

XMUT204 Electronic Design

Practice (Mock up) Exam Questions (Answer)

Section A Electrical Conductivity and Semiconductors [35 marks]

1. It is given that nickel metal (Ni) has a resistivity of $69.5 \text{ n}\Omega\cdot\text{m}$ at 20°C .

- a. Calculate the resistance of a piece of Ni wire that is 15 cm in length and 2 mm in diameter. [2.5 marks]

Solution

Resistance of Ni wire, $R = \rho L/A = (69.5 \times 10^{-9})(0.15)/[\pi(1 \times 10^{-3})^2] = 3.32 \times 10^{-3} \Omega$.

- b. Knowing the carrier mobilities of electrons and holes in the crystalline silicon are $1400 \text{ cm}^2/\text{V}\cdot\text{s}$ and $450 \text{ cm}^2/\text{V}\cdot\text{s}$ respectively, calculate the resistance of a round piece of Si wire that has the same dimensions as the Ni wire in (a) (assuming that Si could be made into wire). It is given that the intrinsic carrier concentration of Si is $1 \times 10^{10} \text{ cm}^{-3}$ at 20°C .

[5 marks]

Solution

The resistance of the intrinsic Si wire:

Conductivity of the Si wire: (2.5)

$$\sigma = ne\mu = (1 \times 10^{10})(1.6 \times 10^{-19})(1400+450) = 2.96 \times 10^{-6} (\Omega\text{cm})^{-1}$$

Resistance of Si wire: (2.5)

$$R = 1/\sigma = 1/2.96 \times 10^{-6} = 3.4 \times 10^5 \Omega\text{cm}$$

- c. Explain how the undoped Si in (b) can be doped p-type and explain how this doping process will change the energy band structure and the number of free charge carriers. [5 marks]

Solution

The Si can be doped p-type by adding group III impurities e.g. B, Al, Ga, etc. With these impurities, the energy band structure changes, as for n-doped

materials the extra electron from a donor impurity is excited into the conduction band and there exists the formation of an impurity band. (2.5)

As for p-doped materials, a mobile hole is created in the valence band and by adding more acceptor impurities, an impurity band is created in this region. For a p-doped material, free charge carriers are predominantly holes (e.g. +charges). (2.5)

- d. Calculate the resistance of the same Si wire as in (b) if it is doped p-type to a carrier density of $5 \times 10^{16} \text{ cm}^{-3}$. [5 marks]

Solution

The resistance of the p-doped Si wire:

Conductivity of the Si wire: (2.5)

$$\begin{aligned}\sigma &= ne\mu = (1 \times 10^{10} \text{ cm}^{-3})(1.6 \times 10^{-19})(1,400) + (5 \times 10^{16} \text{ cm}^{-3})(1.6 \times 10^{-19})(450) \\ &= 2.24 \times 10^{-6} + 3.6 = 3.6 (\Omega\text{cm})^{-1}.\end{aligned}$$

Resistance of doped p-type Si wire: (2.5)

$$R = 1/\sigma = 1/3.6 = 0.277 \Omega\text{cm}.$$

- e. Explain qualitatively how the resistance of (i) the Ni wire (ii) the undoped Si wire and (iii) the p-doped Si wire will change if the temperature should increase to 50°C. In each case also give a reason why you expect this trend in resistance with temperature. [5 marks]

Solution

If temperature is increased to 50°C from room temperature, for Ni wire there is no change in the carrier concentration and carrier mobility will decrease due to increased collisions at higher temperature. The conductivity will thus decrease with increase in the temperature. (2.5)

Whereas for undoped (intrinsic) Si wire and p-doped Si wire, we can see an exponential increase in carrier concentration (intrinsic carriers) with increasing temperature. Carrier mobility will slightly decrease due to increased collisions. However, conductivity will strongly increase with increase in the temperature. (2.5)

2. Determine the number of atom in a lattice of GaAs crystal as shown below. Calculate the number of Ga and As atoms in the lattice for one cm^3 of material (note that length of each side of the lattice is 1.2 nm). [10 marks]

Solution

No of Ga and As atoms in the lattice: (5)

- Ga Atoms = $8 \times 1/8$ atoms (in the corners of the lattice) + $6 \times 1/2$ atoms (on the face/side of the lattice) = 4 Ga atoms/lattice.

