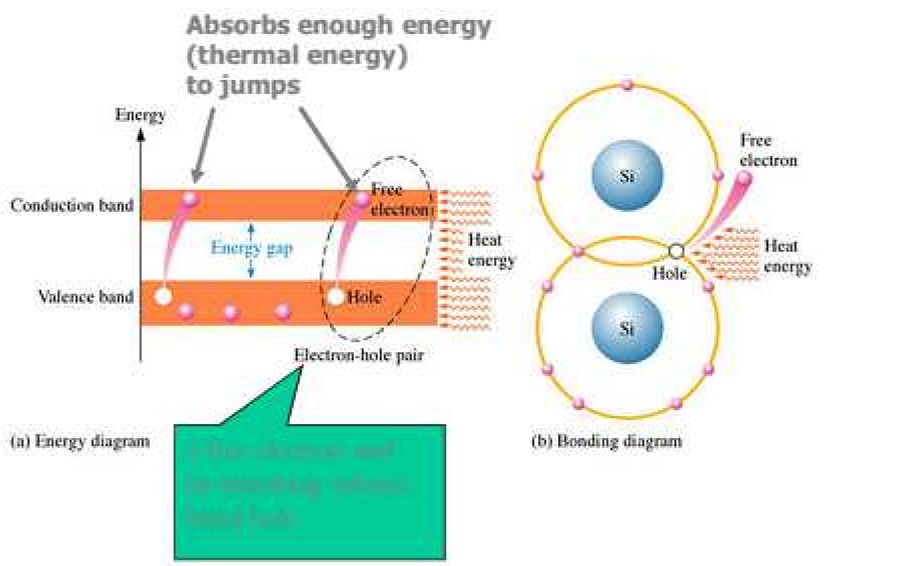


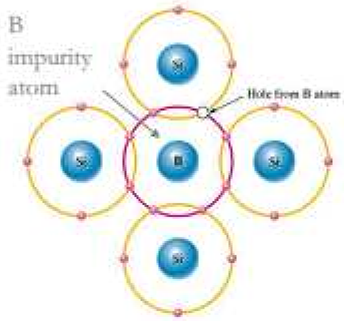
FIGURE 1-11 Creation of electron-hole pairs in a silicon crystal. Electrons in the conduction band are free.

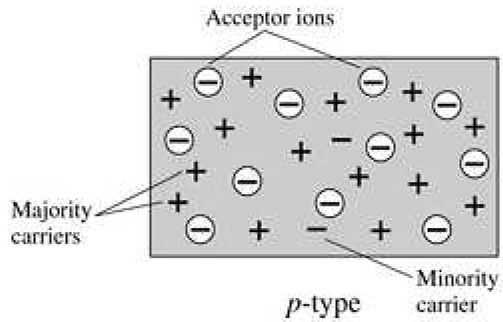
(2 marks)

d. Explain how a p-type semiconductor is formed.

P-type semiconductor:

- Trivalent impurities are added to Si or Ge to create a deficiency of electrons or hole charges
- The holes created by doping process
- The no. of holes can be controlled by the no. of trivalent impurity atoms
- The trivalent atom can take an electron- *acceptor atom*
- Current carries in p-type are holes – majority carries
- electrons – minority carries





(3 marks)

e. Describe the operation of the following diodes and state one application of each.

   i. Zener diode

Zener Diode

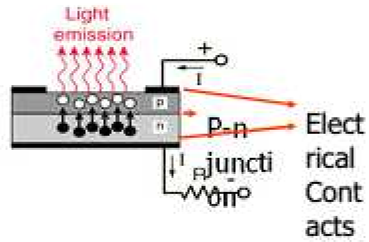
- A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage".
- The device was named after Clarence Zener, who discovered this electrical property
- It is heavily doped in comparison with normal diode to reduce the breakdown voltage.
- Breakdown voltage for commonly available zener diodes can vary widely from 1.2 volts to 200 volts.

