B.Sc. Part-III (Honours) Examination, 2017

Subject : Physics

Paper : XI

Time: 2 Hours **Full Marks: 50**

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

(New Syllabus)

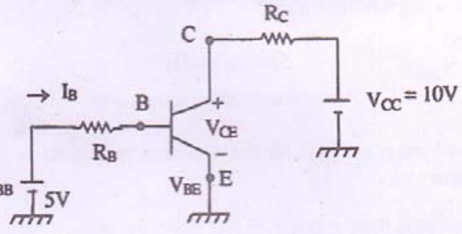
(Electronics)

SECTION-I

Answer *any four* questions. 2×4=8

1. (a) State Richardson's equation explaining different terms.

(b) Consider the following circuit:



Assume $\beta_{d.c} = 100$ and $V_{\mathrm{BE}} = 0.7\mathrm{V}$. Hence find the value of R_B and R_C required to operate the transistor at $I_C = 1mA$ and $V_{\mathrm{CE}} = 5\mathrm{V}$.

(c) Give at least four positive effects of negative feedback.

(d) Comment on (i) output, (ii) Ripple and (iii) Regulation features of L-section and also those of π-section filters.

(e) "Si or Ge diodes do not emit light but GaAs diodes do"—Explain the statement.

(f) The mobility of electron in Si at 300 K is $0.130\ m^2/v.s$. Calculate the diffusion constant of electron.

(g) Express the decimal number–71 in the 8 bit 2's complement form.

SECTION-II

Answer *any two* questions. 12×2=24

2. (a) The plate current I_P in a triode value is given by

$$I_P = 0.005(V_P + 20V_G)^{3/2}\text{mA}$$

where plate voltage V_P and grid voltage V_G are in volts. Calculate the triode parameters at $V_P = 100\text{V}, V_G = 0\text{V}$.

(b) What is Zener diode? Explain the physical mechanism of Zener breakdown in a reverse biased p-n junction. In a volt-ampere characteristic show how does it differ from avalanche breakdown and thermal breakdown phenomena.

(c) With the help of circuit diagram explain the operation of a Zener diode as a voltage regulator.
3+(2+2+2)+3=12

3. (a) Show the basic structure of an n-channel JEFT and briefly explain all the components.

(b) Draw a family of Drain Characteristic curves of a typical n-channel JEFT and explain the nature of the curve.

(c) What is pinch-off voltage V_P? Sketch the depletion region before and after pinch-off.

(d) Using the Drain Characteristic curve explain how a JEFT can be used as a voltage variable resistor.
3+3+(1+2)+3=12

4. (a) Explain how OP-AMP may be used as (i) unit gain buffer and (ii) Inverting amplifier.

(b) Draw a CE amplifier and its small signal low frequency hybrid parameter equivalent circuit. Hence derive expressions for overall current gain and input impedance. Why the simplified h-parameter model is unsuitable for high frequencies? (2+2)+(2+2+2+2)=12

SECTION-III

Answer *any three* questions. 6×3=18

5. (a) With schematic circuit diagram explain the working principle of a BJT collector modulator circuit for generation of AM wave.

(b) A diode envelope detector uses a parallel RC network with $R = 220\text{K}\Omega$ and $C = 200\text{pF}$. If an AM wave with 40% modulation is fed to this detector, what is the highest modulation frequency that can be detected with tolerable distortions? 4+2=6

6. (a) Drawing the necessary circuit diagram (using a BJT) obtain the expression of frequency of oscillation of Colpitts oscillator.

(b) A Colpitts oscillator has a coil with inductance of 40μH and is tuned by a capacitor of 750 pF across the amplifier input and 2500 pF across the output. Find the minimum gain which the amplifier must provide to maintain oscillations. 5+1=6

7. (a) Show by algebraic manipulation (with proper justification) that $\overline{AB} + \bar{A} + AB = 1$.

(b) Consider the function $y = \bar{A}B + A\bar{B}$

Show that it can be written as $y = \overline{\overline{\bar{A}B}.\overline{A\bar{B}}}$

Hence, realize it with a NAND only circuit.

(c) Convert the decimal 13.625 to its binary equivalent. 1½+2½+2=6

8. (a) Draw a voltage divider biasing circuit with an emitter resistor. What do you mean by self-bias circuit?

(b) Describe the method of finding Q-point using load line and transistor characteristic curves. 3+3=6

9. State and explain law of mass action in the context of semiconductor. What do you mean by "effective mass"? How do you get effective mass of hole in valance bond? 3+2+1=6

B.Sc. Part-III (Honours) Examination, 2017

Subject : Physics

Paper : IX

Time: 4 Hours **Full Marks: 100**

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

(Old Syllabus)

Group A

1. Answer *any eight* questions from the following: 2×8=16

(a) Obtain the de Broglie wavelength of a photon of energy E.

(b) Write a statement of 'Bohr's correspondence principle'.

(c) Explain qualitatively the origin of 'continuous' and 'characteristic' X-ray spectra.

(d) State the postulates of the 'Special Theory of Relativity'.

(e) What should be the velocity of a rod so that its length is contracted by 1%?

(f) Why is it that an arbitrary phase factor (for example, $e^{i\delta}$) can always be multiplied with the wave function of a particle without any physical consequence?

(g) Obtain the spectrum of energy eigenvalues of a particle of mass m, described by the wave function $\psi_n(x) = A\sin(n\pi x/L)$, where L is a constant.

(h) Show that $\langle xp\rangle - \langle px\rangle = i\hbar$, where x, p are position and momentum operators respectively and the symbol $\langle\ \rangle$ signifies expectation value taken in an arbitrary state ψ.

(i) Draw the ground-state and the first excited state wave functions of a linear harmonic oscillator and comment on the parities of the states as suggested by the diagrams.

(j) Calculate the kinetic energy of an electron in MeV which can probe the nuclear dimension.

(k) Why is the radioactive decay a statistical process?

(l) Describe briefly how the photons striking the photocathode of a scintillation counter cause an avalanche of electrons.

(m) The experimental value of the quadrupole moment of the nucleus, ${}_8O^{16}$ is 0. What then is the shape of this nucleus?

(n) How can you distinguish between leptons and quarks in terms of the fundamental forces by which they interact?