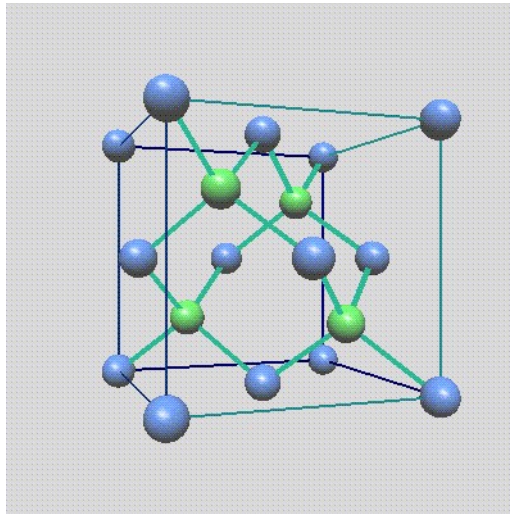
- As atoms = 4×1 atom (inside the lattice) = 4 As atoms/lattice.

No of atoms in 1cm^3 of GaAs crystal: (2.5)

$$= 1/(\text{length})^3 = 1/(1.2 \times 10^{-7})^3 = 5.79 \times 10^{22} \text{ atoms/cell}$$

No of Ga and As atoms: (2.5)

$$= (4+4) \times \text{No of atoms in } 1\text{cm}^3 \text{ of GaAs crystal} = 8 \times 5.79 \times 10^{22} = 4.63 \times 10^{23} \text{ atoms.}$$

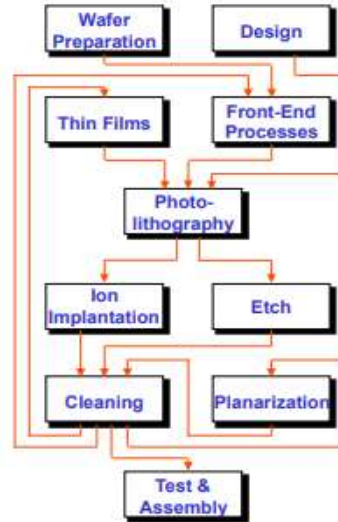


3. Describe the steps required in manufacturing of semiconductor devices.

[2.5 marks]

Solution

- a. Design
- b. Wafer preparation
- c. Front-end processes
- d. Photolithography
- e. Etch
- f. Cleaning
- g. Thin films
- h. Ion implantation
- i. Planarization
- j. Test and assembly



Section B

P-N Junctions and Diodes

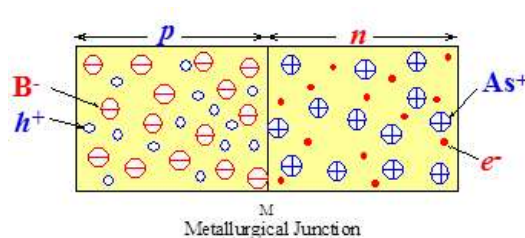
[17.5 marks]

1. A metallurgical junction is formed between N-type and P-type Si.
 - a. Sketch a cross section of this junction immediately after formation (before any charges can move) and show the position of all static and mobile charges.

[2.5 marks]

Solution

Sketch of a cross section of PN junction after its metallurgical formation:



- b. Explain the movement of charge carriers after formation of the junction. What is the driving force for this movement of charge carriers? Explain why the movement of charge carriers across the junction will eventually stop.

[2.5 marks]

Solution

Electric field at the junction that leads to equilibrium of charge settling after the opposite charges are pairing.

- c. It is given that the doping densities are $N_D = 5 \times 10^{15} \text{ cm}^{-3}$ and $N_A = 1 \times 10^{16} \text{ cm}^{-3}$. Calculate the relative width of the depletion layer on each side of the metallurgical junction. [5 marks]

Solution

Relative width of the depletion region of the PN junction.