- The basic function of **zener diode** is to maintain a specific voltage across its terminals within given limits of load change.
- A zener diode operating in breakdown acts as a voltage regulator because it maintains a nearly constant voltage across its terminals over a specified range of reverse-current values.
- Typically it is used for providing a stable reference voltage for use in power supplies and other equipment.

   ii. Light emitting diode

How does it work?

- A typical LED needs a p-n junction
- There are a lot of electrons and holes at the junction due to excitations
- Light emission is due to recombination process
- Recombination – electron recombination happens when an electron moves from conduction band to valence band, losing energy in the process
- You can recall that free electrons in the conduction band are at a higher energy than the holes in the valence band
- Electrons from n need to be injected to p to promote recombination
- Junction is biased to produce even more e-h and to inject electrons from n to p for recombination to happen



Recombination produces light!!

- Various impurities (dopants) are added during the doping process to establish the **wavelength** of the emitted light.
- The wavelength determines the color of visible light.

The seven segment display is an example of LEDs use for display of decimal digits.

(a) LED segment arrangement and typical device

Other applications: Traffic lights, outdoor video screens, message boards

iii. Photodiode

- Photodiodes - a semiconductor p-n junction device whose region of operation is limited to the reversed bias region
- The **photodiode** is used to vary current by the amount of light that strikes it. It is placed in the circuit in reverse bias.
- As with most diodes when in reverse bias, no current flows when in reverse bias, but when light strikes the exposed junction through a tiny window, reverse current increases proportional to light intensity.
- Converts non-electrical energy such as light to electrical energy.
- Photons - energy transmitted as discrete packages, has a level directly related to the frequency of the travelling wave.
- This energy associated with incident light waves is directly related to the frequency of the travelling wave.
- Dark current - current that will exist with no applied illumination.
- Conductivity of semi-conductor is increased.
- Current flow in the semi-conductor is induced.

(6 marks)

Question 3

a. Discuss how a BJT operates

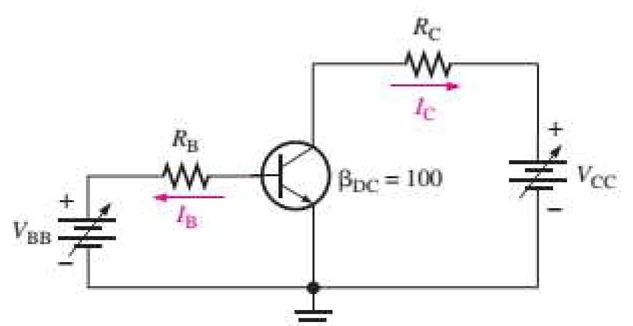
- The **heavily doped *n*-type emitter region** has a very high density of conduction-band (free) electrons, as indicated in Figure 4–4.
- These free electrons easily diffuse through the forward based B_E junction into the **lightly doped and very thin *p*-type base region**, as indicated by the wide arrow.
- The base has a low density of holes, which are the majority carriers, as represented by the white circles.
- A small percentage of the total number of free electrons injected into the base region recombine with holes and move as valence electrons through the base region and into the emitter region as hole current, indicated by the red arrows.

- Most of the free electrons that have entered the base do not recombine with holes because the base is very thin.
- As the free electrons move toward the reverse-biased BC junction, they are swept across into the collector region by the attraction of the positive collector supply voltage.
- The free electrons move through the collector region, into the external circuit, and then return into the emitter region along with the base current, as indicated.
- The emitter current is slightly greater than the collector current because of the small base current that splits off from the total current injected into the base region from the emitter.