Group B

Answer *any four* questions, taking at least *one* from each section. 12×4=48

SECTION-I

2. (a) Discuss the aspects of the photoelectric effect which cannot be explained by classical physics.

(b) Write Einstein's photoelectric equation and explain the significance of the terms therein.

(c) Draw and briefly describe an experimental device which can demonstrate the photoelectric effect. 3+(1+3)+(2+3)=12

3. (a) Explain the 'spin-orbit coupling' of atomic electron and consequent doubling of spectral lines with the necessary equations.

(b) Write a comparative description of the atomic transitions, which give rise to (i) emission of visible light, (ii) emission of characteristic x-rays. Elucidate the transitions which cause the characteristic X-ray spectra of the K, L, M and N series. 6+(2+4)=12

4. (a) An inertial frame O' has velocity (v, 0, 0) with respect to another inertial frame O. If (x', y', z', t') and (x, y, z, t) are the space-time coordinates of an event in O' and O respectively, write the equations which connect these two sets of coordinates.

(b) Using the equations in (a), obtain, (i) the aberration of light from a distant star in terms of the earth's velocity v_e, (ii) the frequency ν' of a light pulse received in O', which has been transmitted in O with frequency ν. 4+3+5=12

SECTION-II

5. A particle of mass m is confined in a one-dimensional box of rigid walls so that it is in the following potential:

$V = 0$ for $-a < x < a$

$V \to \infty$ for $x < -a$ and $x > a$.

The wave function of this particle is found to be

$\psi = C\left(cos\frac{\pi x}{2a} + sin\frac{3\pi x}{a} + \frac{1}{4}cos\frac{3\pi x}{2a}\right)$, inside the wall, and $\psi = 0$ outside the wall.

(a) Calculate C such that the wave function is normalized.

(b) If a measurement of total energy is made, what are the possible values of such a measurement and what is the probability to measure each of them? 6+3+3=12

6. (a) Write down the Schrödinger equation of a one-dimensional harmonic oscillator and the expression of the energy eigenvalue spectrum of such an oscillator.

(b) The lowest-energy eignefunction of this oscillator is given by $\psi_0(x) = \left(\frac{2\pi\nu}{\mathrm{h}}\right)^{1/4} e^{-(\pi m\nu/\mathrm{h})x^2}$, where m is the mass and ν is the classical frequency of the oscillator.

If $\bar{T}$and $\bar{V}$ are respectively the expectation values of kinetic and potential energies of the oscillator in the above state, show that $\bar{T} = \bar{V} = E_0/2$, where E_0 is the zero point energy. (2+1)+(6+3)=12

SECTION-III

7. (a) Elucidate the main observations in the experiment of scattering of alpha particles on gold target, which led to the discovery of the nucleus.

(b) Explain, with simple diagrams, the concept of scattering angle (θ) and impact parameter (b) in the analysis of the alpha-particle scattering experiment on a nucleus.

(c) Describe with a diagram the determination of atomic masses by the Bainbridge mass spectrograph.

2+(2+2)+6=12

8. (a) By which interaction beta particles are emitted from the nucleus? What is the order of magnitude of the range of this interaction?

(b) How did the neutrino hypothesis of Pauli explain the angular momentum conservation and the continuous energy spectrum of the beta particle in the beta decay process?

(c) Elucidate, with a diagram, the experiment by Reines and Cowan for the detection of antineutrinos.

(1+1)+(2+2)+6=12

9. (a) Draw a schematic diagram of the betatron showing the essential parts.

(b) Describe the working principle of the betatron with the help of necessary formulae. 4+8=12

Group C

Answer *any six* questions, taking at least *one* from each section. 6×6=36

SECTION-I

10. A free electron at rest scatters an X-ray photon and thereby the wavelength of the latter changes. Find this change in the wavelength in terms of the scattering angle. 6

11. Obtain the expression of the quantized energies of a one-dimensional harmonic oscillator by applying the Wilson-Sommerfeld quantization rule. 6

SECTION-II

12. Starting from the relativistic form of Newton's second law of motion, obtain the equation of mass-energy equivalence of a particle. 6

13. The frame O′ moves with respect to the frame O in the positive x-direction with uniform velocity v. Obtain the Lorentz transformation equations involving the components of the electric and magnetic fields in these two frames of reference. 6

SECTION-III

14. Following the Bohr model, obtain the expressions of radii of stable orbits and the corresponding energies of the electron in the hydrogen atom. 3+3=6

15. Starting from the time-dependent Schrödinger equation in three dimensions, obtain the expressions of probability density and probability current density by setting up the continuity equation. 3+3=6

16. Both the states ψ_{em} and $(L_x + iL_y)\psi_{em}$ are eigenstates of the operators L^2 and L_z, $\vec{L}$ being the orbital angular momentum operator. If the eigenvalues of L^2 and L_z for ψ_{em} are $l(l+1)\hbar^2$ and $m\hbar$ respectively, find the corresponding eigenvalues of the state $(L_x + iL_y)\psi_{em}$. 3+3=6

SECTION-IV

17. (a) Write the expressions of (i) mass defect and (ii) binding energy of a nucleus of mass M, having N neutrons and Z protons.

(b) Obtain the mass defect and binding energy per nucleon of the ${}_{47}\text{Ag}^{108}$ nucleus in atomic mass unit and MeV respectively. (1+1)+(2+2)=6

18. (a) What are the constituents of the 'primary cosmic rays' and the 'cosmic ray showers'?

(b) Describe how the pi-meson was discovered by the 'Nuclear Emulsion Technique'. (1+1)+4=6

19. (a) What is the difference between leptons and quarks so far as their participation in the fundamental interactions is concerned.