Build in potential, V_0 : (2.5)

$$V_0 = V_T \ln \left[\frac{N_A N_B}{(n_i)^2} \right] = 0.025 \ln \left[\frac{(5 \times 10^{15})(1 \times 10^{16})}{(1 \times 10^{10})^2} \right] = 0.558 \text{ V}$$

Width of depletion region, W : (2.5)

$$W = \sqrt{\frac{2\epsilon(N_A + N_B)V_0}{eN_A N_B}} = \sqrt{\frac{(2)(8.85 \times 10^{-12})(5 \times 10^{15} + 1 \times 10^{16})(0.558)}{(1.6 \times 10^{-19})(5 \times 10^{15})(1 \times 10^{16})}}$$
$$= 4.22 \times 10^{-7} \text{ cm}$$

- d. Explain how the application of (i) a forward bias and (ii) a reverse bias will change the properties of the junction and how it will influence the movement of charge carriers over the junction and explain the movement of charge carriers over the junction under each of these conditions. [2.5 marks]

Solution

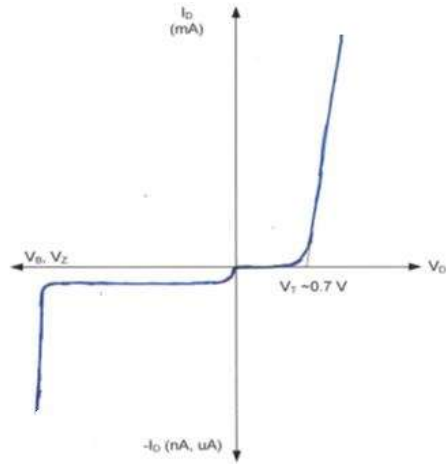
Electrons and holes are constantly replenished by the external voltage sources, so the current eventually would flow in the circuit.

2. For a given PN junction in a typical diode:

- a. Sketch the expected current-voltage curve for the junction in both forward bias and reverse biases. Clearly indicate the relative magnitude of current flow in each of the two regions. [2.5 marks]

Solution

Sketch of current-voltage curve for PN junction in both forward and reverse biases.



- b. An expression for the built-in voltage of a PN junction is given by:

$$V_0 = \frac{kT}{e} \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

Explain how and why this built-in voltage will vary with operating temperature of the diode. [2.5 marks]

Solution

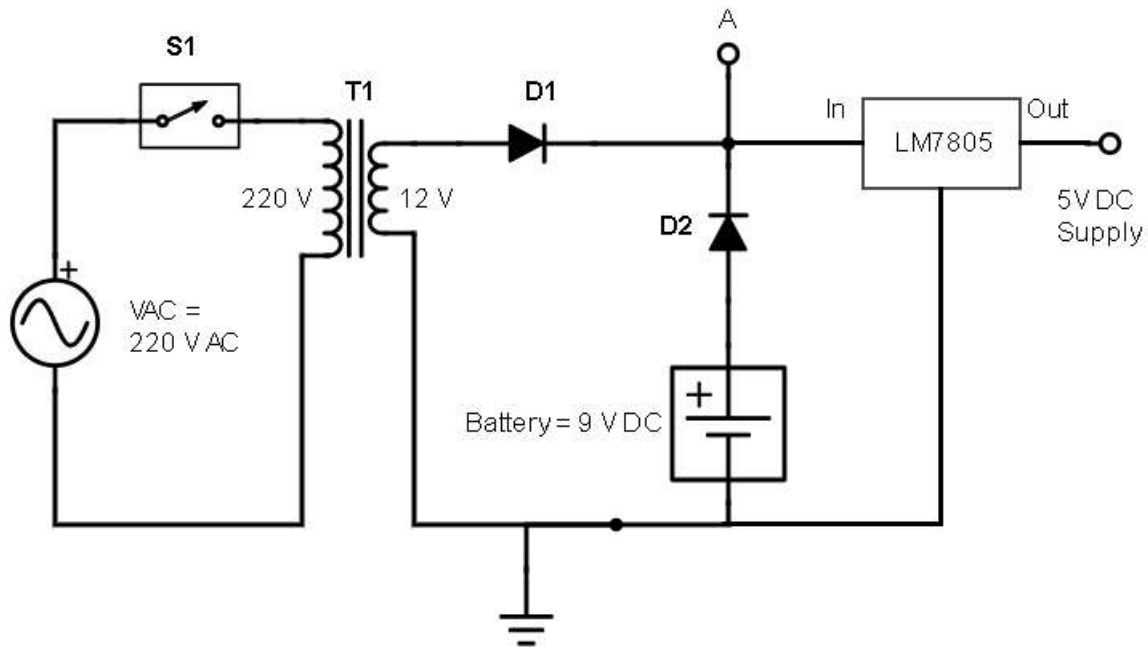
The given equation states that built-in voltage is proportional to temperature. So, increase of temperature means increase in the built-in voltage in the PN junction.