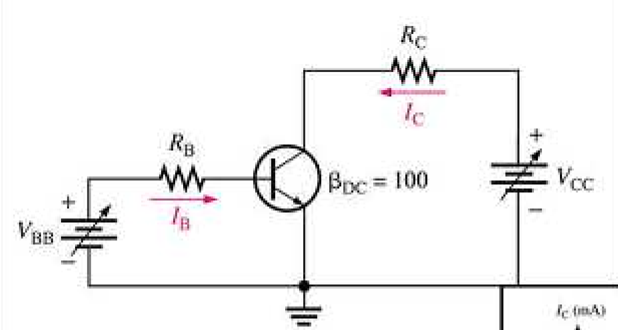
(4 marks)

b. Sketch an ideal family of collector curves for the circuit in Fig. Q4-1 for I_B = 5μA to 25 μA in 5μA increments. Assume that β_{DC} = 100 and that V_{CE} does not exceed breakdown.

(4 marks)

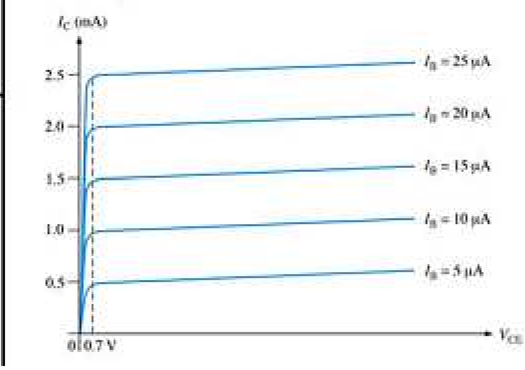


Ex 3-3 Sketch an ideal family of collector curves for for the circuit in Figure for $I_B = 5\ \mu A$ increment. Assume $\beta_{DC} = 100$ and that V_{CE} does not exceed breakdown.



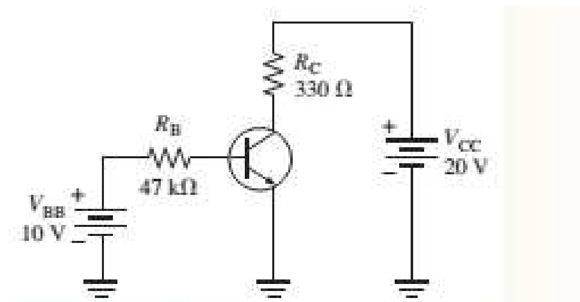
$$\boxed{I_C = \beta_{DC} I_B}$$

I_B	I_C
5 µA	0.5 mA
10 µA	1.0 mA
15 µA	1.5 mA
20 µA	2.0 mA
25 µA	2.5 mA



c. Determine the Q-point for the circuit in Fig. Q4-2 and draw a DC load line. Find the maximum peak value of base current for linear operation. Assume $\beta_{DC} = 200$.

(4 marks)



The Q-point is defined by the values of I_C and V_{CE}.

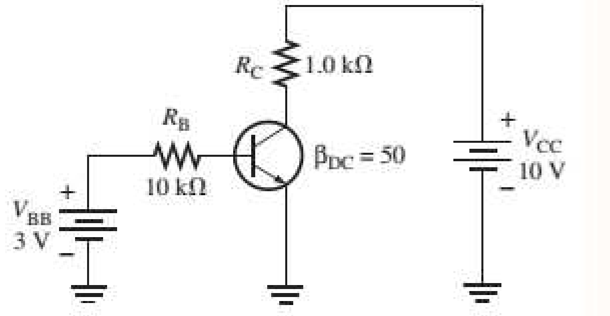
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{10\text{ V} - 0.7\text{ V}}{47\text{ k}\Omega} = 198\ \mu\text{A}$$

$$I_C = \beta_{DC} I_B = (200)(198\ \mu\text{A}) = \mathbf{39.6\ mA}$$

$$V_{CE} = V_{CC} - I_C R_C = 20\text{ V} - 13.07\text{ V} = \mathbf{6.93\ V}$$

The Q-point is at $I_C = 39.6$ mA and at $V_{CE} = 6.93$ V.