(b) Two electrons are kept fixed at a certain distance apart. Calculate the ratio of the magnitudes of the gravitational and the electrical forces between them. 1+5=6

Useful data:

$h = 6.626 \times 10^{-34}\text{J.s}$, $C = 2.998 \times 10^{8}\ m/\text{s}$,

$C = 2.998 \times 10^{8}\ m/\text{s}$, $e = 1.602 \times 10^{-19} C$,

$m_e = 9.109 \times 10^{-31} kg$ $G = 6.670 \times 10^{-11} Nm^2/kg^2$

$\epsilon_0 = 8.8 \times 10^{-12} C^2/N.m^2$ $1\ eV = 1.602 \times 10^{-19}\text{J}$

$M_p = 1.007825u$, $M_n = 1.008665u$,

$M_{\text{Ag}} = 107.905949u$, $1u = 931.5\ \text{Me}V$,

(New Syllabus) B.Sc. Part-III (Honours) Examination, 2017.
Paper - XI (Electronics)

Section - I

1. (a) $J = AT^2 e^{-\left(\frac{e\phi}{kT}\right)}$

where A ⇒ constant independent of the metal
T ⇒ temperature of the metal in Kelvin (K)
$e\phi$ ⇒ work function of the metal
k ⇒ Boltzmann's constant. (JK^{-1})
{e ⇒ electronic charge magnitude. (C)
ϕ ⇒ voltage equivalent of work function (V)}
J ⇒ Thermionic emission current density [Amp/m^2]

(b) From the given circuit diagram,

$$R_C = \frac{V_{CC} - V_{CE}}{I_C} = \frac{10V - 5V}{1mA} = 5k\Omega$$

Again, $I_B \simeq I_C/\beta_{d.c.} = \frac{1mA}{100} = 0.01mA$

$$R_B = \frac{V_{BB} - V_{BE}}{I_B} = \frac{5V - 0.7V}{0.01mA} = 430k\Omega$$

(c) (i) Stabilizes the gain of an amplifier against circuit parameters and voltage supply variations.

(any 4 will do)

(ii) Reduces nonlinear, phase and frequency distortions.
(iii) Increases the bandwidth and hence improves frequency response of an amplifier.
(iv) Input and output impedances can be modified suitably by using negative feedback.
(v) Can reduce internal noise in an amplifier.

(d) For L-section filters: (i) output voltage is relatively low, (ii) low ripple at high currents which makes this type of filter suitable for large load currents, and (iii) Regulation is good except for very low currents.

For π-section filters:

(i) output is relatively high

(ii) Ripple is proportional to load current $\left(\propto \frac{1}{R_L}\right)$

(iii) Regulation is poor.

(e) Physical principle underlying the operation of a LED is the emission of radiation due to recombination of holes and electrons in a special type of semiconductor. The principle of conservation of momentum requires that the electron and the hole which are going to recombine must have exactly equal and opposite momentum. This requirement is very stringent. In Si and Ge such recombination takes place indirectly via traps or recombination centres. As a result the energy liberated goes to heat the crystal. Hence Si and Ge are unsuitable for the construction of LED. However, GaAs being a direct gap semiconductor recombination in it takes place directly and the excess energy is emitted in the form of photon.

(f) From Einstein's relation,

$$\frac{D_n}{\mu_n} = \frac{kT}{e}$$

where D_n is the diffusion coefficient for electrons

(must be written)

μ_n is the mobility of electrons.

k is Boltzmann's constant

T is Temperature is absolute unit.

e is electronic charge.

(units must be written)

$$\therefore D_n = \frac{kT\mu_n}{e} = \frac{1.38\times10^{-23}\,\mathrm{J\,K^{-1}} \times 300\,\mathrm{K} \times 0.130\,\mathrm{m^2/V\text{-}s}}{1.6\times10^{-19}\,\mathrm{C}}$$

$$= 0.0034\ \mathrm{m^2/s}$$

(g) 8 bit sign-magnitude form of +71 is

01000111

∴ 2's complement form of $(-71)_{10}$

= 2's complement of 01000111

= 10111000 + 1

= 10111001.

Section – II

2. (a) $I_P = 5\times10^{-6}\left(V_P + 20V_G\right)^{3/2}$ A

$$\therefore \mu = -\left.\frac{\partial V_P}{\partial V_G}\right|_{I_P} = r_p \times g_m$$

$$g_m = \left.\frac{\partial I_P}{\partial V_G}\right|_{V_P} = 5\times10^{-6}\times\frac{3}{2}\left(V_P+20V_G\right)^{1/2}\times 20$$

$$= 150\times10^{-6}\left(100+20\times0\right)^{1/2} \text{ A/V}$$

$$= 1500\times10^{-6} \text{ A/V} = 1.5 \text{ mA/V}.$$

$$\& \ 1/r_p = \left.\frac{\partial I_P}{\partial V_P}\right|_{V_G} = 5\times10^{-6}\times\frac{3}{2}\left(V_P+20V_G\right)^{1/2}\times 1$$

$$= \frac{15}{2}\times10^{-6}\left(100+20\times0\right)^{1/2} \text{ A/V}$$

$$= \frac{15\times10}{2}\times10^{-6} \text{ A/V}$$

$$= 75\times10^{-6} \text{ A/V}.$$

$$\therefore r_p = \frac{1}{75\times10^{-6}} \text{ V/A}$$

$$\therefore \mu = \frac{1}{75\times10^{-6}}\,\frac{V}{A}\times 1500\times10^{-6}\,\frac{A}{V} = 20$$

2. (b) Please see A1 and next page →

2. (b)

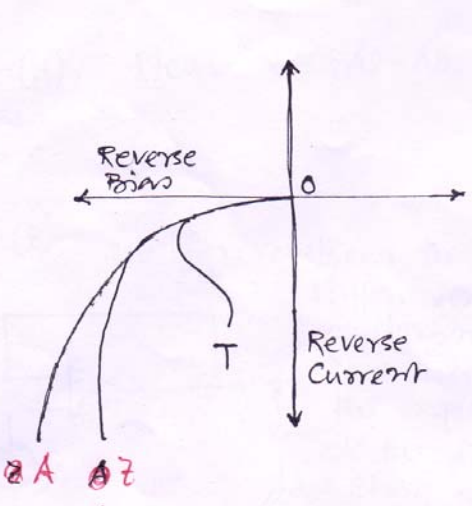
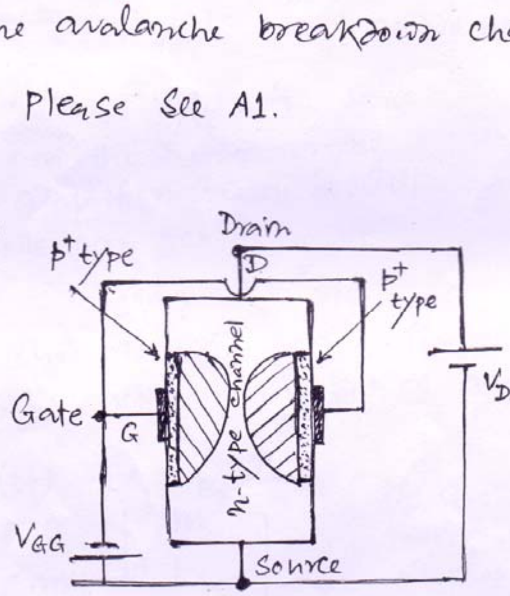