Section C

Diode Applications

[125 Marks]

1. There are many applications of diode in electronics.
 - a. Consider the circuit below showing a regulated 5 V supply from the mains voltage. A switch is incorporated that can disconnect this device from the mains supply.



Now answer the following questions:

- a. What is the purpose of the 9 V battery in the circuit? [2.5 mark]

Solution

The 9 V battery provides bias voltage for the biased clipper part of the circuit.

- b. What is the purpose of each of the two diodes in the circuit? [2.5 mark]

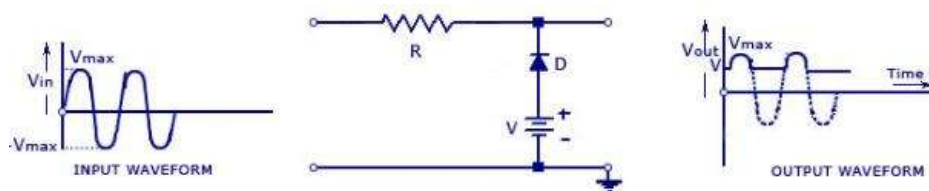
Solution

D1 is part of the half-wave rectifier circuit allowing only positive pulse going through and D2 is part of the biased clipper circuit removing positive waveform of the signal at $V_{bias}-0.7\text{ V}$.

- c. What would be the expected voltage at point A in the circuit when the switch is respectively closed and open? [2.5 mark]

Solution

Ripple voltage at point A in the circuit will drop from supply voltage of 12 V to 8.3 V (e.g. $V_{bias}-0.7\text{ V}$).

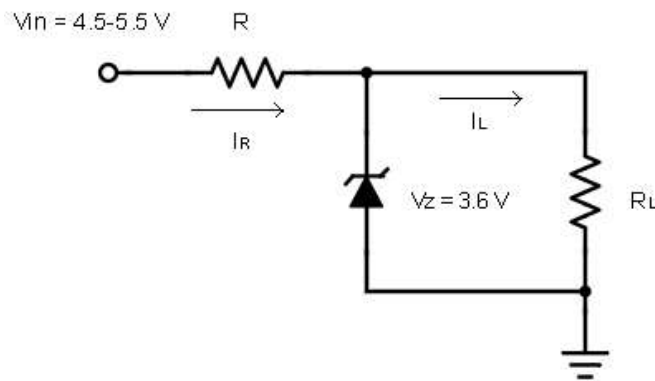


- d. What components are missing from this circuit that you would normally expect? [2.5 mark]

Solution

Missing components are the smoothing capacitors and the load.

2. You need to use a Zener diode as voltage regulator ($V_Z = 3.6 \text{ V}$) as shown in the circuit below. The input voltage, V , can vary between 4.5 and 5.5 V and the load resistance R_L is fixed at 200Ω .