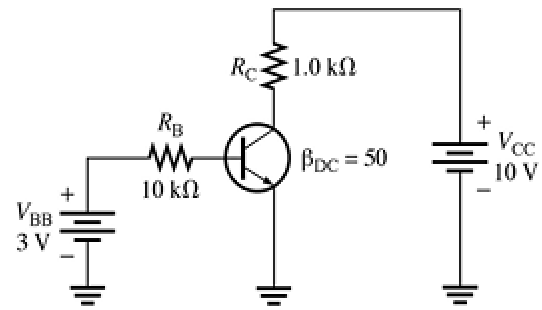
d. Determine whether or not the transistor in Fig. Q4-3 in is saturation mode. Assume $V_{CE(sat)}$=02.V



First, determine $I_{C(sat)}$

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}$$

$$= \frac{10V - 0.2V}{1.0k\Omega} = 9.8\ mA$$



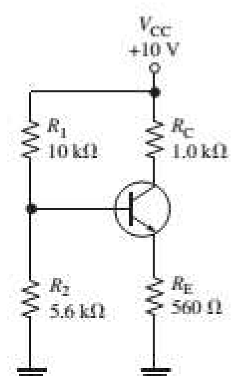
Now, see if I_B is large enough to produce $I_{C(sat)}$.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{3V - 0.7V}{10k\Omega} = \frac{2.3V}{10k\Omega} = 0.23\ mA$$

$$I_C = \beta_{DC} I_B = (50)(0.23\,mA) = 11.5\ mA$$

(4 marks)

e. Determine V_{CE} and I_C in the stiff voltage divider biased transistor circuit in Fig. Q4-4. Assume that β_{DC} = 100.



Solution The base voltage is

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{5.6\,\text{k}\Omega}{15.6\,\text{k}\Omega}\right)10\text{ V} = 3.59\text{ V}$$

So,

$$V_E = V_B - V_{BE} = 3.59\text{ V} - 0.7\text{ V} = 2.89\text{ V}$$

and

$$I_E = \frac{V_E}{R_E} = \frac{2.89\text{ V}}{560\ \Omega} = 5.16\text{ mA}$$

Therefore,

$$I_C \cong I_E = \mathbf{5.16\ mA}$$

and

$$V_C = V_{CC} - I_C R_C = 10\text{ V} - (5.16\text{ mA})(1.0\,\text{k}\Omega) = 4.84\text{ V}$$

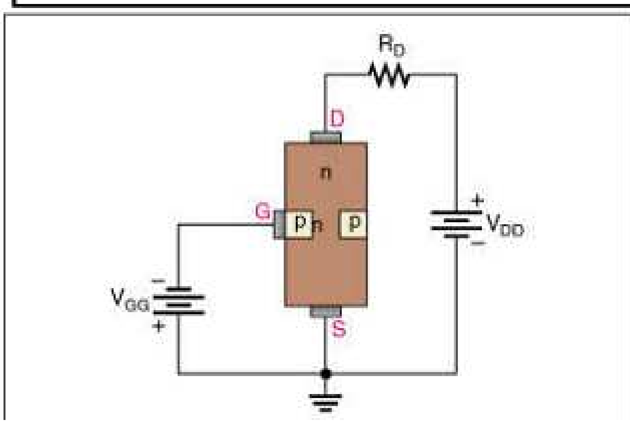
$$V_{CE} = V_C - V_E = 4.84\text{ V} - 2.89\text{ V} = \mathbf{1.95\ V}$$

(4 marks)

Question 4

a. Describe how a JFET operates.