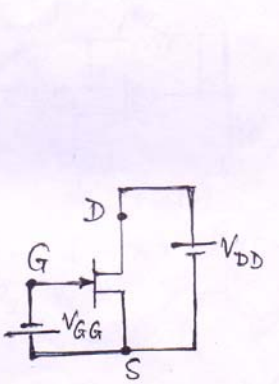
Fig shows volt-ampere characteristics of a p-n junction in breakdown region. [From the figure it can be seen that the thermal breakdown (T) has a negative differential resistance region.] Z represents the Zener breakdown while A represents the avalanche breakdown characteristic.

2. (c) Please See A1.

3. (a)

(1½)



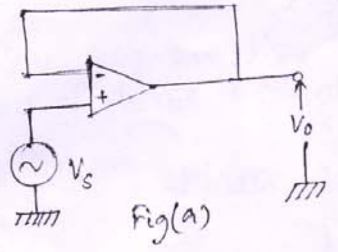


Circuit symbol with supply voltages.

The basic structure of an n-Channel JFET consists of a uniformly doped n-type semiconductor bar with two ohmic contacts at its two ends. Current is caused to flow through the bar by applying a voltage between the end terminals. (1½) The terminal through which the majority carriers (here electrons) enter the bar is called SOURCE. The other terminal through which the majority carriers leave the bar is called DRAIN. On two sides of the n-type bar p-n junctions are formed by doping the sides heavily with p-type impurities. These impurity regions are called the GATE. The region of the n-type bar between the two gates regions through which the majority carriers move from source to drain is called CHANNEL.

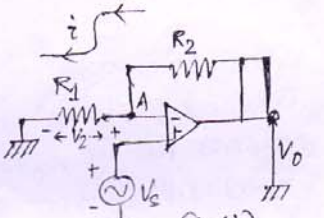
3. (b) - (d). Please See A2-A3.

4. (a) (i) The figure shows the circuit of a unit gain buffer. Since it has practically an infinite input resistance and zero output resistance. It allows the input voltage to be transferred to the output without any change and at the same time avoids the loading of the source.



Fig(a)

Here, $V_0/V_s = 1$ Since from the non-inverting amplifier shown beside, we can get



Fig(b)

$$V_0/V_s = 1 + R_2/R_1$$

And in unit gain buffer amplifier shown in fig(a) we have made $R_1 = \infty$ and/or $R_2 = 0$.

(ii)

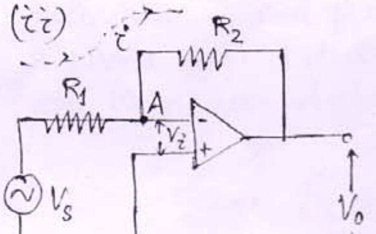


Fig shows an inverting amplifier using an OP AMP. The amplifier employs negative feedback through the resistor R_2. If v_i is the potential at A, then output $v_0 = -Av_i$. Since the open loop gain $A \to \infty$, for a finite v_0 we must have $v_i \to 0$. Also since input impedance $R_i \to \infty$, practically no current enters into the OP AMP input terminals. Thus the point A remains at ground potential and this is known as "virtual ground". Thus current i through R_1 is also the current through R_2.

$$\therefore i = \frac{v_s - v_i}{R_1} = \frac{v_i - v_0}{R_2}$$

Since open loop gain $v_o/v_i \to \infty$ So for a finite v_o, $v_i \to 0$.

$$\therefore i = \frac{v_s - 0}{R_1} = \frac{0 - v_o}{R_2}$$

$\therefore$ Close loop gain of the inverting OP-AMP is,

$$v_o/v_s = -R_2/R_1$$

The negative sign indicates that the output is 180° out of phase with the input.

4. (b) Please See A3.

&

At high frequencies the collector junction capacitance tends to short the load. So its effect must be included. At high frequencies the time taken by the carriers, injected into the base, to diffuse through the base may become comparable with the signal time period. Then some carriers may get trapped in the base and take unusually long time to reach the collector. As a result combination in the base increases, the transistor α and β decreases. The time delay introduces a phase shift between collector and emitter currents and introduces distortion in the output signal.

Section - III

5. (a) Please See A4.

5. (b) The RC time constant is limited as

$$RC \leqslant \frac{1}{m_a \cdot \omega_m}$$

$m_a \to$ modulation index
$\omega_m \to$ modulating frequency.

$$\therefore f_m \leqslant \frac{1}{2\pi m_a R.C.} =$$

$$\therefore f_m\Big|_{max} = \frac{1}{2 \times \pi \times 0.4 \times 220 \times 10^3\,\Omega \times 100 \times 10^{-12}\,F}\,Hz = 9.04\,Hz$$

6. (a) Please See A4.

6. (b) For a Colpitts oscillator using transistor, the minimum value of h_{fe} required for sustained oscillation is,

$$h_{fe} = C_2/C_1 = 3.3$$

7. (a) $\overline{AB} + \overline{A} + AB = \overline{A} + \overline{B} + \overline{A} + AB$ (using De Morgan's law)

$= \overline{A} + \overline{B}(1+A) + AB$ $\left[\because \overline{A}+\overline{A} = \overline{A} \text{ and } 1+A = 1\right]$

$= \overline{A} + \overline{B} + A(\overline{B}+B)$

$= \overline{A} + \overline{B} + A$ $\quad [\because B+\overline{B} = 1]$

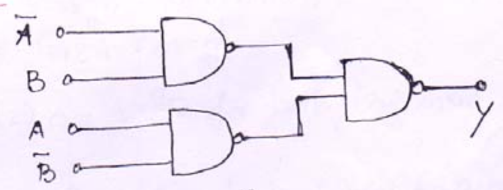
$= 1 + \overline{B}$ $\quad [\because A+\overline{A} = 1]$

$= 1$

(b) $Y = \overline{A}B + A\overline{B}$

$\therefore \overline{Y} = \overline{\overline{A}B} \cdot \overline{A\overline{B}}$

$\therefore Y = \overline{\overline{Y}} = \overline{\overline{\overline{A}B} \cdot \overline{A\overline{B}}}$ (Applying De Morgan's theorem)



NAND only circuit.