Answer the following questions based on this circuit:

- a. Calculate the load current I_L . [2.5 mark]

Solution

Load current, $I_L = V_Z/R_L = 3.6 \text{ V}/200 \Omega = 18 \text{ mA}$

- b. Calculate the minimum value for the resistor R to ensure turning on of the zener diode assuming $I_{Z(\text{min})} = 2 \text{ mA}$. [5 mark]

Solution

Applying KCL, $I_R = I_Z + I_L$ and assuming $I_{Z(\text{min})} = 2 \text{ mA}$ (2.5)

$$I_R = 2 \text{ mA} + 18 \text{ mA} = 20 \text{ mA}$$

Value of the resistor: (2.5)

$$R = (V_{IN(\text{min})} - V_Z)/I_R = (4.5 \text{ V} - 3.6 \text{ V})/20 \text{ mA} = 45 \Omega$$

This is to ensure that zener diode is on at minimum zener current.

- c. Calculate the maximum power dissipation in the resistor R . [5 mark]

Solution

Maximum power dissipated is when the voltage across the resistor is highest. (2.5)

$$V_R = V_{IN(max)} - V_Z = 5.5 - 3.6 = 1.9 \text{ V}$$

Maximum power dissipated in the resistor: (2.5)

$$P_R = (V_R)^2/R = (1.9)^2/45 = 80.2 \text{ mW}$$

- d. Calculate the maximum power dissipated in the Zener diode. [7.5 mark]

Solution

Maximum power dissipated in the zener diode when the current that flows in the zener diode is at its highest value (notice that current at the load is maintained to be constant).

Current through the resistor: (2.5)

$$I_{R(max)} = (V_{IN(max)} - V_Z)/R = (5.5 - 3.6)/45 = 42.22 \text{ mA}$$

Current through zener diode: (2.5)

$$I_{Z(max)} = I_{R(max)} - I_L = 42.22 \text{ mA} - 18 \text{ mA} = 24.22 \text{ mA}$$

Max. power dissipated in the zener diode: (2.5)

$$P_Z = V_Z I_Z = (3.6)(24.22 \text{ mA}) = 87.2 \text{ mW}$$

3. A light emitting diode is manufactured by forming a PN junction in a semiconductor material that has an energy gap $E_g = 3.1 \text{ eV}$.

- a. Calculate the approximate wavelength of the light that will be emitted by this device. [2.5 mark]

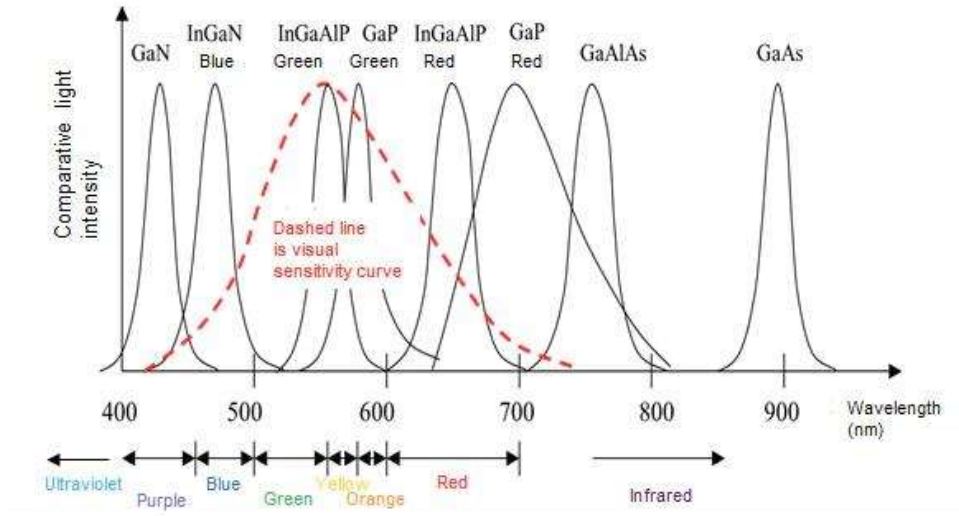
Solution

Wavelength of the light, $\lambda(\text{nm}) = 1240/E_g (\text{eV}) = 1240/3.1 \text{ eV} = 400 \text{ nm}$ (i.e. violet colour).