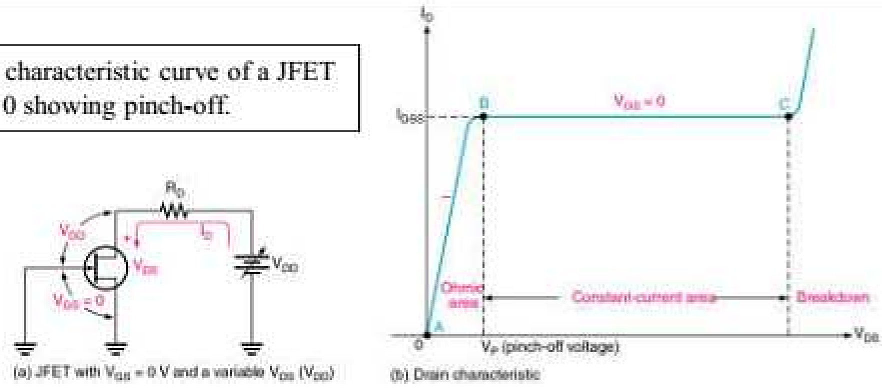
Figure shows dc bias voltages applied to an channel device. V_{DD} provides a drain-to-source voltage and supplies current from drain to source. The current is controlled by a field that is developed by the reverse biased gate-source junction (gate is connected to both sides). With more V_{GG} (reverse bias) the field (in white) grows larger. This field or resistance limits the amount of current flow through R_D.



The JFET is always operated with the gate-source pn junction reverse-biased.

Let's first take a look at the effects with a $V_{GS} = 0V$. I_D increases proportionally with increases of V_{DD} (V_{DS} increases as V_{DD} is increased). This is called the ohmic region (point A to B) because V_{DS} and I_D are related by Ohm's law. As V_{DS} increases from point B to point C, the reverse-bias voltage from gate to drain (V_{GD}) produces a depletion region large enough to offset the increase in V_{DS}, thus keeping I_D relatively constant.

The drain characteristic curve of a JFET for $V_{GS} = 0$ showing pinch-off.



(4 marks)

b. The partial data sheet in Fig for a 2B5459 JFET indicates that typically I_{DSS} for 9mA and $V_{GS(off)}$ = -8V (maximum). Using these values, determine the drain current for V_{GS} = 0V, -1V and -4V.

For $V_{GS} = 0$ V,

$I_D = I_{DSS} = 9$ mA

For $V_{GS} = -1$ V,

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2 = (9mA)\left(1 - \frac{-1V}{-8V}\right)^2$$
$$= (9mA)(1-0.125)^2 = (9mA)(0.766) = 6.89mA$$

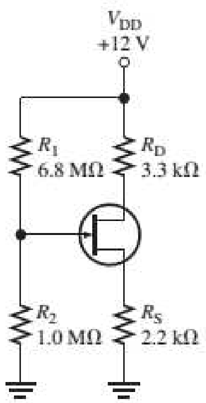
For $V_{GS} = -4$ V,

$$I_D = (9mA)\left(1 - \frac{-4V}{-8V}\right)^2 = (9mA)(1-0.5)^2 = (9mA)(0.25) = 2.25mA$$

(4 marks)

c. Determine I_D and V_{GS} for the JFET with voltage-divider bias in Fig. Q4-1, given that for this particular JFET the parameter values are such that $V_D \cong 7V$.

(4 marks)



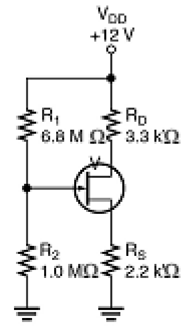
$$I_D = \frac{V_{DD} - V_D}{R_D} = \frac{12V - 7V}{3.3k\Omega} = \frac{5V}{3.3k\Omega} = 1.52mA$$

Calculate the gate-to-source voltage as follows:

$$V_S = I_D R_S = (1.52mA)(2.2k\Omega) = 3.34V$$

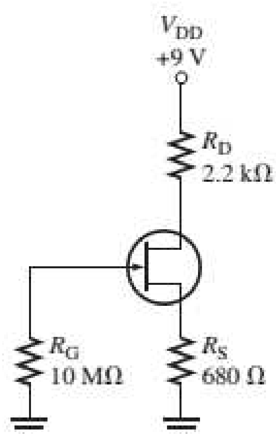
$$V_G = \left(\frac{R_2}{R_1 + R_2}\right) V_{DD} = \left(\frac{1.0M\Omega}{7.8M\Omega}\right) 12V = 1.54V$$