(c) Integer part

$$\begin{array}{r|l l} 2 & 13 & 1 \\ 2 & 6 & 0 \\ 2 & 3 & 1 \\ 2 & 1 & 1 \\ & 0 & \end{array}$$

$\therefore (13)_{10} = (1101)_2$

Fractional part

$0.625 \times 2 = 1.250 = 0.25$ plus a Carry 1

$0.25 \times 2 = 0.50 = 0.50$ plus a Carry 0

$0.50 \times 2 = 1.00 = 0$ plus a Carry 1

$\therefore (0.625)_{10} = (0.101)$

$\therefore$ Adding integer and fractional parts, $(13.625)_{10} = (1101.101)_2$

8. Please see A5.

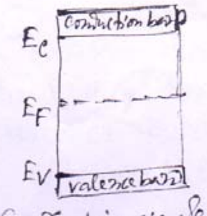
9. It can be shown that the concentration n of free electrons in the conduction band and concentration p of free holes in the valence band in a semiconductor is given by

$$n = 2.\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2} e^{-(E_c-E_F)/kT} = N_c\, e^{-(E_c-E_F)/kT} \quad (1)$$

$$\text{and } p = 2.\left(\frac{2\pi m_h^* kT}{h^2}\right)^{3/2} e^{(E_v-E_F)/kT} = N_v\, e^{(E_v-E_F)/kT} \quad (2)$$

where,

k = Boltzmann const
T = Temperature in absolute scale.
h = Planck's constant.
m_e^* = Effective mass of electrons
m_h^* = effective mass of holes
E_c = Energy corresponding to the bottom of conduction band
E_V = Energy corresponding to the top of valence band
E_F = Fermi energy.



for Intrinsic Semiconductor

Eqs. (1) and (2) are valid for both intrinsic and extrinsic semiconductors.

∴ product of electron-hole concentrations under thermal equilibrium is given by,

$$np = N_c N_v\, e^{-(E_c-E_v)/kT} = N_c N_v\, e^{-E_G/kT} \quad (3)$$

where $E_G \equiv E_c - E_v$ and the product becomes independent of Fermi level. And since it is valid for either intrinsic or extrinsic semiconductor material, writing $n = n_i$ and $p = p_i = n_i$ we get,

$$np = n_i^2 \quad (4)$$

where n_i is the intrinsic carrier concentration. Eq. (4) is called the mass action law. It states that the product of free electron and hole concentrations is constant independent of the amount of donor or acceptor impurities at a particular temperature.

Addition of n-type impurities increases the number of free electrons over the intrinsic carrier concentration but decreases the number of holes due to increased recombination of holes with excess electrons. Similarly the addition of p-type impurities increases the number of holes and decreases the number of free electrons.

It is found that when quantum mechanics is used to specify the motion within the crystal of an electron or hole on which external field is applied, it is possible to treat the hole and electron as imaginary classical particles with effective positive masses m^* and m_e^* respectively. This approximation is valid provided that the externally applied fields are much weaker than the internal periodic fields produced by the lattice structure. In a perfect crystal these imaginary particles respond only to the external fields. Thus, the effective-mass approximation allows us to use Newton's laws to determine the effect of external forces on the electrons and holes within the crystal by removing the quantum features of the problem.

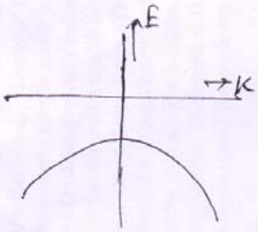


Fig shows E-K diagram of holes. In valence band

$$E = p^2/2m_h^* = \frac{\hbar^2 k^2}{2m_h^*}$$

$$\therefore dE/dk = \frac{2k\hbar^2}{2m_h^*} = \frac{k\hbar^2}{m_h^*}$$

$$\therefore d^2E/dk^2 = \hbar^2/m_h^*$$

$$\therefore m_h^* = \hbar^2 \left(d^2E/dk^2\right)^{-1}$$

which is the effective mass of holes in valence band.

A 1

2.(c

2(b)(i)

4.11 Zener Diode

In a reverse biased p-n junction a small amount of reverse saturation current flows which is almost independent of the reverse-bias voltage. However, if the reverse voltage exceeds certain critical value the current suddenly rises to a very large value. This is referred to as breakdown in diodes. Unless the diode is specially designed it may damage the diode. Diodes which have adequate power dissipation capabilities to operate in the breakdown region are called *breakdown diodes* or *Zener diodes*. The breakdown of a p-n junction may occur due to the effects of a strong electric field in the depletion region or the heat generated by the reverse current. The breakdown phenomenon is reversible. The diode returns to normal function on removal of the applied reverse voltage, provided the reverse current does not exceed the maximum rating prescribed by the manufacturer.

(ii) Zener breakdown

When both sides of a p-n junction are heavily doped, the width of the depletion region becomes very small and electric field at the junction may become very high with relatively small reverse bias. In this case carriers get very few chances to generate new carriers through collision. But in the simple covalent bonding model it is possible to initiate the breakdown by the direct rupture of covalent bonds. The strong electric field existing at the junction may exert sufficiently strong force on a bound electron and tear it out of the covalent bond. The new electron-hole pairs thus created increase the reverse current. The phenomenon was theoretically explained by Zener to result from quantum mechanical tunnelling of carriers through the barrier at the junction. In tunnelling phenomenon an electron confined by a potential barrier, higher than its energy, is shown to have a finite probability to pass through the barrier. The probability of tunnelling increases with the decrease in the width of the depletion region i.e., with the increase in doping concentration. Break down by the above process is known as *Zener breakdown*. It does not involve collisions of carriers with the crystal ions. The field strength starting the process is about 2×10^7 V/m. This value can be reached at or below 6 V for heavily doped diodes. For lightly doped diodes the breakdown occurs at voltages greater than 6 V and avalanche multiplication is then the predominant breakdown mechanism. Whatever be the breakdown mechanism, breakdown diodes are most commonly called Zener diodes.