- b. Sketch the expected output spectrum and explain how this may differ from the wavelength calculated in (i). [5 marks]

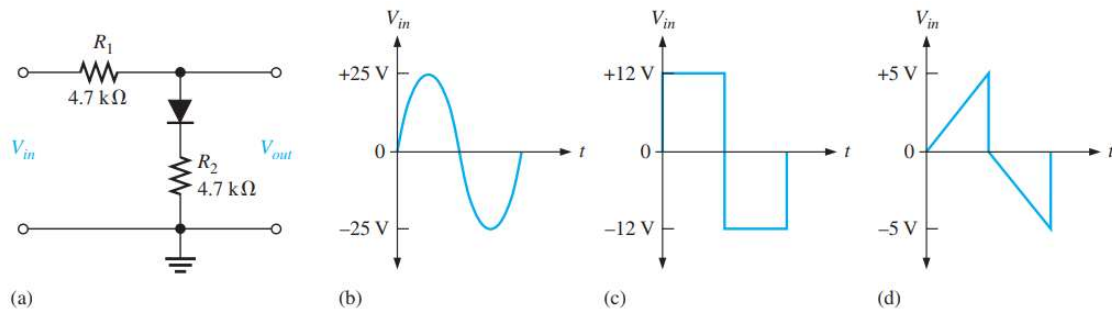
Solution

Sketch of output spectrum of the LED: (2.5)



Based on the sketch above, at the wavelength of 400 nm, the light given out by the LED is at the region of the violet (purple) colour. (2.5)

4. Determine the peak-to-peak output voltage and waveform for the circuit in (a) for each input voltage in (b), (c), and (d). [15 marks]



Solution

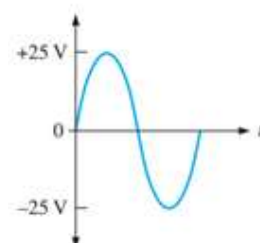
For wave form in (b)

(5)

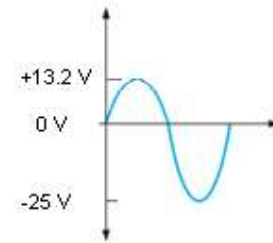
$$V_{+} = [4.7k\Omega / (4.7k\Omega + 4.7k\Omega)] * 25 \text{ V}$$

$$+0.7 \text{ V} = +13.2 \text{ Volt}$$

$$V_{-} = -25 \text{ Volt}$$



input

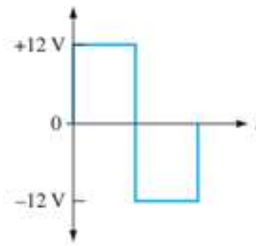


output

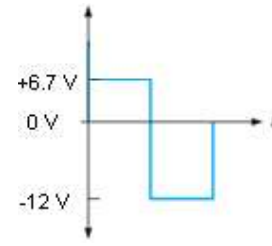
For wave form in (c)

(5)

$V_+ = 4.7\text{k}\Omega / (4.7\text{k}\Omega + 4.7\text{k}\Omega) * 12\text{ V}$
 $+ 0.7\text{ V} = +6.7\text{ Volt}$
 $V_- = -12\text{ Volt}$



input

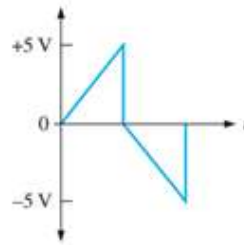


output

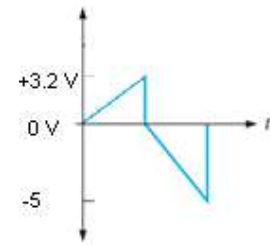
For waveform in (d)

(5)

$V_+ = 4.7\text{k}\Omega / (4.7\text{k}\Omega + 4.7\text{k}\Omega) * 5\text{ V}$
 $+ 0.7\text{ V} = +3.2\text{ Volt}$
 $V_- = -5\text{ Volt}$