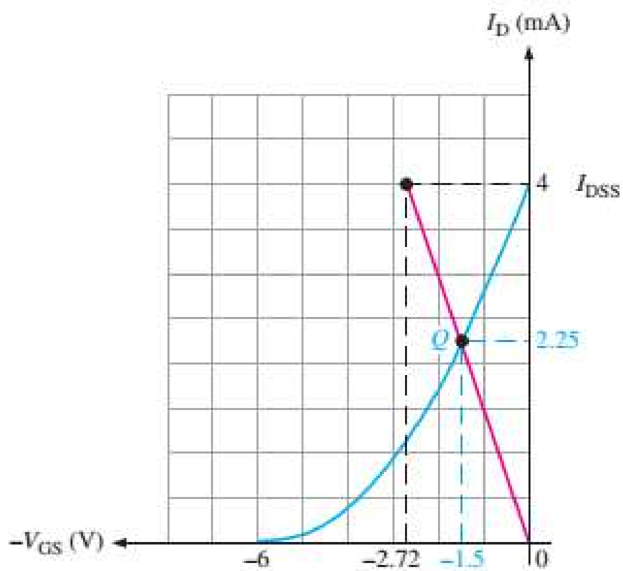
$$V_{GS} = V_G - V_S = 1.54V - 3.34V = -1.8V$$



d. Determine the Q-point for the JFET circuit in Fig. Q4-3. The transfer characteristic curve is shown.

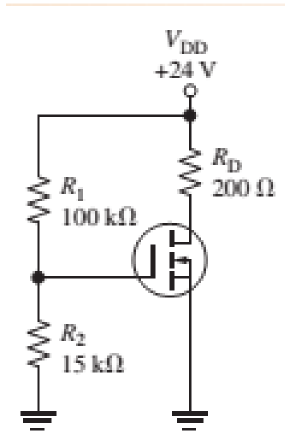
(4 marks)





e. Determine V_{GS} and V_{DS} for the E-MOSFET in Fig. Q4-4. Assume that this particular MOSFET has minimum values of $I_{D(on)}$ = 200 mA and V_{GS} = 4V and $V_{GS(th)}$ = 2V.

(4 marks)



Ex. 7-9 The data sheet for a 2N7008 E-MOSFET gives $I_{D(on)}$ = 500 mA (minimum) at V_{GS} = 10 V and $V_{GS(th)}$ = 1 V. Determine the drain current for V_{GS} = 5 V.

First, solve for K using Equation,

$$K = \frac{I_{D(on)}}{(V_{GS} - V_{GS(th)})^2} = \frac{500\,mA}{(10V - 1V)^2} = \frac{500\,mA}{81V^2} = 6.17\,mA/V^2$$

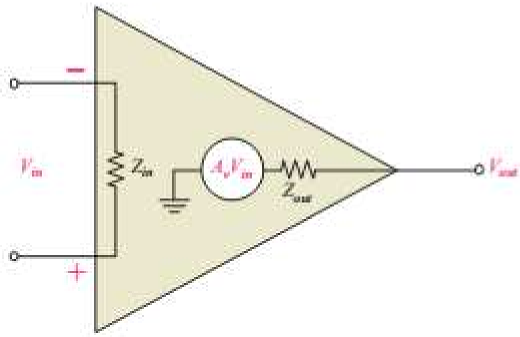
Next, using the value of K, calculate ID for VGS = 5 V.

$$I_D = K(V_{GS} - V_{GS(th)})^2 = (6.17\,mA/V^2)(5V - 1V)^2 = 98.7\,mA$$

Question 5

a. Draw a diagram showing practical op-amp

Practical op-amps have characteristics that often can be treated as ideal for certain situations, but can never actually attain ideal characteristics. In addition to finite gain, bandwidth, and input impedance, they have other limitations.