* The temperature coefficient of Zener breakdown voltage is negative i.e. breakdown voltage decreases with temperature.

From band theory of solids it is found that for a heavily doped p-n junction under reverse biased condition the n-side conduction band may appear opposite to the p-side valence band (Fig. 4.11-1). There exists many empty states in the n-side conduction band opposite to the many filled states of the p-side valence band. If the barrier between the bands is narrow and of finite height a large current may flow due to tunnelling of electrons from the p-side valence band to the n-side conduction band. For lightly doped diodes with higher breakdown voltages the width of the depletion region will be too wide for tunnelling. For this at higher voltages avalanche breakdown is predominant

*

(c) A Simple Zener regulator

A typical application of a Zener diode as a voltage regulator is shown in Fig. 4.11-3. In the breakdown region the voltage across the Zener diode is almost independent of current through it. This fact makes it useful as a voltage-regulator device. The Zener diode in Fig. 4.11-3 maintains a constant output voltage $V_0 = V_Z$ independent of variations in load resistance R_L or the variation of input voltage $V_i (> V_Z)$ so long as the diode remains in the breakdown region.

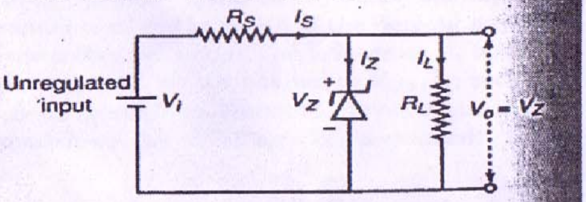


Fig. 4.11-3: A simple Zener regulator

From Fig. 4.11-3 we can write

$$I_S = I_Z + I_L \tag{4.11-4}$$

$$\text{where} \quad I_S = \frac{V_i - V_z}{R_S} \quad \text{and} \quad I_L = \frac{V_0}{R_L} \tag{4.11-5}$$

To discuss *load regulation* let V_i remains constant and R_L is varied. Since the voltage V_Z across the Zener remains constant, I_S *is independent of load*. Hence in this case

$$\delta I_Z = -\delta I_L$$

Thus Zener current changes with change in load current due to change in R_L but output remains constant at V_Z.

Now let us consider *line regulation*. Let R_L remains fixed and V_i is varied. Since V_0 tends to remain constant at V_Z, I_L *remains constant*. Then from Eq. (4.11-4),

$$\delta I_Z \doteq \delta I_S$$

Thus when load is fixed and input varies Zener current I_Z and total current I_S change in such a way as to maintain I_L and hence V_0 constant. Any change in V_i appears across the series limiting resistance R_S.

Choice of R_S

A series resistance R_S is always used to limit the Zener current to less than its maximum current rating I_{ZM}. Otherwise the Zener diode will burn out. There is also a lower limit of the value of I_Z. If I_Z goes below knee current I_{ZK}, Zener fails to regulate the output voltage. So there is a maximum value of R_S for which regulation is obtained. Also, there is a minimum values of V_i for proper circuit operation. Another way to get a loss of regulation is by drawing too much load current.

The minimum value of R_S that prevents the diode from being damaged is given by

$$R_{S,\min} = \frac{V_{i,\max} - V_Z}{I_{ZM}} \tag{4.11-6}$$

where I_{ZM} is given by Eq. (4.11-1).

The maximum permitted value of R_S is set by the condition that the current through the Zener must not go below I_{ZK}. The worst case occurs for $V_{i,\min}$ and $I_{L,\max}$. Then I_Z drops to minimum I_{ZK}. Hence

$$R_{S,\max} = \frac{V_{i,\min} - V_Z}{I_{L,\max} + I_{ZK}} \tag{4.11-7}$$

$$\approx \frac{V_{i,\min} - V_Z}{I_{L,\max}} \tag{4.11-8}$$

A2

3.(b) 9.4 Static Characteristics of a JFET and its d.c. Biasing

A circuit arrangement for drawing the static characteristic curves of a JFET is shown in Fig. 9.4-1. In common source mode the variation of drain current I_D with drain-source voltage V_{DS} taking the gate-source voltage V_{GS} as parameter gives the common source drain characteristics.

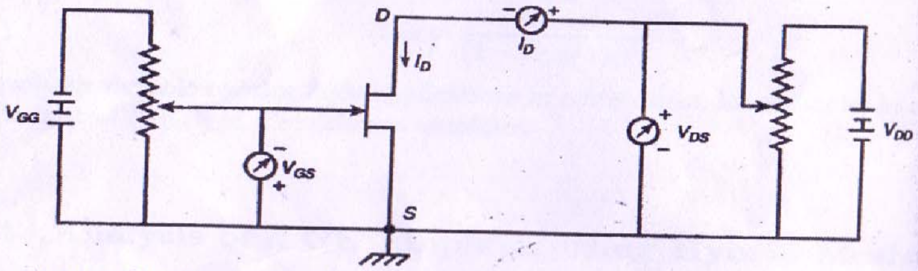


Fig. 9.4-1: Circuit arrangement for drawing the characteristic curves of an *n* channel JFET (for a *p*-channel JFET just reverse the polarities of the batteries and the meters)