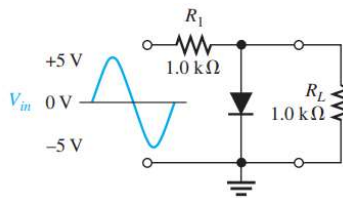


input

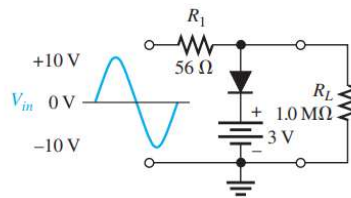


output

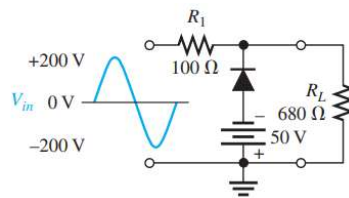
5. Determine the peak-to-peak values and waveform of the voltage across load resistor R_L for each circuit in the figure below. [15 marks]



(a)



(b)



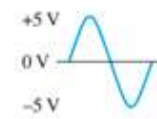
(c)

Solution

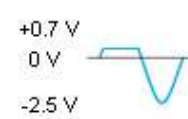
For circuit in (a)

(5)

$V_+ = +0.7\text{ V}$
 $V_- = [1\text{k} / (1\text{k} + 1\text{k})] * (-5\text{ V}) = -2.5\text{ V}$



input

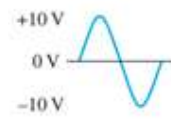


output

For circuit in (b)

(5)

$V_+ = 3\text{ V} + 0.7\text{ V} = +3.7\text{ V}$
 $V_- = [1\text{ M}\Omega / (1\text{ M}\Omega + 56\Omega)] * (-10\text{ V}) = -10\text{ V}$



input



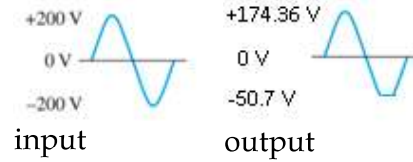
output

For circuit in (c)

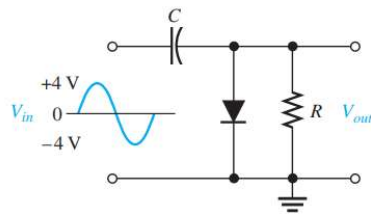
(5)

$$V+: [680\Omega / (680\Omega + 100\Omega)] * (200\text{ V}) = +174.36\text{ V}$$

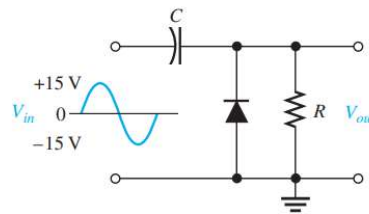
$$V-: -50\text{ V} - 0.7\text{ V} = -50.7\text{ V}$$



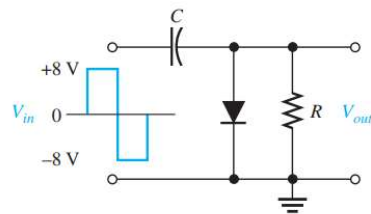
6. For each circuit given in the figure below:



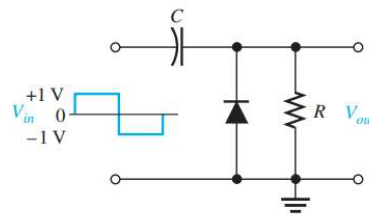
(a)



(b)



(c)



(d)

Sketch the waveforms and determine the peak-to-peak values of the output voltage and DC voltage of each circuit. Assume the RC time constant is much greater than the period of the input. [20 marks]

Solution

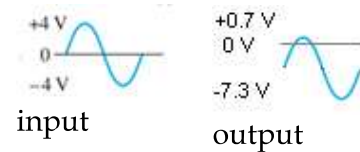
For circuit in (a)