(3 marks)

b. Define the following Op-amp parameters:

i. Common mode rejection ratio

The ability of an amplifier to amplify differential signals and reject common-mode signals is called the **common-mode rejection ratio (CMRR)**.

CMRR is defined as $\mathbf{CMRR} = \frac{A_{ol}}{A_{cm}}$

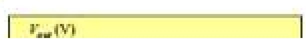
ii. Open-loop voltage gain

Open-loop voltage gain The voltage gain of an op-amp without external feedback.

iii. Slew rate

Slew rate: The **slew rate** is the maximum rate of change of the output voltage in response to a step input voltage

$$\text{Slew Rate} = \frac{\Delta V_{out}}{\Delta t}$$



(3 marks)

c. For a certain D-MOSFET, I_{DSS} = 10 mA and $V_{GS(off)}$ = -8V.

i. Is this an n-channel or a p-channel?

ii. Calculate I_D at V_{GS} = -3 V

iii. Calculate I_D at V_{GS} = +3V

$$\boxed{\text{(a) The device has a negative VGS(off); therefore, it is a n-channel MOSFET.}}$$

$$(b)\quad I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_{GS(off)}}\right)^2 = (10\,mA)\left(1-\frac{-3V}{-8V}\right)^2 = 3.91\,mA$$

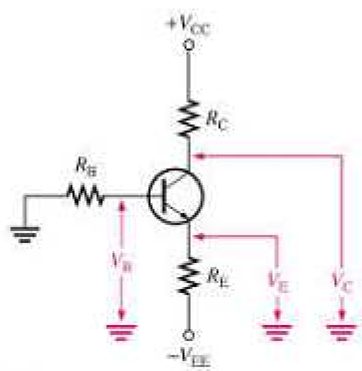
$$(c)\quad I_D = (10\,mA)\left(1-\frac{+3V}{-8V}\right)^2 = 18.9\,mA$$

(6 marks)

f. Describe the following BJT terms:

i. Emitter bias

- This type of circuit is independent of **β** making it as stable as the voltage-divider type.
- The drawback is that it requires two power supplies.



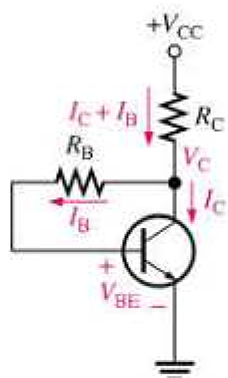
(a)

ii. Collector bias

Collector-feedback bias is kept stable with negative **feedback**, although it is not as stable as voltage-divider or emitter. With increases of I_C, less voltage is applied to the base. With less I_B, I_C comes down as well. The two key formulas are shown below.

$$I_B = (V_C - V_{BE})/R_B$$

$$I_C = (V_{CC} - V_{BE})/(R_C + R_B/\beta_{DC})$$



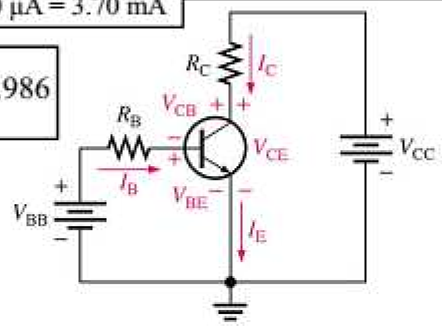
(4 marks)

g. Determine the dc current gain β_{DC} = 100 and the emitter current I_E for a transistor where I_B = 50 µA and I_C = 3.65 mA.

$$\boxed{\beta_{DC} = \frac{I_C}{I_B} = \frac{3.65mA}{50\mu A} = 73}$$

$$\boxed{I_E = I_C + I_B = 3.65 \text{ mA} + 50 \text{ µA} = 3.70 \text{ mA}}$$

$$\boxed{\alpha_{DC} = \frac{I_C}{I_E} = \frac{3.65mA}{3.70mA} = 0.986}$$



(4 marks)