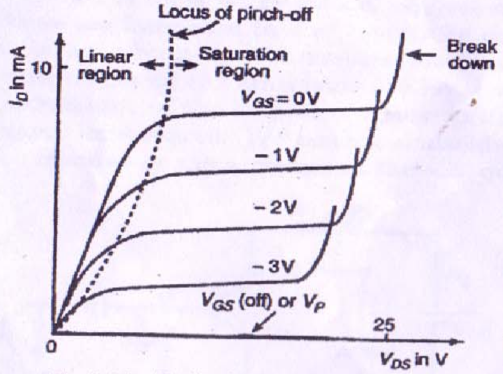
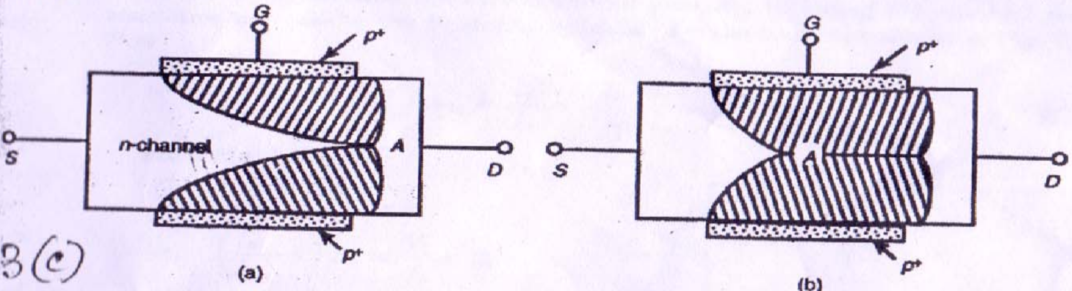


Fig. 9.4-2: Drain characteristics of typical *n*-channel JFET

Fig. 9.4-2 shows the drain characteristics for a typical n-channel JFET. Each of characteristic curves can be divided into there regions: (i) the ohmic or *linear region* where I_D is approximately proportional to V_{DS} (ii) *the saturation region* where I_D is almost constant and independent of V_{DS} and (iii) the *breakdown region* where I_D rises abruptly to large values. To explain the nature of the curves we first consider the curve with $V_{GS} = 0$.

For $V_{GS} = 0$, the channel between the gate regions is entirely open and the n-channel bar acts as a simple resistor. Hence as V_{DS} is increased from zero I_D increases linearly with it. As I_D increases the ohmic voltage drop along the n-type channel region reverse biases the gate junctions.Depletion layers are formed and the effective conducting channel cross-section decreases. Because of the gradual ohmic potential drop along the length of the channel the gate becomes more reverse biased near the drain end than at the source end. So the width of the depletion layer increases as we go from source to drain end. I_D is thus constrained to flow through a wedge-shaped channel. As V_{DS} is increased more the channel becomes narrower causing the resistance between the source and the drain to increase. This makes I_D versus V_{DS} curve nonlinear. Ultimately at a certain value of V_{DS} the depletion regions meet each other and the channel is said to be *pinched off*. In pinch-off condition the current almost saturates. The pinch-off current flows due to injection of carriers from channel into the depletion region at A, where the depletion regions meet (Fig. 9.4-3). As V_{DS} is increased further the width of the depletion regions tend to increase and the point A moves towards the source. The voltage at A, however, remains unchanged and hence I_D remains constant. At high values of V_{DS}, I_D suddenly rise to large values. This is due to avalanche breakdown across the reverse biased gate junction. Between pinch-off point and breakdown the JFET acts like a *constant current source*.



3(c)

Fig. 9.4-3: Channel of JFET (a) at pinch-off (b) beyond pinch-off

If a gate voltage V_{GS} is applied to reverse bias the gate junction then depletion region is formed even when $V_{DS} = I_D = 0$. This decreases the channel cross-sectional area for current flow. It increases resistance and reduces the saturation drain current. Since the reverse bias voltage is added up with the ohmic voltage drop due to flow of I_D, pinch-off and breakdown both occur for smaller values of V_{DS}. The dashed line in Fig. 9.4-2 is the locus of pinch-off point for various V_{GS}. It is given by the equation $V_{DS} = V_{GS} - V_P$ where V_P is the pinch-off voltage as defined below.

Gate cut off or pinch off voltage

From the drain characteristics of Fig. 9.4-2 it is found that in the saturation region I_D decreases with increase in reverse bias gate source voltage. Practically for certain value of V_{GS} the drain current is reduced to zero. This voltage is called *gate-source cut off voltage* or pinch off voltage and is labelled as $V_{GS}(\text{off})$ or V_P. At this voltage the conducting channel disappears. Note that V_P is negative for n-channel device and positive for p-channel device.

3(d)

JFET as a voltage variable resistor

From the characteristic curves of JFET (Fig. 9.4-2) it is observed that below the pinch-off and for small V_{DS}, the $V_{DS} - I_D$ curves are almost straight lines of slope determined by the value of the gate voltage V_{GS}. Moreover, a JFET is a symmetrical device in which the source and the drain may be interchanged. Hence below pinch-off a JFET may be

3(d) Contd.

A3

→ used as a linear resistor whose resistance value can be varied by the gate voltage. The ohmic d.c. rresistance of the JFET when operated in the ohmic region with $V_{GS} = 0$ is approximately given by $R_{DSO} = \frac{|V_P|}{I_{DSS}}$ where I_{DSS} is the value of saturation drain-to-source current with the gate shorted to the source (i.e., with $V_{GS} = 0$). The variation of resistance level with V_{GS} can be closely approximated by following relation:

$$R_{DS} = \frac{R_{DSO}}{(1 - V_{GS}/V_P)^2}$$

A voltage variable resistor finds applications in many areas, for example, in automatic gain control (AGC) in a multistage amplifier.

4(b)

7.4 Analysis of a CE Amplifier using Hybrid Model

We consider the basic circuit of a single stage low frequency CE amplifier using a simple resistive load R_L as shown in Fig. 7.4-1. R_s is the internal resistance of the signal source. To analyse the performance of the amplifier analytically the circuit of Fig. 7.4-1 is replaced by its a.c. equivalent h-parameter circuit as shown in Fig. 7.4-2. As we are interested in a.c. quantities only, the d.c. sources and coupling capacitors are short circuited. We assume low frequency operation such that various internal capacitances of the transistor are not appreciable in effect. Now to understand the performance of the amplifier we are to find out current gain, voltage gain, input and output impedances. We assume sinusoidal variations for the current and voltage and use effective or r.m.s. values of the a.c. quantities for analysis.