(5)

$$V+: \text{Sinewave which peak at } +0.7\text{ V}$$

$$V-: \text{Sinewave which peak at } -4 - 4 + 0.7 = -7.3\text{ V}$$

$$\text{DC Voltage: } [0.7 + (-7.3)] / 2 = -3.3\text{ V}$$



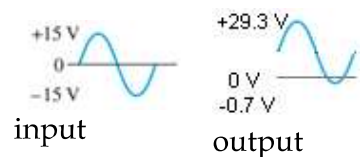
For circuit in (b)

(5)

$$V+: \text{Sinewave which peak at } 15 + 15 - 0.7 = 29.3\text{ V}$$

$$V-: \text{Sinewave which peak at } -0.7\text{ V}$$

$$\text{DC Voltage: } [29.3 + (-0.7)] / 2 = 14.3\text{ V}$$



For circuit in (c)

(5)

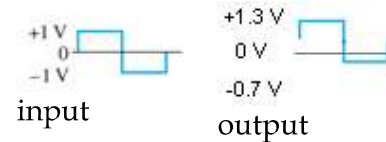
V+: Squarewave which peak at +0.7 V
V-: Squarewave which peak at -8 - 8 + 0.7 = -15.3 V
DC Voltage: $[0.7 + (-15.3)]/2 = -7.3$ V



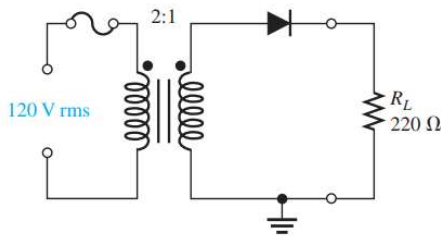
For circuit in (d)

(5)

V+: Squarewave which peak at $1+1-0.7 = +1.3$ V
V-: Squarewave which peak at -0.7 V
DC Voltage: $[1.3+(-0.7)]/2 = +0.3$ V



7. Determine the peak and average power delivered to R_L in the figure given below. [10 marks]



Solution

RMS secondary voltage: (2.5)

$$V_s = V_p (N_s/N_p) = 120 (1/2) = 60 \text{ V (rms)}$$

Average secondary voltage: (2.5)

$$V_s (\text{ave}) (\text{half wave}) = V_s (\text{peak})/\pi = V_s (\text{rms})/(0.707 \times \pi) \\ = 60/(0.707 \times \pi) = 27.02 \text{ V}$$

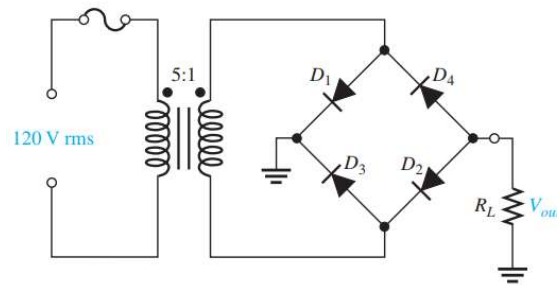
Peak power: (2.5)

$$P (\text{peak}) = V (\text{peak})^2/R = (60/0.707)^2/220 = 32.7 \text{ A}$$

Average power: (2.5)

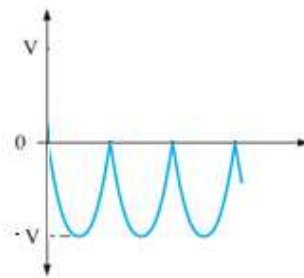
$$P (\text{ave}) = V (\text{ave})^2/R = (27.2)^2/220 = 3.36 \text{ A}$$

8. Draw the output voltage waveform for the bridge rectifier given in the figure below. Notice that all the diodes are reversed from circuits shown earlier in the chapter. [5 marks]



Solution

The waveform across the load resistor (V_{out}) is as shown below: (2.5)



In this case, in the output we will see negative voltage of the full-wave bridge rectifier. (2.5)

$$V_{out} (\text{peak}) = (V_{in} (\text{rms}) / 0.707) \times (1/5)$$

$$= (120 / 0.707) \times (1/5) - (0.7 \times 2) = 32.55 \text{ V}$$

9. Installation of solar power systems requires analysis using the Maximum Power Point (MPP) curve graph.