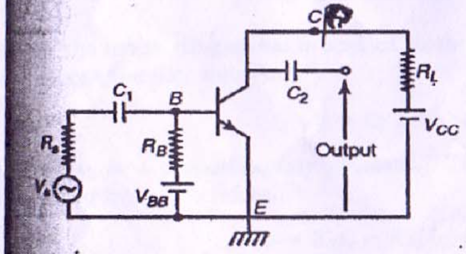


Fig. 7.4-1: A basic CE amplifier

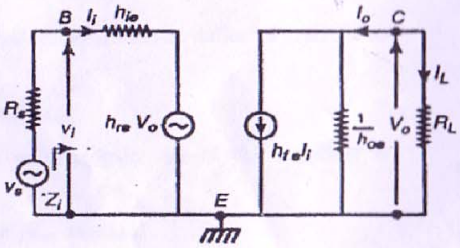


Fig. 7.4-2: h-parameter equivalent circuit

Current gain (A_I) :

The current gain, A_I, is defined as the ratio of output load current to input current i.e.,

$$A_I = \frac{I_L}{I_i} = -\frac{I_0}{I_i} \tag{7.4-1}$$

The circuit diagram of a Colpitts oscillator using a trans and a LC network is shown in fig 11.11-1. Note that the circu is similar to that of Hartley oscillator ——— with the capacitor and inductor interchanged in the tank circuit. The resistors R_1, R_2, $R_E - C_E$ combination and the d.c. source V_{CC} provide stabilized self bias. C_i and C_o act as blocking or coupling capacitor. R_{fc}, the radio frequency choke, prevents RF current from reaching the collector supply; it also provides d.c. load for the collector. The inductor L and the capacitors C_1, C_2 form the frequency determining tank circuit. As soon as the supply is switched on, a transient flows in the tank circuit. The voltage across C_1 is fed back to the input of the CE amplifier. Since the points O is grounded the points A and B are 180° out of phase. The CE amplifier introduces additional phase shift of 180°. Thus the Barkhausen phase requirement of 360° around the loop for oscillation is fulfilled. If the amplifier provides sufficient gain the condition of unity loop gain i.e., $|A\beta| = 1$ may be satisfied and sustained oscillation will be obtained.

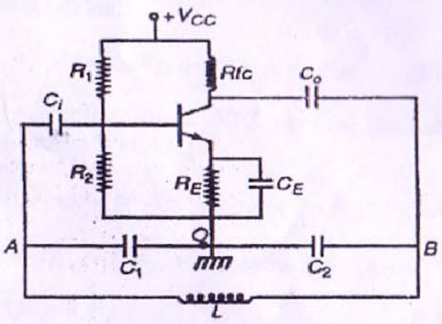


Fig. 11.11-1: A BJT Colpitts Oscillator

To analyse the performance of the oscillator we consider, for simplicity, the approximate h-parameter equivalent circuit of Fig. 11.10-2 where Z_1, Z_2 and Z_3 represent capacitive and inductive reactances. Let $Z_1 = jX_1$, $Z_2 = jX_2$ and $Z_3 = jX_3$ where $X_1 = -\frac{1}{\omega C_1}$, $X_2 = -\frac{1}{\omega C_2}$, $X_3 = \omega L$, ω being the angular frequency of oscillation. Now applying Kirchhoff's law to the input and output circuits we get the Eqs. (11.10-1) and (11.10-2). Then, as done in **Section 11.10**, we may arrive at the Eq. (11.10-4) and (11.10-5).

Now from Eq. (11.10-5),

$$-\frac{1}{\omega C_1} - \frac{1}{\omega C_1} + \omega L = 0 \text{ or, } \omega^2 = \frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) \qquad (11.11\text{-}1)$$

Therefore, the frequency of oscillation is

$$f = \frac{1}{2\pi\sqrt{LC_s}} \qquad (11.11\text{-}2)$$

where C_s is given by

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} \qquad (11.11\text{-}3)$$ ✓

From Eq. (11.10-4) we get the condition of oscillation as

$$-(1 + h_{fe})\frac{1}{\omega C_2} + \omega L = 0 \text{ or, } 1 + h_{fe} = \omega^2 LC_2$$

not needed

Using Eq. (11.11-1),

$$h_{fe} = \frac{C_2}{C_1} \qquad (11.11\text{-}4)$$

Thus $h_{fe} \geq C_2/C_1$ is the condition for sustained oscillation.

8.

6.4 Voltage Divider Bias or Self Bias

The most commonly used voltage divider bias arrangement applied to an *n-p-n* transistor in CE mode is shown in Fig. 6.4-1. The current directions shown in Fig. 6.4-1 are the actual conventional current directions. The voltages are denoted by the standard double subscript notations. C_1 and C_2 are the so called coupling or blocking capacitors. Reactances of C_1 and C_2 are chosen very small at the lowest signal frequency and hence they allow easy flow to a.c. but blocks d.c. These capacitors make it possible to connect the input signal source or the output of the amplifier to the input of the next stage without affecting its d.c. biasing.

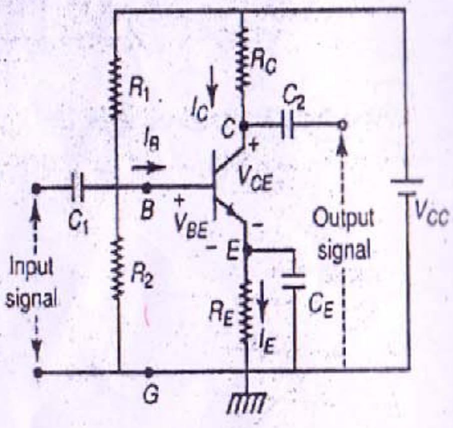


Fig. 6.4-1: Voltage divider bias arrangement

The capacitor C_E is known as *by-pass capacitor*. Its reactance is chosen very small compared to R_E. It prevents R_E from providing a.c. negative feedback gain loss but d.c. negative feedback remains. In this circuit R_1 and R_2 act as *potential divider*. The p.d. across R_E tends to reverse bias the emitter junction while p.d. across R_2 tends to forward bias it. If temperature increases, I_{CBO} and I_C increase. The p.d. across R_E increases which makes the emitter junction less forward biased. As a result base current I_B decreases. This in turn checks the increase in I_C and it tries to bring I_C back to its original value. Thus the stabilization of Q-point is maintained automatically by the circuit and for this the circuit is called *self bias circuit*.

Determination of Q-point by using load line

To find the d.c. operating point we can neglect the capacitors. Now applying Thevenin's theorem to the left of the base B and the ground G in Fig. 6.4-1 we get the